Enterprise Composition Architecture for Micro-Granular Digital Services and Products

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Abstract

The digitization of our society changes the way we live, work, learn, communicate, and collaborate. This defines the strategical context for composing resilient enterprise architectures for micro-granular digital services and products. The change from a closed-world modeling perspective to more flexible open-world composition and evolution of system architectures defines the moving context for adaptable systems, which are essential to enable the digital transformation. Enterprises are presently transforming their strategy and culture together with their processes and information systems to become more digital. The digital transformation deeply disrupts existing enterprises and economies. Since years 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. Digitization fosters the development of IT systems with many rather small and distributed structures, like Internet of Things or mobile systems. In this paper, we are focusing on the continuous bottom-up integration of micro-granular architectures for a huge amount of dynamically growing systems and services, like Internet of Things and Microservices, as part of a new digital enterprise architecture. To integrate micro-granular architecture models to living architectural model versions we are extending more traditional enterprise architecture reference models with state of art elements for agile architectural engineering to support the digitalization of services with related products, and their processes.
Keywords: Service-Dominant Digital Products, Digital Transformation, Internet of Things, Microservices, Open-World Architectural Integration, Architectural Composition.

1. Introduction

Data, information and knowledge are fundamental core concepts of our everyday activities and are driving the digital transformation of today’s global society [5], [18]. New services and smart connected products expand physical components by adding information and connectivity services using the Internet [16].

Digitization [18] defines the process of digital transformation, which is promoted by important technological megatrends: cloud and services computing, big data, mobile systems, and social networks. The disruptive change of current business interacts with all information systems that are important business enablers for the digital transformation. Digitized services and products amplify the basic value and capabilities, which offer exponentially expanding opportunities. 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 [33].

The Internet of Things (IoT) [1], [22], [15] 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 [1] are smart enterprise networks, smart cars, smart industries, and smart portable devices. Objects from the real world are mapped into the virtual world. 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 [17] and adaptable digital systems.

Both business and technology are impacted from the digital transformation [33] by complex relationships between architectural elements. This directly affects the adaptable digitization architecture for digital services and products and their related digital governance [27]. Enterprise Architecture Management (EAM) [9] for services computing is the approach of choice to start from and to organize, build and utilize distributed capabilities for the digital transformation [28], [3], [30].

Digitization [18] 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 [33] with extensions for semantic support.

A lot of software developing enterprises have switched to integrate Microservice architectures to handle the increase velocity [4], [2]. 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 [5], 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 research in progress paper is part of an on-going conceptual research about fundamental architectural models, but not their implementation or case studies, to investigate the following main research question: *How can an enterprise architecture for digital services and products be modeled to support the open-world integration and management for a huge amount of micro-granular digital structures, like Internet of Things and Microservices?*

The following Section 2 sets the fundamental context for service-dominant digital products. Section 3 focusses on architecting micro-granular systems and services with Internet of Things and Microservices, while Section 4 presents our high scalable digital enterprise architecture. Section 5 details our architectural composition model. Finally, we summarize in Section 6 our research findings, mentioning some limitations, and sketch our future research steps.

2. Service-Dominant Digital Products

The service-dominant (S-D) logic [23-24] is a service-centered approach and to some extend opposite to the traditional goods-centered paradigm for large parts of the traditional business. The principal idea is that all economic exchanges can be defined as service-to-service exchanges considering also associated real or digital products. The origin of the service-dominant logic relies on ten fundamental axioms [23] for defining service businesses, including digital services and products. The origin of service-dominant logic was slightly extended through modifications and additional premises [24] to a body of five axioms and eleven foundational premises.

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 [30], are software-intensive [18] and therefore malleable and usually service-oriented [5]. Digital products are able to increase their capabilities via accessing cloud-services and change their current behavior [32]. How value is created by these changes is shown in Fig. 1.

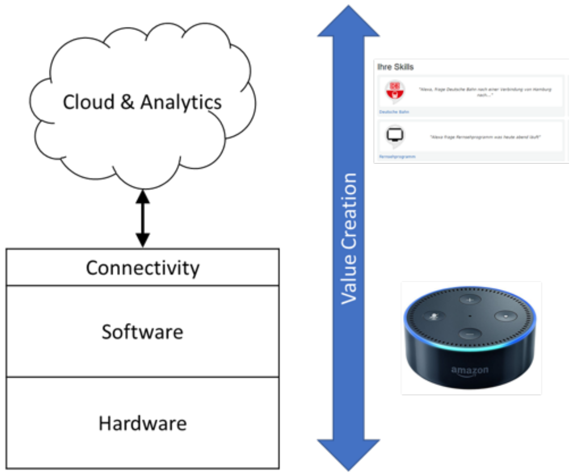

Fig. 1. Hybrid value creation of Digital Products.

New ways of interaction with the customer are enabled [10] by combining a product consisting of hardware and software with cloud-provided services. Current research suggests that different customers will use such devices for different use cases enabling new ways of triggering and interaction with business processes. An example is Amazon Alexa [26] 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 [18] 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 [30], [3] for new business solutions, having new smart connected functionalities.

In the beginning, digitization was considered a primarily technical term [28]. Thus, a number of technologies is often associated with digitization [30]: cloud computing, big data often combined with advanced analytics [25], social software, and the Internet of Things [1], [15]. New technologies are associated with digitalization such as deep learning [19]. 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 [18] perspective.

Classical industrial products are static [3]. 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. This is the basis for the so called 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. 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.

Digitized products also enable network effects [29] 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 [3]. 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 [29]. 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. 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.

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 [23-24] 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. Architecting Micro-Granular Systems and Services

Digitalization promotes massively distributed systems, which are based on the development of IT systems with many rather small and distributed structures, like Internet of Things, mobile systems, cyber physical systems, etc. Additionally, we have to support digitalization by a dense and diverse amount of different service types, like microservices, REST services, etc. and put them in a close relationship with distributed systems, like Internet of Things. The change from a closed-world modeling perspective to more flexible open-world composition and evolution of system architectures defines the moving context for adaptable systems, which are essential to enable the digital transformation. This has a strong impact for 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 complex models.

3.1. Internet of Things

The Internet of Things [1], [15] is our typical use case for micro-granular systems, which are today not well covered by an enterprise architecture. The Internet of Things 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. Real world objects are mapped into the virtual world. The interaction with mobile systems, collaboration support systems, and systems and services for big data and cloud environments is extended. Furthermore, the Internet of Things is an important foundation of Industry 4.0 [17] and adaptable digital enterprise architectures [33].

The Internet of Things, supports smart products as well as their production enables enterprises to create customer-oriented products in a flexible manner. Devices, as well as human and software agents, interact and transmit data to perform specific tasks as parts of sophisticated business or technical processes [15], [4]. The Internet of Things embraces not only a things-oriented vision [1] but also an Internet-oriented and a Semantic-oriented one. A cloud-centric vision for architectural thinking of a ubiquitous sensing environment is provided by [22].

A layered Reference Architecture for the Internet of Things is in [31] and Fig. 2, where layers can be implemented using suitable technologies.

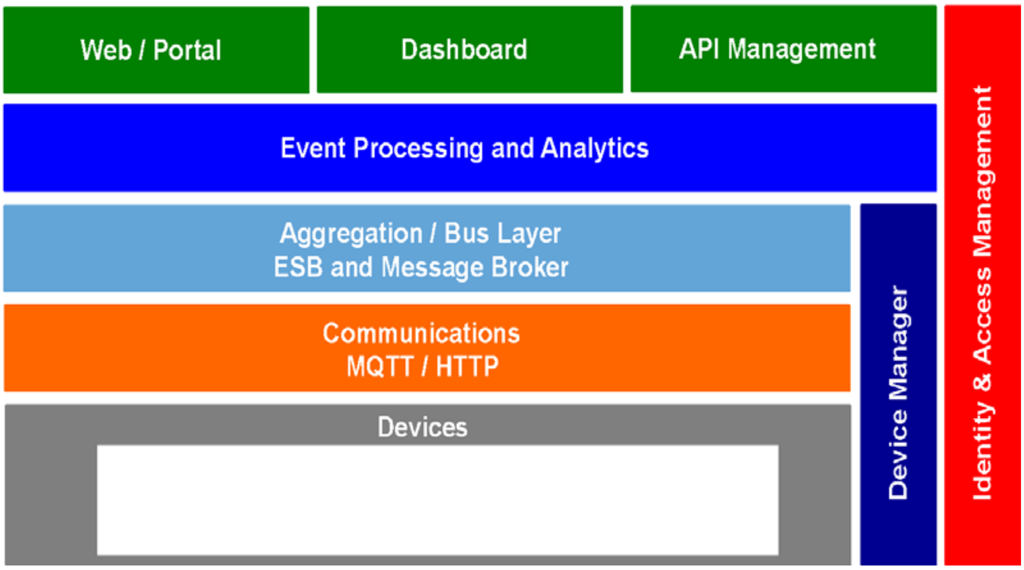

Fig. 2. Internet of Things Reference Architecture [31].

The main question is, how the Internet of Things architecture fits in a context of a service-based enterprise computing environment? A service-oriented integration approach for the Internet of Things is referenced in [20]. The core issue is, how millions of devices can be flexibly connected to establish useful advanced collaborations within business processes. The service-oriented architecture abstracts the heterogeneity of embedded systems, their hardware devices, software, data formats and communication protocols. The typical setting includes a cloud-based server architecture, which enables interaction and supports remote data management and calculations. By these means, the Internet of Things integrates software and services into digitized value chains.

From the inherent connection of a magnitude of devices, which are crossing the Internet over firewalls and other obstacles, are resulting a set of generic requirements [7]. Because of so many and dynamically growing numbers of devices we need an architecture for scalability. Typically, we additionally need a high-availability approach in a 24x7 timeframe, with deployment and auto-switching across cooperating datacenters in the case of disasters and high scalable processing demands. The Internet of Thing architecture has to support automatically managed updates and remotely managed devices. Typically, often connected devices collect and analyze personal or security relevant data. Therefore, it should be mandatory to support identity management, access control and security management on different levels: from the connected devices through the holistic controlled environment.

The contribution from [20] considers a role-specific development methodology and a development framework for the Internet of Things. The development framework specifies a set of modeling languages for a vocabulary language to be able to describe domain-specific features of an IoT-application, besides an architecture language for describing application-specific functionality and a deployment language for deployment features. Associated with programming language aspects are suitable automation techniques for code generation, and linking, to reduce the effort for developing and operating device-specific code.

The metamodel for Internet of Things applications from [15] specifies elements of an Internet of Things architectural reference model like IoT resources of type: sensor, actuator, storage, and user interface. Base functionalities of IoT resources are handled by components in a service-oriented way by using computational services. Further Internet of Thing resources and their associated physical devices are differentiated in the context of locations and regions.

3.2. Microservices

Microservices addresses our second fundamental use-case for micro-granular architectures, which are developed and operated in an open-world. The open-world approach fundamentally changes the rules of engineering and management by following a high distributed and globally metaphor for the new setting of a digital business operating model. This new bottom-up tailored digital operating model changes the perspective of a classical top-down oriented enterprise architecture.

The Microservices approach is spreading quickly. Defined by James Lewis and Martin Fowler, as in [4], it is a fine-grained, service-oriented architecture style combined with several DevOps elements. A single application is created from a set of services. Each of them is running in its own process. Microservices communicate using lightweight mechanisms. Often, Microservices are combined with NoSQL databases from on-premise and optional Cloud environments.

Microservices implement business capabilities and are independently deployable, using an automated deployment pipeline. The centralized management elements of these services are reduced to a minimum. Microservices are implemented using different programming languages. Different data storage technologies may be used. As opposed to big monolithic applications, a single Microservice tries to represent a unit of functionality that is as small and coherent as possible. This unit of functionality or business capability is often referred to as a bounded context, a term that originates from Domain-Driven Design (DDD) [4].

Microservices and Microservices Architectures (MSA), as in [30], is considered to be an important enabler for the digital enterprise and the digital transformation. The fundamental concept of architecture is defined as structure of components, their inter-relationships, together with principles and guidelines for governing their design and evolution.

Both the architecture and the instantiation of these components define the architectural style as a more concrete combination of features in which architecture is expressed. Therefore, the Microservices Architecture is considered to be more an architectural style for aligning small and self-contained services with business activities. The conceptual representation of a Microservices solution delimits primarily independent and self-contained services to serve specific business functions or processes.

The Open Group's White Paper [2] sketches in Fig. 3 a Microservice Reference Architecture for the application example of a rainy-day grocer.

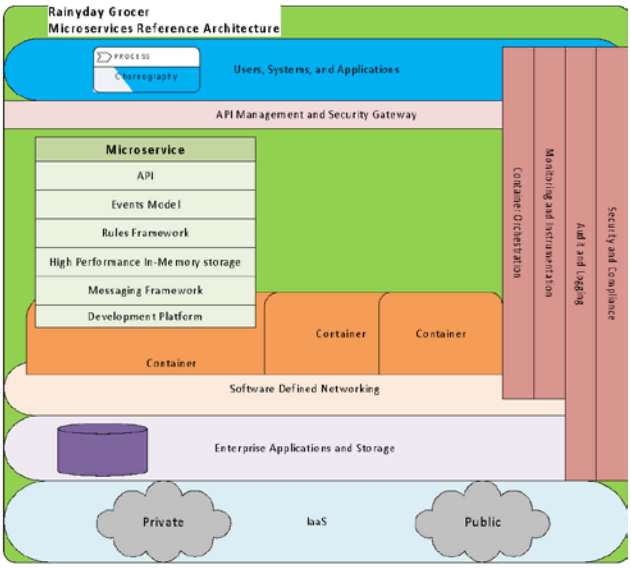

Fig. 3. Microservices Reference Architecture [2].

The problem space in [2] defines a holistic view for specific pain points, which are addressed by MSA, like decreasing the complexity of the development, operation, and management of services. A key obstacle today is that changes in a complex software produces long and complicated change cycles. Typically, the modularity of a system even built from Web Services tends to weaken over time. Therefore, Microservices promote to be both independent and self-contained. Scaling of a tightly-coupled service system requires scaling of the entire application.

Because instantiation of additional services and service instances is performed independently, Microservices Architectures could much better support scalability by providing restart and relocation of services. Further, Microservices should keep each service most independent and aligned with a single business process of a business function.

Microservices should be designed to be self-contained by integrating with specific needed platform and infrastructural elements. Microservices does not require a large pre-existing infrastructure. As exemplified by DevOps [11], Microservices support processes of Continuous Development (CD) in small environments and Continuous Integration (CI). Additionally, Microservices should also naturally support resiliency and scalability in both cloud and on-premise environments.

Microservices need a strong DevOps culture [11] to handle the increased distribution level and deployment frequency. Moreover, while the single Microservice may be of reasonably low complexity, the overall complexity of the system has not been reduced at all. Microservices enable technological heterogeneity and thus reduce the possibility of lock-ins by outdated technology. Unfortunately, classical enterprise architecture approaches are not flexible enough for the kind of diversity and distribution present in a Microservice Architecture.

4. Digital Enterprise Architecture

Enterprise Architecture Management [9], as today defined by several standards like [13-14] 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 [18] and be both holistic and easily adaptable [33]. Furthermore, a digital architecture sets the base for the digital transformation enabling new digital business models and technologies that are based on a large number of micro-structured digitization systems with their own micro-granular architectures like IoT [15], [31], mobile devices, or with Microservices [2], [11].

We are extending our service-oriented enterprise architecture reference model for the context of digital transformation with micro-granular structures and considering associated multi-perspective architectural decision-making [8] models, which are supported by viewpoints and functions of an architecture management cockpit. DEA - Digital Enterprise Architecture Reference Cube provides an architectural reference model [33] for bottom-up integrating dynamically composed micro-granular architectural models (Fig. 4). DEA for architecting digital products and services is more specific than existing architectural standards of architecture management, like in [13-14].

DEA has a base in [33] and provides now ten extended integral architectural domains for a holistic architectural classification model, which is able to embed mirco-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 transformations [30], [3], [16] independent of different domains. The Open Group Architecture Framework TOGAF [13] provides the basic blueprint and structure for extended service-oriented enterprise architecture domains. Metamodel extensions are additionally provided by considering and integrating ArchiMate Layer models from [14].

Metamodels and their architectural data are the core part of the enterprise architecture. Enterprise architecture metamodels [9] should enable decision making [33] as well as the strategic and IT/business alignment. Three quality perspectives are important for an adequate IT/business alignment and are differentiated as: (i) IT system qualities: performance, interoperability, availability, usability, accuracy, maintainability, and suitability; (ii) business qualities: flexibility, efficiency, effectiveness, integration and coordination, decision support, control and follow up, and organizational culture; and finally (iii) governance qualities: plan and organize, acquire and implement deliver and support, monitor and evaluate (e.g., [27]).

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

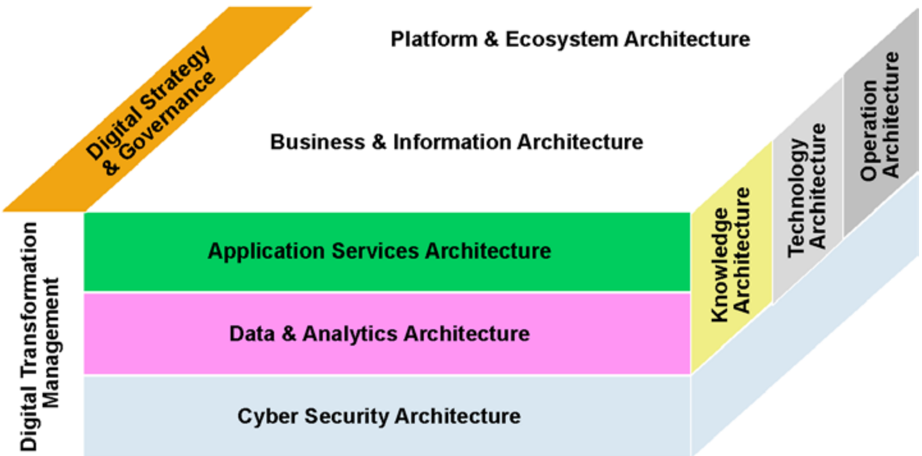

Fig. 4. Digital Enterprise Architecture Reference Cube.

Architecture governance, as in [27], defines the base for well aligned management practices through specifying management activities: plan, define, enable, measure, and control. Digital governance 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 a 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 a plenty of diverse micro-granular structures, like Internet of Things or Microservices.

5. Architecture Composition Model

Digital transformation [16], [3], [30] not only changes our personal lives but also has massive implications on the competitive landscape. To win in this new environment, established companies need to develop new digitized products and services quickly, interact across channels, analyze customer behavior in real-time, and leverage digital processes. Digitization can lower entry barriers for new players but causing long-understood boundaries between sectors to become more ambiguous and permeable. The nature of digital assets disaggregates value chains, creating openings for focused, fast-moving competitors.

Adaptability for architecting open micro-granular systems like Internet of Things or Microservices is mostly concerned with heterogeneity, distribution, and volatility. It is a huge 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 [4] consists of partial DEA-Data, partial DEA-Models, and partial EA-Metamodel. Microservices are associated with DEA-Mini-Models and/or objects from the Internet of Things. Our model elements (Fig. 5) are specializations and extensions from the Meta Object Facility (MOF) standard [12] of the Object Management Group (OMG).

We have extended the base model layer M1 of MOF to be able to host additionally metadata. Metadata are descriptive data of the monitored run-time data, which are collected by monitoring processes during the systems' operation. Monitoring tools are able to visualize run-time data with their metadata. Typically, we have today in many cases no real connective information from the operational data and data from enterprise architectures. Our goal is to connect these levels of the MOF model to provide an integral and most consistent architectural data. Additionally, we have associated the original metamodel from layer M2 with our architectural ontology with integration rules. Integration rules define options for model integration based on previous successful integrations in similar cases or based on human provided decisions of fundamental integration options. Currently we are researching the aspect of automatic integration of architectural models based on architectural data analytics and deep-learning mechanisms. 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.

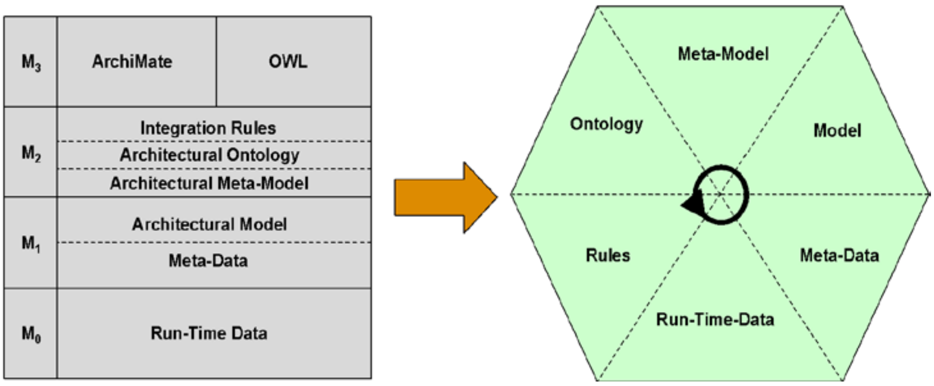

Fig. 5. Structure of EA-Mini-Descriptions [4].

Regarding the structure of EA-Mini-Descriptions, the highest layer M3 [4] represents an abstract language concepts used in the lower M2 layer. It can be also seen as the meta-metamodel 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 [14]). The models can be seen as a structured representation of the lowest layer M0 [12].

Volatile technologies, requirements, and markets typically drive the evolution of business and IT services. Adaptation is a key success factor for the survival of digital enterprise architectures [4], [33], platforms, and application environments. Weil and Woerner introduces in [28] the idea of digital *ecosystems* that can be linked with main strategic drivers for system development and system evolution. Reacting rapidly to new technology and market contexts improves the fitness of such adaptive ecosystems. Being a bit closer to the architecture and design of systems, Trojer et al. coined in [21] 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 automated documentation of digital architectures and to summarize integration foundations for federated architectural model management.

During the integration of DEA-Mini-Models as micro-granular architectural cells in Fig. 6, for each relevant object e.g., Internet of Things object or Microservice, the step-wise composed time-stamp dependent architectural metamodel becomes adaptable [4]. Changes of the architectural composition result from changed architectural model elements considering a bottom-up composition strategy. The resulting overall architectural model includes both changes in model elements and in their interaction. The architectural composition at time (t+1) reflect these changes compared to the previous composition version at time (t). Furthermore, this architecture composition can be mostly be automatically synthesized by respecting the integration context from a growing number of previous similar integrations.

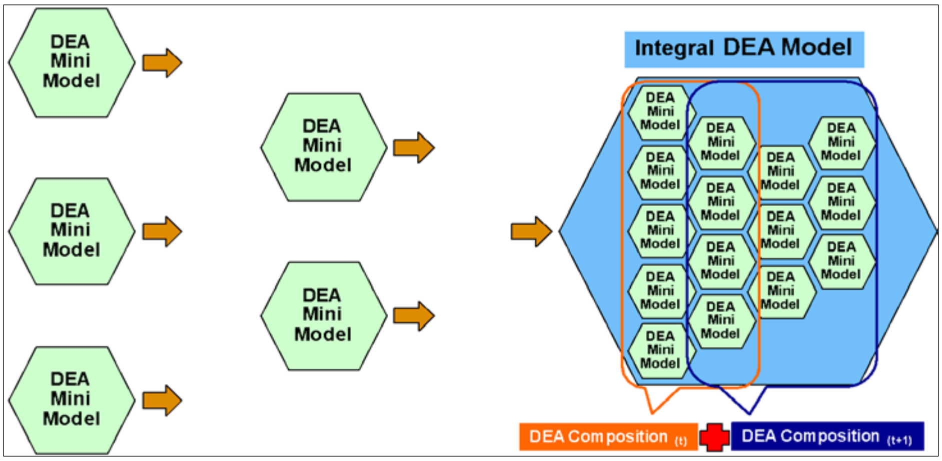

Fig. 6. Architectural Federation by Composition [33].

In 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 collaborative decision process, introduced and developed by Jugel in [8].

6. Conclusion

Based on our research question we have first set the architectural context for service-dominant digital products to support digitalization and the digital transformation of products and services. In this paper we have identified the need for a bottom-up integration of a huge amount of dynamically growing micro-granular systems and services, like microservices and the Internet of Things, as part of a new suited digital enterprise architecture. 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 fast 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 digitalization 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 global available and heterogeneous micro-granular systems with own 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 for the fast-growing service economy.

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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