Decision-oriented Composition Architecture for Digital Transformation

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Abstract. 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 systems with many rather small and distributed structures, like Internet of Things or mobile systems. 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. This has a strong impact for architecting 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. In this paper, we are focusing on a decision-oriented architectural composition approach to support the transformation for digital services and products.

Keywords: Digital Services and Products, Digital Transformation, Digitization Architecture, Architectural Composition and Evolution, Decision Management

1 Introduction

Nowadays, more and more smart connected products and services are available and extending physical components capabilities using the Internet [1]. Furthermore, digitization, as introduced by Schmidt et al. [2], enables new data-driven processes and increases better decision making. Intelligent cars and smart devices are for instance part of a new digital economy with digital products, services, and processes [3].

Digitization [2] requires the appropriate alignment of digital business models with digital technologies, wich are synchronuously directed by new digital strategies. 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 [4] with extensions for semantic services.

Both business and technology are impacted from the digital transformation by complex relationships between architectural elements, which directly affect the adaptable digitization architecture [3] for digital products and services and their related digital governance. Enterprise Architecture Management (EAM) [5] organize, build and utilize distributed capabilities for the digital transformation [6], [7], [8].

Furthermore, the digitization process [3] demands flexibility to adapt to rapidly changing business requirements and newly emerging business opportunities. Therefore, many enterprises using concepts like Internet of Things [9], [10] and Microservice Architectures (MSA) [11], [12] to handle this fast digitization process. Applications built this way consist of several fine-grained services that are independently scalable and deployable. Using Microservice Architectures [11] organizations can increase agility and flexibility for business and IT systems, which fits better with small-sized integrated systems in the age of digital transformation.

Unfortunately, the current state of art and practice of enterprise architecture lacks an integral understanding of fast and flexible adaptation of architectures and decision management when integrating by composition of micro-granular systems and services, like Microservices and Internet of Things for the context of digital transformation and evolution of architectures. Our goal is to extend previous approaches of static closed-world enterprise architecture modeling to fit for the flexible and adaptive digitization when integrating new services and products coming from the open-world. This fundamental change from the closed to the open-world architectural modeling should be achieved by introducing suitable mechanisms for decision-oriented collaborative architectural engineering and methods for integrating micro-granular architectures by a new composition approach.

Our current paper extends our previous work and is part of an ongoing research project including different current and past research results. We investigate the following main research question in this paper:

What are suitable decision-oriented architectural composition and evolution approaches for flexible integrating and managing a huge amount of micro-granular structures, like Internet of Things and Microservices to support their flexible open-world integration as part of digital services and products?

The following Section 2 sets the base for the digital transformation with the context of digitized services and products. Section 3 focusses on architecting digital structures, systems, and technologies, while Section 4 presents suitable service-based architectural composition and software evolution approaches. In Section 5 we are investigating concepts and mechanisms for architectural decision management of multi-perspective digital architectures. Finally, we conclude in Section 6 our research findings and limitations and sketch our future research steps.

2 Digital Services and Products

Digital services [2] and associated digital products are software-intensive as well as malleable and usually service-oriented [13]. These services are able to increase their capabilities as well as change their behaviour [13]. Furthermore, digitized products can be able to support as well as increase the co-creation of the (service) value together with customers and (other) stakeholders [2].

In general, classical industrial products are static [6]. However, digitization provides the means to enrich them by digital services to be more flexible [32]. For instance, every industrial product can be complemented by services. These services can be updated and extended.

The Internet of Things [9], [10] drives the creation of digital products and services. The devices connected to the internet can exchange easily different information to support business processes. Furthermore, it is possible to get maintenance relevant data to run a better predictive maintenance approach. Therefore, more customer-oriented products will be available on the market. Furthermore, through linking data from different sources [14], it is possible to get better basements for decisions.

Additionally, platforms [15] and standardized interfaces [16] are important to support digitized services and products. Otherwise, the heterogeneity will destroy the value and the community effects of this new digitized services and products.

3 Digital Enterprise Architecture

Architecture Management [5], as today defined by several standards like [17] and [18], uses a quite large set of different views and perspectives for managing current IT. An effective architecture management approach for digital enterprises should additinally support the digitization of products and services [2] and be both holistic and easily adaptable [3], [13]. 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 [3] like IoT [9], [10], mobile devices, or with Microservices [11], [12].

We are extending our previous service-oriented enterprise architecture reference model for the context of digital transformation with micro-granular structures considering associated multi-perspective architectural decision-making [19], which is supported by functions of an architectural cockpit [20]. Enterprise Services Architecture Reference Cube (ESARC) provides an architectural reference model [3] by bottom-up integrating dynamically composed micro-granular architectural models (Fig. 1). ESARC for digital products and services is more specific than existing architectural standards of architecture management, like in [17], [18].

ESARC [3], [13] uses eight integral architectural domains to provide a holistic classification model. Currently, it is still abstract from a concrete business scenario or technologies, because it is applicable for concrete architectural instantiations to support digital transformations [13], [7], [8]. The Open Group Architecture Framework TOGAF [19] 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 [18].

Metamodels and their architectural data are the core part of the enterprise architecture. Enterprise architecture metamodels [5], [21] should enable decision making [21] 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., [13]).

ESARC extends by a holistic view the metamodel-based extraction and bottom-up integration (Section 4) for micro-granular viewpoints, models, standards, frameworks and tools of a digital enterprise architecture model. ESARC 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.

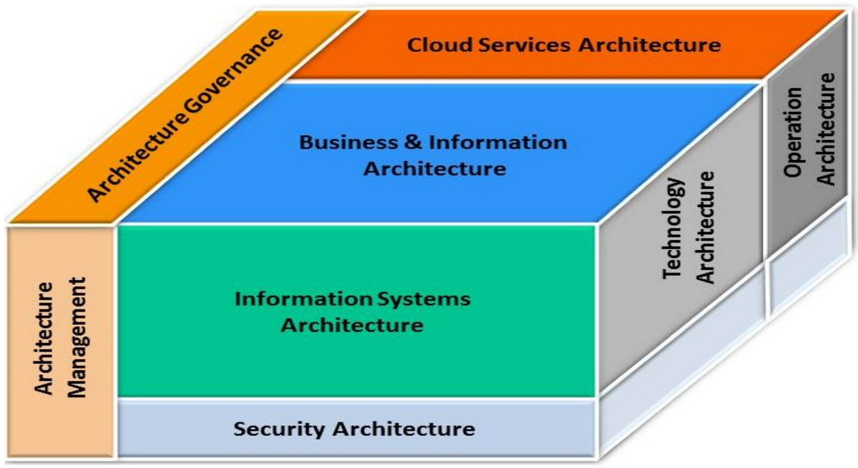

Fig. 1. Enterprise Services Architecture Reference Cube [3], [13]

Architecture governance, as in [22], 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 [23] 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 [24] 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.

4 Architectural Composition

Digital transformation [1], [6], [7] 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, analyse customer behaviour 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 [11] 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 [3]. Our model structures (Fig. 2) are extensions of the Meta Object Facility (MOF) standard [25] of the Object Management Group (OMG).

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

Regarding the structure of EA-Mini-Descriptions, the highest layer M3 [11] 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 [18]). The models can be seen as a structured representation of the lowest layer M0 [25].

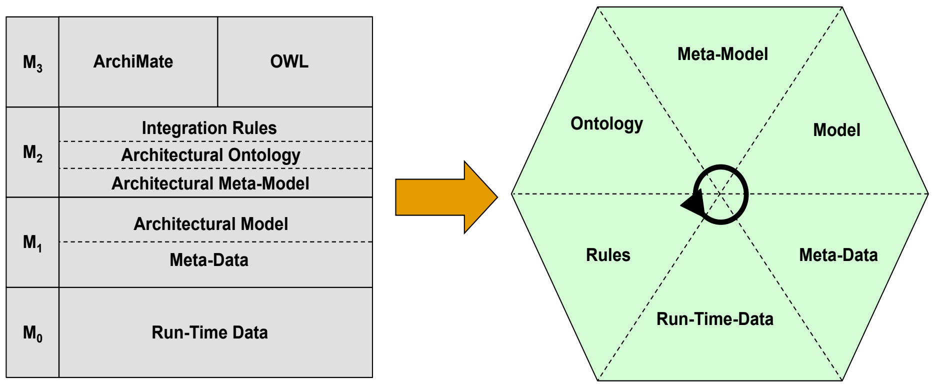

Fig. 2. Structure of EA-Mini-Descriptions [13]

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 [2], [3], platforms, and application environments. Weil and Woerner introduces in [6] 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 [26] 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 (Fig. 3) for each relevant object, e.g., Internet of Things object or Microservice, the step-wise composed time-stamp dependent architectural metamodel becomes adaptable [11] [3]. Furthermore, it can be mostly be automatically synthesized by respecting the integration context from a growing number of previous similar integrations [3].

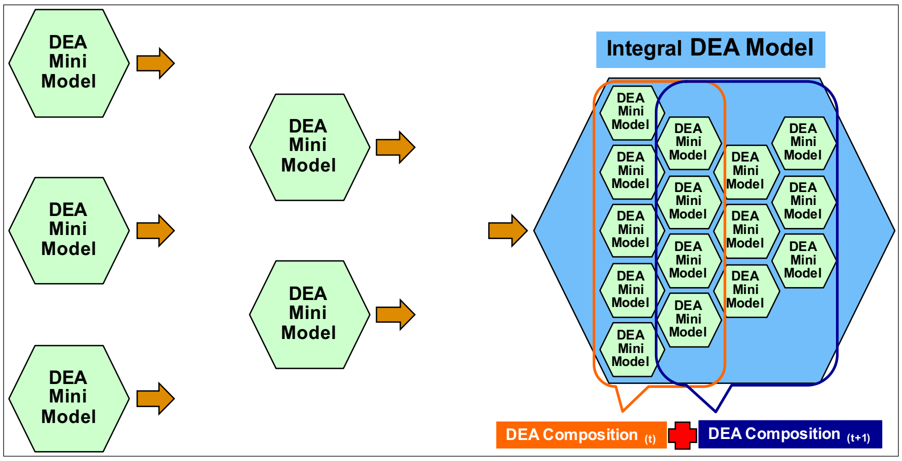

Fig. 3. Architectural Federation by Composition [3], [11]

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 [19] and [20], as in the following Section 5.

The Enterprise Services Architecture Model Integration (ESAMI) [13] (see Fig. 4) method is based on correlation analysis, which provides an instrument for a systematic manual integration process. Typically, this process of pair wise mappings is of quadratic complexity. We have linearized the complexity of these architectural mappings by introducing a neutral and dynamically extendable architectural reference model, which is supplied and dynamically extended from previous mapping iterations. Furthermore, we have adopted modeling concepts from ISO/IEC 42010 [27], like *Architecture Description*, *Viewpoint*, *View*, and *Model*.

The *Correlation Index* for different IoTs or microservices (red middle columns) with respect to the current *Reference Model* (yellow columns on the left) is created. Based on these *Correlation Indices*, the *Integration Options* for each service (green columns on the right) are chosen and the selection is integrated into the *Reference*

Model. This continuous model refinement allows to integrate even extremely heterogeneous microservices that may not even share a complete metamodel.

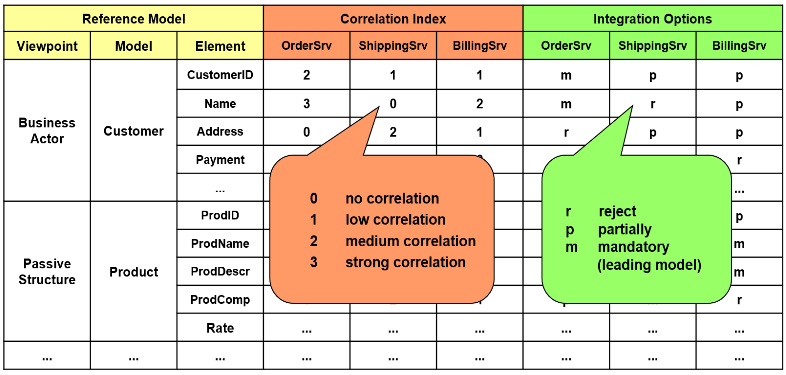

Fig. 4. Correlation Analysis and Integration Matrices [13]

These architectural metamodels are composed of their elements and relationships and are represented by architecture diagrams. The ESAMI approach is based on special correlation matrices, which are handled by a manual process to identify similarities between analyzed model elements. The chosen elements are then integrated according to their most valuable contribution towards a holistic reference model. In each iteration of this bottom-up approach, we are analyzing the fit of each new microservice metamodel in comparison with the context of the existing integrated set of services' metamodels.

5 Decision Management

Our current research links decision objects and processes to multi-perspective architectural models and data. We are extending the more fundamentally approach of decision dashboards for Enterprise Architecture [23], [5], [21] and integrate this idea with an original Architecture Management Cockpit [19], [20] for the context of decision-oriented digital architecture management for a huge amount of micro-granular architectural models from the open-world.

As shown in Fig. 5, the architectural cockpit [19], [20] enables analytics as well as optimizations using different multi-perspective interrelated viewpoints on the system under consideration [3]. Multiple perspectives of architectural models and data result from a magnitude of architectural objects, which are typed according the dimension categories of a digital enterprise architecture from section 2. Additionally, we have to consider analytics and decision viewpoints in a close association with the architectural core information.

The ISO Standard 42010 [27] defines, how the architecture of a system can be documented through architecture descriptions. Jugel et al. [20] develops and introduces a special annotation mechanism adding additional needed knowledge via an architectural model to an architecture description.

The advantage of architectural decision mechanisms is a close link between architectural artefacts and architectural models with explicit decisions, both from a classical

Enterprise Architecture Management perspective and a new way of managing micro-granular structures and systems as well.

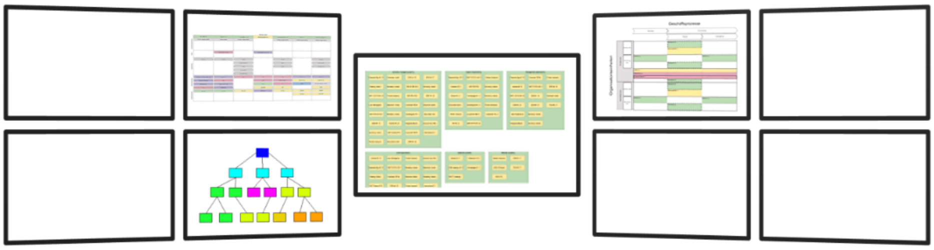

Fig. 5. Architecture Management Cockpit [20]

In addition, **[**19**]** reveals a viewpoint concept by dividing it into an Atomic Viewpoint and a Viewpoint Composition. Therefore, coherent viewpoints can be applied simultaneously in an architecture cockpit to support stakeholders in decision-making [20]. Fig. 6 illustrates the decision metamodel, as extension of [28], showing the conceptual model of main decisional objects and their relationships.

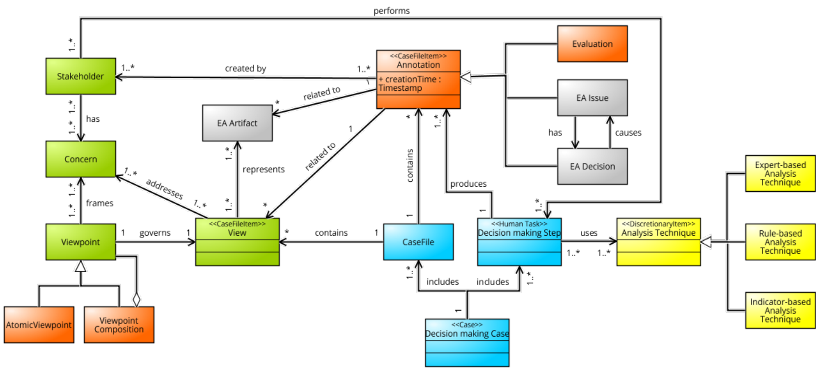

Fig. 6. Architecture Decision Metamodel [19]

According to the architecture management cockpit [19], [20], each possible stakeholder can utilize a viewpoint that shows the relevant information. Furthermore, these viewpoints are connected in a dynamically way to each other, so that the impact of a change performed in one view can be visualized in other views as well.

6 Conclusion

Regarding our research question, we have first set the architectural background for digital services as well as digital products by focusing on main digitization concepts. Second, we have showed the need for an extended understanding and support of micro-granular systems as well as architectural models, like Internet of Things and Microservices.

The bottom-up composed digital enterprise architecture is a living digital enterprise architecture composition, which is in line with adaptive models and digital transformation mechanisms. This aspect of living architectural models fundamentally extends existing quite static standard frameworks like MODAF [29]. 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 and open issues of managing inconsistencies and semantic dependencies.

Our research question has pointed to a new viewpoint of an architectural composition, supported by a multi-perspective architecture management and decision environment for micro-granular digital architectures. Our novel main outcomes result from specific methods, mechanisms and environments for a decision-supported bottom-up integration for a huge amount of open-world micro-granular architectural structures as extended artifacts of a new tailored multi-perspective digital enterprise architecture. Furthermore, we are currently working on an extended architectural cockpit for digital enterprise architectures, related (engineering) processes using different extended decision support mechanisms.

Future research should be in the field of mechanisms for flexible and adaptable integration of digital enterprise architectures. Similarly, it may be of interest to extend human-controlled integration decision by automated systems, e.g. via mathematical comparisons (similarity, Euclidean distance), ontologies with semantic integration rules, or data analytics and data mining with deep learning mechanisms.

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