# Software Evolution for Digital Transformation

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Keywords: Digital Transformation, Digital Enterprise Architecture, Software Evolution.

Abstract: In current times, a lot of new business opportunities appeared using the potential of the Internet and related digital technologies, like Internet of Things, services computing, cloud computing, big data with analytics, mobile systems, collaboration networks, and cyber physical systems. Enterprises are presently transforming their strategy, culture, processes, and their information systems to become more digital. The digital transformation deeply disrupts existing enterprises and economies. Digitization fosters the development of IT environments with many rather small and distributed structures, like Internet of Things. This has a strong impact for architecting digital services and products. The change from a closed-world modeling perspective to more flexible open-world and living software and system architectures defines the moving context for adaptable and evolutionary software approaches, which are essential to enable the digital transformation. In this paper, we are putting a spotlight to service-oriented software evolution to support the digital transformation with micro-granular digital architectures for digital services and products.

## 1 INTRODUCTION

Nowadays, data, information and knowledge are fundamental core concepts of our everyday activities and are driving the digital transformation of today's global society (El-Sheikh, et al., 2016; Schmidt et al. 2015). New services and smart connected products expand physical components by adding information and connectivity services using the Internet (Porter et al., 2014) (El-Sheikh, et al., 2016).

Digitization (Schmidt et al., 2016) is enabled by four megatrends of cloud, big data, mobile, and social technologies. This disruptive change interacts with all information systems that are important business enablers for the current digital transformation.

Digitized services and products amplify the basic value and capabilities, which offer exponentially expanding opportunities (Schmidt at al., 2016). Digitization enables human beings and autonomous objects to collaborate beyond their local context using digital technologies. The exchange of information enables better decisions of human beings, and of intelligent objects. Furthermore, social networks, smart devices, and intelligent cars are part of a wave of digital economy with digital products, services, and processes, which are driving an information-driven vision (Zimmermann et al. 2018).

The Internet of Things (IoT) (Uckelmann et al., 2011) connects a large number of physical devices to each other using wireless data communication and interaction based on the Internet as a global communication environment. Additionally, we have to consider challenging aspects of the overall software and systems architecture to integrate base technologies and systems, like cyber-physical systems, social networks, big data with analytics, services, and cloud computing. Typical examples for the next wave of digitization (Zimmermann et al. 2018). are smart enterprise networks, smart cars, smart industries, and smart portable devices.

Objects from the real world are mapped into the virtual world (Zimmermann et al. 2018). Furthermore, the important interaction with mobile systems, collaboration support systems, and service-based systems for big data as well as cloud environments is extended. Additionally, the Internet of Things is an important foundation of Industry 4.0 (Schmidt et al., 2015) and adaptable digital systems.

Both business and technology are impacted from the digital transformation (Zimmermann et al., 2015) by complex relationships between architectural elements. This directly affects the adaptable digitization architecture for digital services and products and their related digital governance (El-



Zimmermann, A., Schmidt, R., Bogner, J., Jugel, D. and Möhring, M.
Software Evolution for Digital Transformation.
DOI: 10.5220/0006815702050212
In *Proceedings of the 13th International Conference on Evaluation of Novel Approaches to Software Engineering (ENASE 2018)*, pages 205-212
ISBN: 978-989-758-300-1

Sheikh, et al., 2016). Enterprise Architecture Management (EAM) (Lankhorst et al., 2017) for services computing is the approach of choice to start from and to organize, build and utilize distributed capabilities for the digital transformation (Weill et al., 2015), (Westerman et al., 2014), (Brynjolfsson et al., 2014).

Digitization (Schmidt, et al., 2016) requires the appropriate alignment of business models and digital technologies for new digital strategies and solutions, as same as for their digital transformation. Current digitized applications are integrating Internet of Things, Web services, REST services, Microservices, cloud computing, big data, machine learning with new frameworks and methods, emphasizing openly defined service-oriented software architectures (Zimmermann, et al. 2015) with extensions for semantic support.

A lot of software developing enterprises have switched to integrate Microservice architectures to handle the increase velocity (Bogner et al., 2016) (Zimmermann et al. 2018). Therefore, applications built this way consist of several fine-grained services that are independently scalable and deployable. The fast-moving process of digitization demands flexibility to adapt to rapidly changing business requirements and newly emerging business opportunities.

Unfortunately, the current state of art in research and practice of enterprise architecture lacks an integral understanding of software evolution (El-Sheikh et al., 2016), when integrating a huge amount of micro-granular systems and services, like Microservices and Internet of Things, in the context of digital transformation and evolution of architectures. Our goal is to extend previous quite static approaches of enterprise architecture to fit for flexible and adaptive digitization of new products and services. This goal shall be achieved by introducing suitable mechanisms for collaborative architectural engineering and by positioning open micro-granular architectures.

Our current short paper is part of an on-going research and investigates the following main research question:

*What are main software evolution approaches to support the flexible open-world transition of systems for the digital transformation?*

The following Section 2 sets the fundamentals for the digital transformation of digitized services and products. Section 3 focusses on architecting digital structures, systems, and technologies, while Section 4 presents suitable service-based software evolution approaches. Section 5 puts a snapshot on main related work. Finally, we summarize in Section 6 our research findings, mention some limitations, and sketch our future research steps.

## 2 DIGITAL TRANSFORMATION

Digital transformation is the current dominant type of business transformation having IT both as a technology enabler and as a strategic driver for digitization. Digitized services and associated products (Westerman et al., 2014), are software-intensive (Schmidt, et al., 2016) and therefore malleable and usually service-oriented (El-Sheikh, et al., 2016). Digital products are able to increase their capabilities via accessing cloud-services and change their current behaviour (Zimmermann et al. 2016). How value is created by these changes is shown in Figure 1.

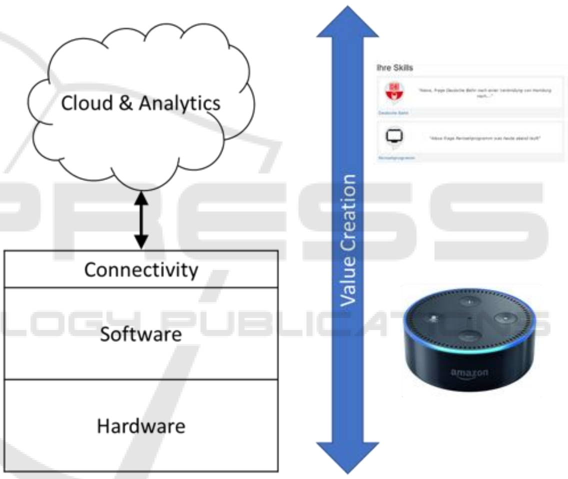


Figure 1: Hybrid value creation of Digital Products.

By combining a product consisting of hardware and software with cloud-provided services new ways of interaction with the customer are enabled (Möhring et al. 2018). Current research suggests that different customers will use such devices for different use cases enabling new ways of triggering and interaction with business processes (Möhring et al. 2018). An example is Amazon Alexa (Warren, 2016) that consists of a physical device with microphone and speaker e.g. Echo Dot, and services, called “Alexa skills”. The set of Alexa skills is dynamic and can be tailored to the customer’s requirements during run-time. The lifecycle of digitized products is extended by the acquisition and decommissioning of services.

Digitized products and services (Schmidt et al. 2015) support the co-creation of value together with the customer and other stakeholders in different ways. First, there is a permanent feedback to the provider of the product. The internet connection of the digitized product allows to collect permanently data on the usage of the product by the customer. Second, the data provided by a large number of digitized products are able to provide new insights, which are not possible with data from a single device.

Current research argues that digital products and services are offering disruptive opportunities (Westerman et al., 2014), (Brynjolfsson et al., 2014) for new business solutions, having new smart connected functionalities.

In the beginning, digitization was considered a primarily technical term (Weill et al., 2015). Thus, a number of technologies is often associated with digitization (Westerman et al., 2015): cloud computing, big data often combined with advanced analytics (Veneberg, et al., 2016), social software, and the Internet of Things (Atzori, et al., 2010). New technologies are associated with digitalization such as deep learning (Schmidthuber, 2015). They allow computing to be applied to activities that were considered as exclusive to human beings.

Therefore, the present emphasis on digitization become an important area of research. Our thesis is, that digitization embraces both a product and a value-creation (Schmidt et al., 2016) perspective.

Classical industrial products are static (Brynjolfsson et al., 2014). You 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. They can be upgraded via network connections. In addition, their functionality can be extended or adapted using external services. Therefore, the functionality of products is dynamic and can be adapted 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.

Digitized products are able to capture their own state and submit this information into linked contexts. The provider can remotely determine, whether the product is still functional and trigger, where appropriate, maintenance and repairs. Evaluation of status information and analysis of the history of use of the product can be predicted when a malfunction of the product is probable. A maintenance or replacement of the product is performed before predicted data of failure. The data collected also provide information for a repair on the spot, so that a high first-time solution rate can be achieved. At the same time, storage can be improved in this way of spare parts. By this means, preventive maintenance can be implemented. Unscheduled stoppages can this way be significantly reduced.

This is the basis for the servitization of products. Not a physical product, but a service is sold to the customer. The service usage is measured and lays the foundation for usage-based billing models.

Digitized products also enable network effects (Weitzel et al., 2000) that grow exponentially with the number of participating devices. An increase in the number of digitized products increases the incentive for providers of add-on services and complementary skills (Brynjolfsson et al., 2014). At the same time this increase the attractiveness for further digitized products. In summary, an exponential growth can be achieved.

Therefore, significant first-mover advantages exist. Network effects emerge not only for the functionality but also for the analytical exploitation of data collected by the digitized products. These effects are called network intelligence (Schmidt et al., 2016). By bringing together data from many devices and not only single devices, trends can be detected much earlier and more accurately. Further improvements can be achieved by linking data from different sources, also external one. In this way, it is possible to establish correlations that would not have been possible considering data from a single device. This effect increases with the number of devices.

The digitized products become part of an information system, which accelerates the learning and knowledge processes across all products (Evans, et a., 2012). The manufacturer can win genuine information about the use of the product. Important information for the development of new products can be obtained in this way. Therefore, a number of other beneficial effects can be achieved as network optimization, maintenance optimization, improved restore capabilities, and additional evidence against the consideration of individual systems.

The presented concepts enable a fundamental change of the value-creation model. Traditional products were created with a tayloristic view in mind, that emphasized the separation of production and consumer in order to enable centralized production and thus scaling effects. Now, the co-creation (Vargo et al., 2008) approach of service-dominant logic can be implemented because of the continuous connection of the products with the manufacturer. The consumer converts dynamically to be co-producer. Platforms are complementary to products, which cooperate via standardized interfaces.

## 3 DIGITAL ARCHITECTURE

The new possibilities enabled by digitized products also require new approaches in Architecture Management (Lankhorst et al., 2017). Today several standards are available (TOGAF, 2011), (Archimate, 2016) containing a large set of different views and perspectives for managing current IT. Therefore, an effective architecture management approach for digital enterprises should support digitization of products and services (Schmidt, et al., 2016) and should be both holistic and easily adaptable (Zimmermann, et al., 2015). Architecture management should also enable both digital transformation of existing processes and the creation of new business models. At the same time they have to support technologies that are based on a large number of systems with micro-granular architectures (Zimmermann et al. 2015) like IoT, mobile devices, or with Microservices. It is a huge challenge to continuously integrate numerous dynamically growing architectural models and metamodels from different microstructures with micro-granular architecture into a consistent digital architecture.

A Digital Architecture (in Section 3) provides a conceptual blueprint to help define the structure and operation of an organization having the goal to determine, how a digital transformed organization with their digitized products and services can most effectively achieve its current and future objectives. Several approached and methods have been proposed in (El-Sheikh et al., 2016) to address the challenges and trends in the evolution of Service-oriented and Enterprise Architectures to manage the digital transformation.

To cope with these challenges, we extend our previous service-oriented enterprise architecture reference model for the context of digital transformation with Microservices and Internet of Things considering associated architectural decision making (Jugel, et al., 2015), which is supported by functions of an architectural cockpit (Jugel, et al., 2014).

Enterprise Services Architecture Reference Cube (ESARC) provides an architectural reference model (Zimmermann et al., 2015) enabling specific viewpoints for evolved micro-granular enterprise architectures (Figure 2). ESARC for digital products and services is more specific than existing architectural standards of architecture management (TOGAF, 2011), (Archimate, 2016).

ESARC provides eight integral architectural domains to provide a holistic classification model. While it is applicable for concrete architectural instantiations to support digital transformations, it still abstracts from a concrete business scenario or technologies. The Open Group Architecture Framework (TOGAF, 2011) together with (Archimate, 2016) provides the basic blueprint and structure for our extended service-oriented enterprise architecture domains.

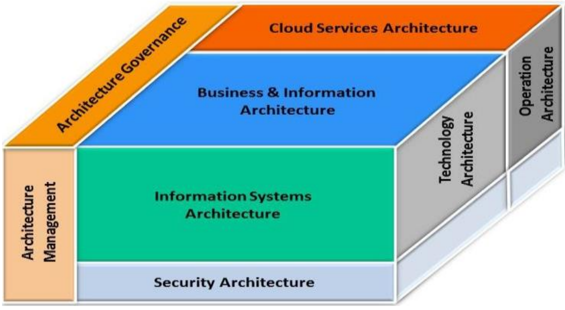


Figure 2: Enterprise Services Architecture Reference Cube (Zimmermann et al. 2015).

Our research extends an existing metamodel-based model extraction and integration approach from (Zimmermann et al., 2015) for digital enterprise architecture viewpoints, models, standards, frameworks and tools. The approach supports the adaptable integration of micro-granular architectures. Currently, we are working on the idea of continuously integrating small architectural descriptions for relevant objects of a digital architecture.

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). DEA-Mini-Models consists of partial DEA-Data, partial DEA-Models, and partial EA-Metamodel. They are associated with Microservices and/or objects from the Internet of Things. These structures are based on the Meta Object Facility (MOF) standard (MOF, 2011) of the Object Management Group (OMG).

The highest layer M3 represents abstract language concepts used in the lower M2 layer and is called, therefore, the meta-metamodel layer. The next layer M2 is the metamodel integration layer and defines the fundamental entities for M1 (e.g. models from UML or ArchiMate (Archimate, 2016). These models are a structured representation of the lowest layer M0 that is formed by collected concrete data from real-world use cases with instantiations of architectural data.

By integrating DEA-Mini-Models micro-granular architectural cells (Figure 3) for each relevant IoT object or Microservice, the integrated overall architectural metamodel becomes adaptable and can mostly be automatically synthesized by respecting the integration context from a growing number of previous similar integrations. In the case of new integration patterns, we have to consider additional manual support.

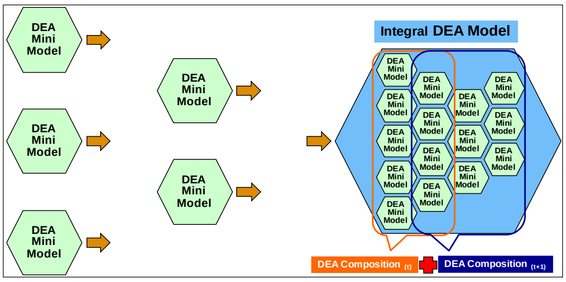


Figure 3: Architectural Federation by Composition.

The challenge of our current research is to federate these DEA-Mini-Models to an integral and dynamically growing DEA model and information base by promoting a mixed automatic and collaborative decision process (Jugel, et al., 2015) and (Jugel, et al., 2014).

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 special 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.

# 4 SOFTWARE EVOLUTION

The digital transformation (Porter, et al., 2014) highly increased the competitive pressure and urges enterprises to quickly develop new digitized products and services. Time to market is a key differentiator in digital transformation. The quicker a business is, the more successful it is likely to be. But more established businesses have delivered technology solutions to their employees and customers on lengthy release schedules that no longer make sense in today's accelerated environment.

The nature of digital assets disaggregates value chains, creating openings for focused, fast-moving competitors. Furthermore, the customer expects to interact seamlessly across different channels. Enterprises have to analyse customer behaviour in real-time. At the same time digitization lowers the market entry barriers for new competitors, by dissolving long-understood boundaries between sectors. These challenges require a better support for software evolution.

Principally we can identify, as in (Wilde, et al., 2016), two broad perspectives of software evolution: First, software can be designed anticipating change by the original software developer to make evolution easier by predicting possible change perspectives of a new software. The main mechanism of proactive change is based on modularity structures of services. Secondly, software evolution can be handled during the maintenance phase by using special tools and methods. The intention here is to support understanding of software structures of the existing code, as fast and easy as possible.

The implementation of flexible and maintainable services strongly depends on service quality of services (Gebhart et al., 2016). In the past, most quality of service indicators were designed for method-driven Web Services with SOAP. Today, many new services are designed in a resource-oriented way using REST or Microservices, to follow an easier technology-independent approach. Many of the existing quality indicators for Web Services can be mapped to resource-oriented services. Resource-oriented services can also be engineered using Microservices, as mentioned.

Decision analytics (Zimmermann et al., 2016) provides increasingly complex and decision support, particularly for the development and evolution of sustainable enterprise architectures (EA), and this is duly needed. Tapping into these systems and techniques, the engineers and managers of the software and system architecture become part of a viable enterprise, i.e. a resilient and continuously evolving service-oriented architectures and systems that enable and drive innovative business models.

Main challenges of service computing for the next ten years guide a redefinition of service computing, which are postulated by (Bouguettaya et al., 2017). The service computing manifesto maps out in (as in Figure 4) a strategy that positions emerging concepts and technologies to support the service paradigm. The service computing manifesto recommends focusing on four main research directions by specifying both challenges and a research roadmap: service design, service composition, crowdsourcing based reputation, and the Internet of Things.

An important prerequisite for building and analysing sound service systems and architectures is a formal understanding of the nature of services and their model-supported relationships. We have to currently consider a big change from traditional closed-world software engineering approaches to the open-world of service systems with autonomous parts (Zimmermann, et al., 2015).

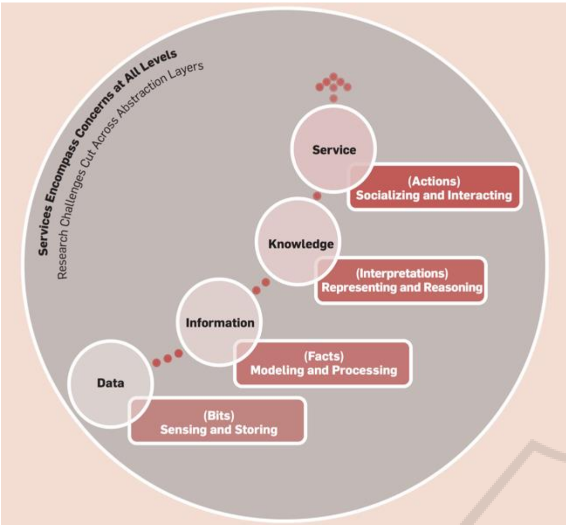


Figure 4: Abstractions along the Computing Value Chain.

An important prerequisite for building and analysing sound service systems and architectures is a formal understanding of the nature of services and their model-supported relationships.

Cloud computing as a new service delivery model, which gives inspiration to integrate service computing and cloud computing. So, cloud computing is a main influencing factor for the service computing manifesto in (Bouguettaya et al., 2017), while other important influencers for service computing are mobile computing, big data, and social computing.

In the next wave of service composition (Bouguettaya et al., 2017), we have to integrate a fast growing and large set of non-WSDL-described services: REST services, Microservices, and partial services, like IoT or Android apps. In an open-world setting of big data existing static service selection, composition, and recommendation are inadequate and should be extended by large-scale Web and cloud service composition, big data driven service composition, and social network based service compositions.

Trust plays an important role for a functional service ecosystem. Crowdsourcing provides effective means for collecting data through collaborations within communities. Reputation mechanisms and crowdsourcing in social networks support predicting credibility, which is important for derive trust.

Innovative models are required for the composition of Internet of Things (IoT) (Bouguettaya et al., 2017) and (Patel et al. 2015). IoT poses two fundamental challenges: communication with things, and management of things. One additional challenge is that things are resource-constrained, making it practical impossible to combine IoT with heavy standards like, SOAP and BPEL. The IoT component model is further heterogeneous and multi-layered, typically with devices, data, services, and organizations. The IoT designed functionality is more dynamic and context-aware than in traditional settings.

The resulting fundamental IoT challenges (Bouguettaya et al., 2017) are related to continuously maintaining cyber personalities and context information for IoT devices, and continuously discovering, integrating, and reusing IoT and their data. Graph-based approaches and machine-learning techniques can facilitate discovery of hidden relationships between IoT and helping detecting correlations among IoT.

## 5 RELATED WORK

Research published in (Veneberg et al., 2016) combines the more large-grained enterprise architecture and fine-grained operational data, which is an interesting approach. The intention of the approach is to fill the gap between the disciplines enterprise architecture and big data and to set a new base for architectural decision support.

This quite new combination was called enterprise architecture intelligence by the authors. It is aimed at compensating existing shortcomings from each of the two unrelated base disciplines and to provide an integrated architectural model. Central in this research is the new enterprise architecture intelligence lifecycle (EAIL), which follows the design science methodology.

Two-speed architecture (Bossert, 2016) has the objective to separate elements that are required for quickly changing the customer experience from other elements that are more important for the integrity of transactions. It differentiates systems that must be more flexible and agile from those that must be more reliable and deliver high stability and quality. To enable a differentiating customer experience, a two-speed architecture must cut across different layers of the technology stack

The fast-speed-architecture contains the channels that are pivotal for the customer experience. New functionalities must be implemented at the same speed within the same deployment cycle. Also, the traditional systems of record systems must move into the fast speed architecture. It must be possible to quickly adapt customer and product data structures to enable new digital business models.

## 6 CONCLUSION

Based on our research question we have first set the context of digital transformation for evolving software systems to support digital architectures for new designed digital services and products. We have leveraged an adaptive architecture integration approach for open-world integrations of globally accessed systems and services with their local architecture models, to be able to support digital transformation mechanisms for flexible software and systems compositions.

We contribute to the literature in different ways. Looking to our results, we have identified the need for a bottom-up integration of a huge amount of dynamically growing micro-granular systems and services, like mobile systems, Microservices and the Internet of Things. To integrate micro-granular architecture models from an open-world we are extending more traditional enterprise architecture reference models with state of art elements for agile architectural engineering to support the digitization of products, services, and processes. Secondly, we have exemplarily focused on Internet of Things and Microservices architectures, which are much influencing the current digital enterprise architecture, by changing the viewpoint for modelling complex systems in an open-world. This is a fundamental extension of our seminal work on architectural reference models to be able to openly integrate through a continuously bottom-up approach a huge amount of micro-granular systems with own and heterogeneous local architectures. We have thirdly investigated current and next elements of a service-oriented enterprise architecture to point to main influence factors, challenges and research areas for the evolution of enterprise architecture and the evolving discipline of service computing.

Some limitations (e.g. use and adoption in different sectors, or the IoT integration technologies) must be considered. There is a need to integrate more analytics-based decisions support and context-data driven architectural decision-making. Limitations can be currently found, while integrating Internet of Things architecture in the field of multi-level evaluations of our approach, as well as in domain-specific adoptions. Furthermore, empirical evaluations via case study research would be a good starting point for future research.

We are currently working on extended decision support mechanisms for an architectural cockpit for adaptive digital enterprise architectures and related collaborative processes. Future work will extend mechanisms for adaptation and open integration.

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