Decision-Controlled Digitization Architecture for Internet of Things and Microservices

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Abstract. Digitization of societies changes the way we live, work, learn, communicate, and collaborate. In the age of digital transformation IT environments with a large number of rather small structures like Internet of Things (IoT), Microservices, or mobility systems are emerging to support flexible and agile digitized products and services. Adaptable ecosystems with service-oriented enterprise architectures are the foundation for self-optimizing, resilient run-time environments and distributed information systems. The resulting business disruptions affect almost all new information processes and systems in the context of digitization. Our aim are more flexible and agile transformations of both business and information technology domains with more flexible enterprise information systems through adaptation and evolution of digital enterprise architectures. The present research paper investigates mechanisms for decision-controlled digitization architectures for Internet of Things and Microservices by evolving enterprise architecture reference models and state of the art elements for architectural engineering for micro-granular systems.

Keywords: Digitization Architecture, Architectural Evolution, Internet of Things, Microservices, Decision Analytics and Management

1 Introduction

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 [1]. Digitization enables human beings and autonomous objects to collaborate beyond their local context using digital technologies [2]. Information, data, and knowledge become more important as fundamental concepts of our everyday activities [2]. 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 [1], [2].

The Internet of Things (IoT) [3], [4], and [5] 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 [6], [7] 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 [2] 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 (MSA) [8]. Applications built this way consist of several fine-grained services that are independently scalable and deployable. Using Microservice Architectures, organizations can increase agility and flexibility for business and IT systems, which fits better with small-sized integrated systems and is vital in the age of digital transformation.

Digitization [2] 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 current research in progress paper investigates the research questions, which are answered by following main sections applying a design science methodology [9]:

RQ1: *How should the digital architecture be holistically tailored to integrate a huge amount of Internet of Things and Microservices architectures, researching the hypotheses that these micro-granular structures can be integrated into a consistent view into a digital enterprise architecture?*

RQ2: *How can we architect a huge amount of the Internet of Things and Microservices to support the digitization of products and processes?*

RQ3: *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 specific architectural integration mechanisms for micro-granular systems and services. Section 3 focusses on architecting the Internet of Things for supporting the digital transformation. Section 4 presents an architectural approach to integrating micro-granular systems and services architectures using Microservices. In Section 5 we are investigating concepts and mechanisms for analyzing and decision management of multi-perspective digital architectures with a huge amount of micro-granular systems and services. Finally, we summarize in Section 6 our research findings and limitations, and our ongoing and next work in academia and practice.

2 Digitization Architecture

Today, Enterprise Architecture Management [10]–[13] defines a quite large set of different views and perspectives with frameworks, standards, tools, and practical expertise. An architecture management approach for digital enterprises should support digitization of products and services and should be both holistic [2], [14] and easily adaptable [6]. It should also support digital transformation using new business models and technologies that are based on a large number of micro-structured digitization systems with their own micro-granular architectures like IoT, mobility devices, or with Microservices.

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 [15], which are supported by interactive functions of an EA cockpit [16]. Enterprise Services Architecture Reference Cube (ESARC) [14] is our improved architectural reference model for an extended view on evolved micro-granular enterprise architectures (Fig.1).

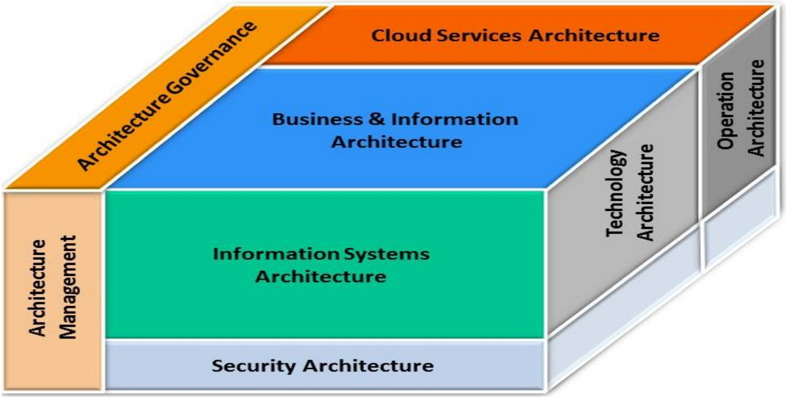

Fig. 1. Enterprise Services Architecture Reference Cube [14][6]

The new ESARC for digital products and services is more specific than existing architectural standards of EAM [12], [13] 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.

Our research extends an existing metamodel-based model extraction and integration approach from [14] for digital enterprise architecture viewpoints, models, standards, frameworks and tools. The approach supports the adaptable integration of micro-granular architecture. Currently, we are working on the idea of continuously integrating small architectural descriptions for relevant objects of a digital architecture. It is a huge 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 [17] 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 [13], or OWL [18]). 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. 2) 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.

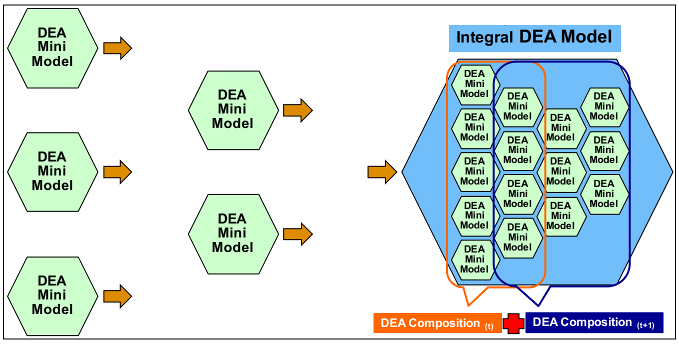

Fig. 2. Federation by Composition of DEA-Mini-Models [8]

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 [3], and [19]. 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 [15] and [16]. We are currently extending model federation and transformation approaches [20], [21] by introducing semantic-supported architectural representations, from partial and federated ontologies [22], [18] 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 [23] and linked this with main strategic drivers for system development and their evolution. Adaptation drives the survival of digital architectures, platforms and application ecosystems.

3 Internet of Things Architecture

The Internet of Things [19] 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 [24] and adaptable digital enterprise architectures [14]. 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 [4], [3].

The Internet of Things embraces not only a things-oriented vision [5] 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 [25]. 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 [19] and (Fig. 2), where layers can be implemented using suitable technologies.

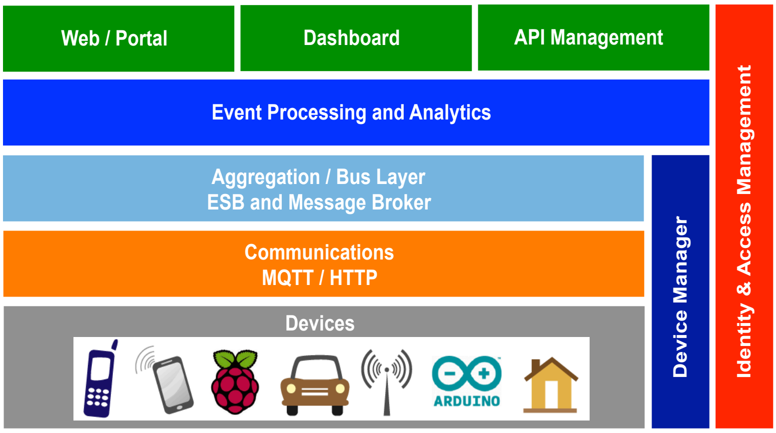

Fig. 4. Internet of Things Reference Architecture [19]

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 [26]. 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.

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 [26]. 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 [3] 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 [3] 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 Microservices Architecture

The Microservices approach is spreading quickly. Defined by James Lewis and Martin Fowler, as in [8], 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 are built 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) [27].

Microservices need a strong DevOps culture [28] 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. Gary Olliffe [28] distinguishes between the inner architecture and the outer architecture of Microservices (Fig. 4).

Using fine-grained independent services, the hindering complexity is shifted from the inner architecture to the outer architecture. There, inter-service communication, service discovery, or operational capabilities are handled. An important advantage of the Microservices architectures is the possibility to apply a best-of-breed approach for each bounded context [29]. Typical examples are: increased application resilience, independent and efficient scalability and faster and easier deployment. Especially the last advantage increases the agility of business and IT systems.

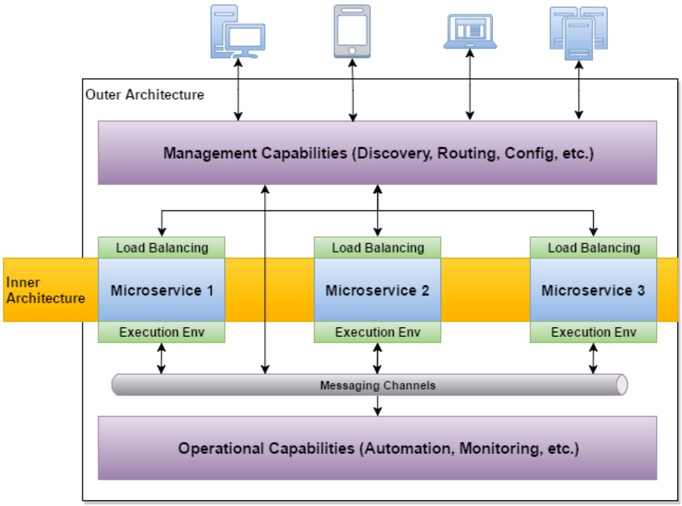

Fig. 4. Microservices Inner and Outer Architecture, based on [28]

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.

5 Decision Analytics

We are exploring in our current research, which extends the more fundamentally approach of a decision dashboard for Enterprise Architecture [30] and [31], how an Architecture Management Cockpit [16], [15] can be leveraged and extended to a Decision Support System (DSS) [31] for digital architecture management. An architectural cockpit in Fig. 5 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.

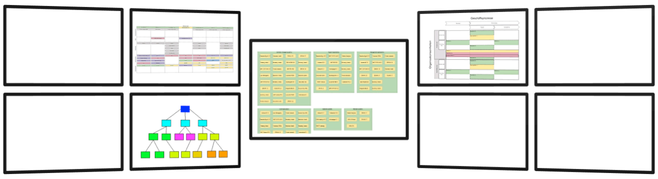

Fig. 5. Architecture Management Cockpit [15], [16]

Jugel et al. [15] 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 [32].

A decision-making step is based on case data consisting of an architectural model and additional insights elicited in previous steps. Consequently, the insights gained during each step contribute to the case file (CaseFile) of the decision-making case. Derived values, like the values of KPIs are thereby not considered additional information, but only a different way of representing and aggregating existing information. If stakeholders based on the values of a KPI decide on affected architecture elements, these decisions and considerations represent new information, which is added to the case file. During decision-making, alternative designs can be identified [13].

The ISO Standard 42010 [33] describes how the architecture of a system can be documented using architecture descriptions. The standard uses views, which are governed by viewpoints to address stakeholders' concerns and their information demands. Jugel et al. [15] introduce an annotation mechanism to add additional knowledge to an architecture description represented by an architectural model. In addition, [15] refines the viewpoint concept of [33] by dividing it into Atomic Viewpoint and Viewpoint Composition to model coherent viewpoints that can be applied simultaneously in a architecture cockpit with central and mobile environments to support stakeholders in decision-making. Architectural Issues and Decisions, were already introduced in the inspiring model of Plataniotis et al. [34]. As described in [34], architectural decisions can be decomposed, translated and substituted into other decisions.

6 Conclusion

We have discussed in this paper the need for a managed bottom-up integration of a huge amount of micro-granular systems and services, that is dynamically growing, like the Internet of Things and Microservices. Followoing our three mentioned research questions we have leveraged a new digital architecture approach to model a living digital enterprise architecture, which is in line with adaptive models and digital transformation mechanisms. We have investigated new architectural properties of micro-granular systems and services, like of Internet of Things and Microservices as a base for integrating them into our digital reference architecture. Strength of our research results from our novel integration of micro-granular structures and systems, while limits are still resulting from an ongoing validation of our research in practice.

We are currently working on an architectural cockpit for digital enterprise architectures and related engineering processes using extended decision support mechanisms. Both mechanisms for adaptation and flexible integration of digital enterprise architectures as well as decisional processes with rationales and explanations will be subject of future research. Similarly, it may be of interest to support the manual integration decision by automated systems, e.g. via mathematical comparisons (similarity, Euclidean distance), ontologies with semantic integration rules, or data analytics and data mining.

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