Open Integration of Digital Architecture Models for Micro-granular Systems and Services

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Abstract: The digital transformation of our society changes the way we live, work, learn, communicate, and collaborate. This disruptive change drive current and next information processes and systems that are important business enablers for the context of digitization since years. Our aim is to support flexibility and agile transformations for both business domains and related information technology with more flexible enterprise information systems through adaptation and evolution of digital architectures. The present research paper investigates the continuous bottom-up integration of micro-granular architectures for a huge amount of dynamically growing systems and services, like Microservices and the Internet of Things, as part of a new composed digital architecture. To integrate micro-granular architecture models into living architectural model versions we are extending enterprise architecture reference models by state of art elements for agile architectural engineering to support digital products, services, and processes.

Keywords: Digital Transformation, Digital Enterprise Architecture, Internet of Things, Microservices, Architecture Metamodel Integration Method, Adaptable Services and Systems

1 Introduction

Information, data and knowledge are fundamental concepts of our everyday activities and are driving the digital transformation of our global society. Smart connected products and services expand physical components from their traditional core by adding information and connectivity services using the Internet. Digitized products and services amplify the basic value and capabilities and offer exponentially expanding opportunities [PH14]. Digitization enables human beings and autonomous objects to collaborate beyond their local context using digital technologies [Sc15]. Information, data, and knowledge become more important as fundamental concepts of our everyday activities. The exchange of information enables more far-reaching and better decisions of human beings, and intelligent objects. Social networks, smart devices, and intelligent cars are part of a wave of digital economy with digital products, services, and processes driving an information-driven vision.

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The Internet of Things (IoT) [PC15], [Uc11], and [AIM10] 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 some challenging aspects of the overall architecture [Zi15] from base technologies: cyber-physical systems, social networks, big data with analytics, services, and cloud computing. Typical examples for the next wave of digitization are smart enterprise networks, smart cars, smart industries, and smart portable devices.

The fast moving process of digitization [Sc15] demands flexibility to adapt to rapidly changing business requirements and newly emerging business opportunities. To be able to handle the increased velocity and pressure, a lot of software developing companies have switched to integrate Microservice Architectures [BZ16]. Applications built this way consist of several fine-grained services that are independently scalable and deployable.

Digitization [Sc15] requires the appropriate alignment of business models and digital technologies for new digital strategies and solutions, as same as for their digital transformation. Unfortunately, the current state of art and practice of enterprise architecture lacks an integral understanding and decision management 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 approaches of quite static 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 integration of micro-granular architectures.

Our research paper investigates specific research questions, which are answered by following main sections:

RQ1: *How should a digital architecture be holistically tailored to openly integrate a huge amount of micro-granular systems and services, like Internet of Things and Microservices architectures?*

RQ2: *What are fundamental elements of architectural models for Internet of Things and Microservices architectures?*

RQ3: *How can we integrate micro-granular architectural models and what are architectural implications for a decision-controlled composition of micro-granular elements, like Internet of Things and Microservices?*

The following Section 2 explains the setting of a digital enterprise architecture and links it with a specific architectural decision environment. Section 3 focusses on architecting the Internet of Things, while Section 4 presents an architectural approach to integrate Microservices. In Section 5 we are extending architectural integration mechanisms for an open world to be able to a-posteriori integrate a huge amount of partial metamodels for micro-granular systems and services. Finally, we summarize in Section 6 our research findings and limitations, and sketching our next steps.

2 Digital Enterprise Architecture

The discipline of Enterprise Architecture Management (EAM) [La13], [Be12] defines today with frameworks, standards [To11] and [Ar16], tools and practical expertise a quite large set of different views and perspectives. This abundance of ingredients for EAM leads in practice often to a "heavy EA" approach, which is not always feasible enough to support practical initiatives of software development and maintenance within a living and changing business and system environment.

We argue in this paper that a new refocused service-oriented EA approach should be both holistic [Zi11] and [Zi13] and easily adaptable [Zi14] for practical support of software evolution and transformation of information systems in growing business and IT environments, which are based on new technologies like social software, big data, services & cloud computing, mobility platforms and systems, security systems, and semantics support. A Digital Architecture should support the digital transformation with new business models and technologies that are based on a large number of micro-structured digitization systems with their own micro-granular architectures like Internet of Things (IoT) [WSO15], mobility devices, or with Microservices [BZ16].

In this paper, we are extending our previous service-oriented enterprise architecture reference model for the context of digital transformations with Microservices and Internet of Things with decision making [JSZ15], which are supported by interactive functions of an EA cockpit [JS14]. Enterprise Services Architecture Reference Cube (ESARC) [Zi14] is our fundamental architectural reference model for an extended view on evolved micro-granular enterprise architectures (Fig. 1).

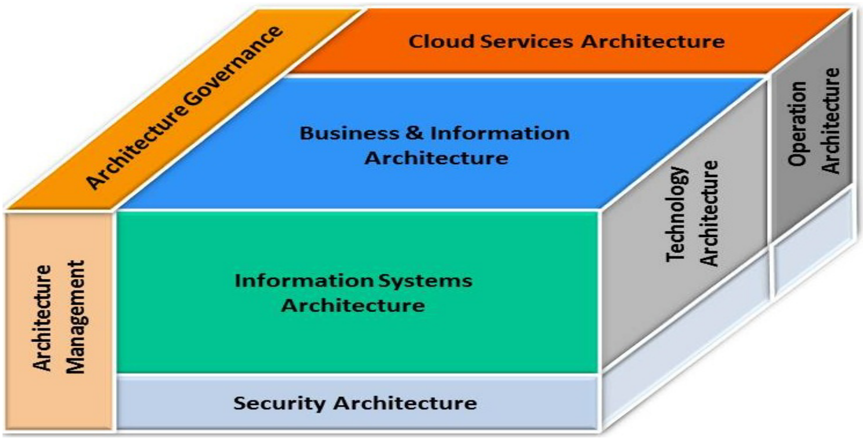

Fig. 1: Enterprise Services Architecture Reference Cube [Zi14][Zi15]

The new ESARC for digital products and services is more specific than existing architectural standards of EAM [To11], [Ar16] and uses 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 [12] provides the basic blueprint and structure for our extended service-oriented enterprise architecture domains.

In our current research, which extends the more fundamentally approach of a decision dashboard for Enterprise Architecture [Be12] and [La13], we are exploring how an Architecture Management Cockpit [JS14], [JSZ15] can be leveraged and extended to a Decision Support System (DSS) for digital architecture management. Our architecture cockpit in Fig. 2 implements a facility, which enables analytics and optimizations using multi-perspective interrelated viewpoints on the system under consideration. Each stakeholder taking part in a cockpit meeting can utilize a viewpoint that displays the relevant information. Viewpoints, which are applied simultaneously, are linked to each other in a such manner that the impact of a change performed in one view can be visualized in other views as well.

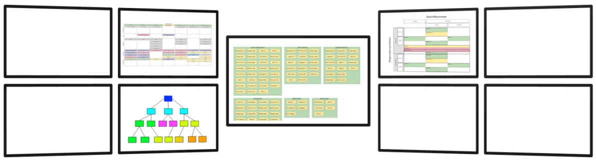

Fig. 2: Architecture Management Cockpit [JS14], [JSZ15]

Jugel et al. [JSZ15] present a collaborative approach for decision-making for architecture management. They identify decision making in such complex environment as a knowledge-intensive process reflecting the balance between decentral and central architectural decisions. Therefore, the collaborative approach presented is built based on methods and techniques of adaptive case management (ACM), as defined in [Sw10].

The ISO Standard 42010 [EH09] describes how the architecture of a system can be documented using architecture descriptions. The standard defines views, which are governed by viewpoints to address stakeholders' concerns and their information demands. Jugel et al. [JSZ15] introduce an annotation mechanism to add additional knowledge to an architecture description represented by an architectural model. In addition, [JSZ15] refines the viewpoint concept of [EH09] by dividing it into Atomic Viewpoint and Viewpoint Composition to model coherent viewpoints that can be applied simultaneously in an architecture cockpit with central and mobile. Architectural Issues and Decisions, were already introduced in the inspiring model of Plataniotis [Pl14]. Architectural decisions can be linked with architectural artifacts, decomposed, translated, and substituted into other decisions.

3 Architecting Internet of Things

The Internet of Things (IoT) fundamentally revolutionizes today's digital strategies with disruptive business operating models [WSO15], and holistic governance models [WR04] for both business and IT. With the huge diversity of Internet of Things technologies and products organizations have to leverage and extend previous enterprise architecture efforts to enable business value by integrating the Internet of Things into existing business and computational environments.

The Internet of Things [WSO15] 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 [Sc15b] and adaptable digital enterprise architectures [PH14]. 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 part of sophisticated business or technical processes [Uc11], [PC15].

The Internet of Things embraces not only a things-oriented vision [AIM10] 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 [Gu13]. 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.

A layered Reference Architecture for the Internet of Things is described in [WSO15] and (Fig. 3), where layers can be implemented using suitable technologies.

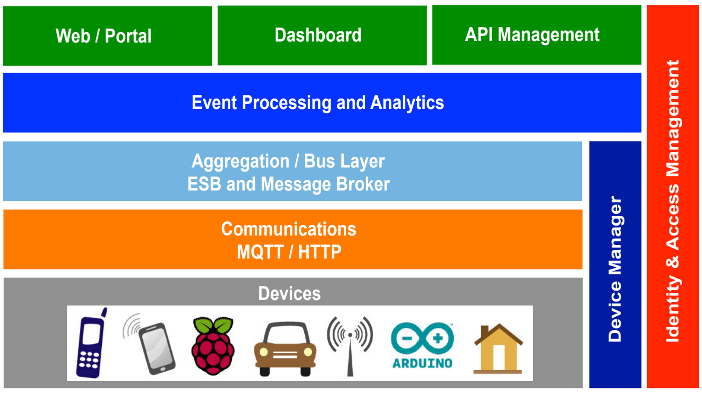

Fig. 3. Internet of Things Reference Architecture [WSO15]

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 [Ga12]. 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 [PC15] 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 [PC15] 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.

4 Architecting Microservices

The term Microservices became popular in the last years and refers to a fine-grained style of service-oriented architecture (SOA) applications combined with several DevOps elements. James Lewis and Martin Fowler define a Microservice Architecture [BZ16] as an approach for developing a single application from a suite of small services, each running in its own process and communicating with lightweight mechanisms, like HTTP. Microservices may additionally access NoSQL databases from on premise and optional Cloud environments.

These services are built around business capabilities and are independently deployable by an automated deployment pipeline. Typically, there is a bare minimum of centralized management of these services. Microservices may be written in different programming languages and can use different data storage technologies. 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 [Ev04].

However, Microservices also come with the need for a strong DevOps culture [Ne15] to handle the increased distribution level and deployment frequency. Moreover, while each single Microservice may be of reasonably low complexity compared to a monolithic application, the overall complexity of the system has not been reduced at all. Gary Olliffe [Ol15] distinguishes between the inner architecture and the outer architecture of Microservices (Fig. 4).

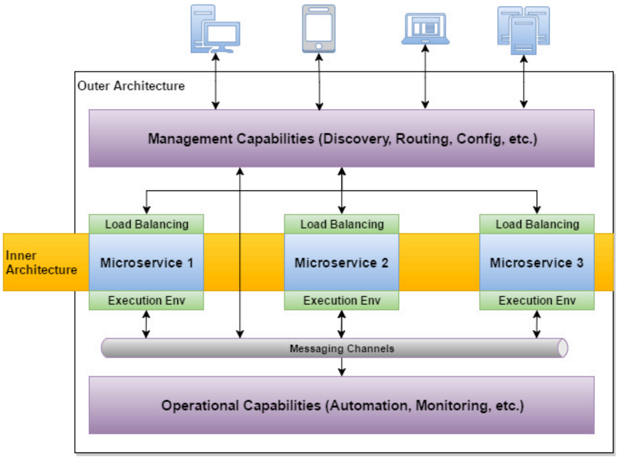

Fig. 4: Microservices Inner and Outer Architecture, based on [Ol15]

By splitting up a big monolith into more fine-grained independent services, you shift most of the hindering complexity from the inner architecture to the outer architecture, where inter-service communication, service discovery, or operational capabilities have to be handled. The greatest benefits that come with Microservices are the possibility to use the best-fitting technology for each *bounded context*. Typical examples are: increased application resilience (if one Microservice fails, the others may not be affected, at least if there is no chaining), independent and efficient scalability instead of replicating the complete monolith, and faster and easier deployment [Ne15]. Especially the last advantage is an important step towards agility of business and IT systems.

Enabling technological heterogeneity is usually considered an advantage of Microservices [BZ16] that allows the selection of the best tool for the job, reduces the possibility of lock-ins for outdated technology, and supports a culture of innovation and experimentation. However, Microservices also come with some risks for the organization. An explosion of technological diversity can quickly become overwhelming and unmanageable. Moreover, you are dependent on employees with the corresponding skills to handle these technologies and programming languages. This is why most organizations that use Microservice Architecture either provide some very basic standardization without limiting their teams' choices too much or encourage the use of only a certain technology subset by offering suitable tooling and infrastructure.

5 Architecture Metamodel Integration Method

Our current work extends our basic service-oriented enterprise architecture model from ESARC by integrating a huge amount of open architectural models of micro-granular systems and services, like IoT and Microservices. To be able to integrate a large amount of architectural resources efficiently we have developed ESAMI – Enterprise Services Architecture Metamodel Integration [Zi13], [Zi15], which is a correlation-based model integration approach for service-oriented enterprise architectures. It is a big challenge to continuously integrate numerous dynamically growing architectural descriptions from different microstructures with micro-granular architecture 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).

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 [MOF11] of the Object Management Group (OMG). The highest layer M3 represents abstract language concepts used in the lower M2 layer and is, therefore, the meta-metamodel layer. The next layer M2 is the metamodel integration layer and defines the language entities for M1 (e.g. models from UML, ArchiMate [Ar16], or OWL [OWL09]). These models are a structured representation of the lowest layer M0 that is formed by collected concrete data from real-world use cases.

By integrating DEA-Mini-Models micro-granular architectural cells (Fig. 5) for each relevant IoT object or Microservice, the integrated overall architectural metamodel becomes adaptable and can mostly be automatically synthesized by considering 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.

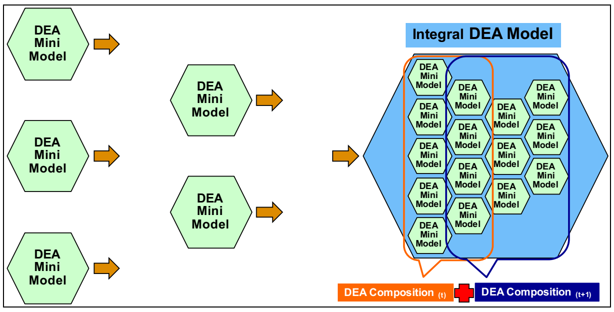

Fig. 5: Federation by Composition of DEA-Mini-Models [BZ16]

A DEA-Mini-Model covers partial EA-IoT-Data, partial EA-IoT-Models, and partial EA-IoT-Metamodels associated with main IoT objects like IoT-Resource, IoT-Device, and IoT-Software-Component [PC15], and [WSO15]. 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 [JSZ15] and [JS14]. We are currently extending model federation and transformation approaches [Tr15], [Fa12] by introducing semantic-supported architectural representations, from partial and federated ontologies [An13], [OWL09] 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 [Ti13] and linked this with main strategic drivers for system development and their evolution. Adaptation drives the survival of digital architectures, platforms and application ecosystems.

6 Conclusion

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. In order to support the digitization of products, services, and processes by integrating micro-granular architecture models for a living and holistic digital enterprise architecture model we have extended traditional enterprise architecture reference models by state of art elements for agile architectural engineering.

According to our research questions we have leveraged a new enterprise architecture approach to model a living digital enterprise architecture, which is in line with adaptive models and digital transformation mechanisms. We have extended in our work the new architectural integration context from the Internet of Things architecture and suppored Microservices for the digital transformation of products and services. Finally, we have extended our previous quite static enterprise architecture reference model to be able to integrate micro-granular systems and services, like Microservices and Internet of Things. This is a fundamental extension of our previous work on the ESARC reference model to be able to integrate through a continuously bottom-up approach a huge amount of micro-granular systems with own and heterogeneous local architectures.

We have additionally considered alternative approaches for the integration of large sets of divergent systems by introducing an open world modeling approach. Our approach has some limitations, which result from our original focus with manually working integration models for existing architectural metamodels assuming a closed word of a classical enterprise.

We are currently working on extended decision support mechanisms for an architectural cockpit for digital enterprise architectures and related engineering processes. Future work will extend both mechanisms for adaptation and flexible integration of digital enterprise architectures as well as decisional processes with rationales and explanations.

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