Architecting Service-Dominant Digital Products

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Abstract. Presently, many companies are transforming their strategy and product base, as well as their culture, processes and information systems to become more digital or to approach for a digital leadership. In the last years new business opportunities appeared using the potential of the Internet and related digital technologies, like Internet of Things, services computing, cloud computing, edge and fog computing, social networks, big data with analytics, mobile systems, collaboration networks, and cyber physical systems. Digitization fosters the development of IT environments with many rather small and distributed structures, like the Internet of Things, Microservices, or other micro-granular elements. 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 micro-granular system architectures defines the moving context for adaptable systems. We are focusing on a continuous bottom-up integration of micro-granular architectures for a huge amount of dynamically growing systems and services, as part of a new digital enterprise architecture for service-dominant digital products.

Keywords: Digital transformation · Service-dominant logic ·
Value-oriented digital products · Digital enterprise architecture ·
Decision management

1 Introduction

Influenced by the digital transformation many enterprises are presently transforming their strategy, culture, processes, and their information systems to become more digital. Data, information and knowledge are fundamental core concepts of our everyday activities and are driving the digital transformation of today's global society [7, 50].

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New services and smart connected products [31] expand physical components by adding information and connectivity services using the Internet.

Digitization [35] defines the process of digital transformation, which is promoted by important technological megatrends: Internet of Things, cloud, edge and fog computing, 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 humans, as well as 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 call for an information-driven vision [54, 57].

The digital transformation deeply disrupts existing enterprises and economies. Digitization fosters the development of IT systems with many, globally available and diverse 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 integrating high distributed systems and services.

Unfortunately, the current state of art in research and practice of enterprise architecture lacks an integral understanding of software evolution [8, 58], 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 extension of our ENASE 2018 paper [58] focuses in this paper on a fundamental research question:

> *How can a value-oriented digital enterprise architecture for service-dominant digital products and services be modeled to support the open-world integration and management for a huge amount of dynamically growing micro-granular digital structures, like Internet of Things and Microservices?*

We will proceed as follows. First, we will set the fundamental architectural context for digital transformation. Then we present our digital modeling approach for systematically defining value-oriented service-dominant digital products in order to enable a mapping of digital business models to digital product compositions and digital architectures. Based on the target of digital architectures we are focusing on architecting micro-granular systems and services with Internet of Things and Microservices, while the next section gives the larger integration context with an original and high scalable digital enterprise architecture. In the following section we are presenting our architectural composition model for bottom-up integrating micro-granular digital products and services into a digital enterprise architecture. Then we provide insides to our methods and mechanisms for architectural decision management for multi-perspective digital architectures. Based on these steps, we sketch fundamental aspects of an architectural evolution path for digital systems and services. Finally, we conclude in the last section our research findings and mentioning our future work.

2 Digital Transformation

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 [50], are software-intensive [35] and therefore malleable and usually service-oriented [8]. Digital products are able to increase their capabilities via accessing cloud-services and change their current behavior [53].

The service-dominant S-D logic [41–43] 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 [42] for defining service businesses, including digital services and products. The origin of service-dominant logic was slightly extended through modifications and additional premises [43] to a body of five axioms and eleven foundational premises.

New ways of interaction with the customer are enabled [19] 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 [46] 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 [35] 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 [7, 50] for new business solutions, having new smart connected functionalities.

In the beginning, digitization was considered a primarily technical term [48]. Thus, a number of technologies is often associated with digitization [50]: cloud computing, big data often combined with advanced analytics [44], social software, and the Internet of Things [1, 29]. New technologies are associated with digitalization such as deep learning [36]. 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 [35] perspective.

Classical industrial products are static [7]. 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 [35] 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.

Digital products also enable network effects [49] 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 [7]. 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 [49]. 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 [35] 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 [42] approach of service-dominant logic [43] can be implemented because of a persisting continuous connectivity of digital products with the manufacturer. The consumer converts dynamically to be co-producer. Platforms are complementary to products, which cooperate via standardized interfaces.

3 Value-Oriented Digital Products

The business and technological impact of digitization [35] has multiple aspects, which directly affect digital architectures of service-dominant digital products. Unfortunately, our current modeling approach for designing proper digital service and product models suffers from having many uncontrolled diverse modeling approaches and structures, where value-orientation of integral composed services and systems is only partially fulfilled. High quality digital models should follow a clear value and service perspective. But today, we currently have no sound value relationship from digital strategies, to the resulting digital business modeling, and subsequently to a value-oriented enterprise architecture, which today often has seldom proper aligned service and product model representations. The core idea of the present contribution and current paper is to present and discuss a new introduced integral value-oriented model composition approach by linking digital strategies with digital business models for digital services and close aligned products by means of an extended multi-perspective digital enterprise architecture model.

Value is commonly associated with worth and aggregates potentially required categories like worth, importance, desirability and usefulness. The concept of value is important in designing adequate digital services with their associated digital products, and to align their digital business models with value-oriented enterprise architectures. From a financial perspective the value of the integrated resources and the price defines the main parts of the monetary worth.

A current conceptualization of value as a service-based view is offered by [41] and [16] considering a conceptual framework of service-dominant (S-D) logic [42, 43] and its service-ecosystem perspective. The distinction between the concepts of value-in-use and value-in-exchange dates back to the antiquity and continue to influence our today's value view. Since the work of Adam Smith and the development of economic science the value-in-exchange as a measure for price a person is willing to pay for a service or a product moved to the forefront. Smith recognized the value-in-use as the real value and value-in-exchange as the nominal value. The digital marketing discipline nowadays shifted to a nominal use of the value perspective [41] considering customer experience and customer satisfaction as important value-related concepts.

Characteristics of value modeling for a service ecosystem were elaborated by [41]. Value has important characteristics: value is phenomenological, co-created, multidimensional, and emergent. Value is phenomenological means that value is perceived experimentally and differently by various stakeholders in the varying context within a service ecosystem. Value is co-created though the integration and exchange of resources between multiple stakeholders and related organizations. Value is also multidimensional, which means that value is aggregated up of individual, social, technological and cultural components. Value results as emergent value from specific manifestations of relationships between resources and resource combinations. Therefore, the resulting real value cannot be determined ex-ante. Value propositions are value promises for a typical, but not exactly known customer at design time and should be realized later when using these digital services and associated products.

Through exploiting the base of service-dominant logic and by means of design research a focused set of four design principles for business-model-based management methods was elaborated in [4]. The first principle defines the proactive base for an ecosystem-oriented management by positioning the orchestration tasks for specific actors in a service ecosystem, defining an organization's role as focal orchestrator in the service ecosystem, and for sharing the risks, costs, and revenues among multiple actors. The second principle about a technology-based management defines responsibilities for using digital infrastructures, for decoupling informational assets from products and facilitate product exchange, and for driving value creation through digital channels. Principle three about mobilization-oriented management postulate the mobilization of operand resources, like knowledge and capabilities, which are the fundamental source of strategic benefit, and further uncovering and utilizing internal knowledge. The last principle about co-creation-oriented management demands for customer involvement, to reflect on co-creation through customer journey as dynamic interaction, and for recalibrating service bundles to optimize customer's experience.

Our current paper sketches our view of an integrated value perspective combined with a service perspective, as in Fig. 1. Today, we are experiencing a starting set of now not well consolidated digital strategy frameworks, like in [28] which are loosely associated with traditional strategy frameworks, as in [3].

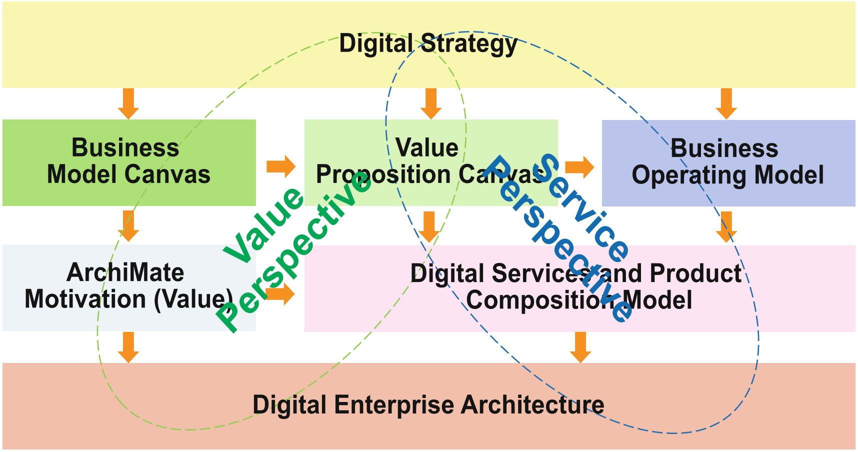


Fig. 1. Value perspective of service-dominant logic.

Our starting point is a model of the digital strategy, which provides direction and sets the base and a value-oriented framing for the digital business definition models, with the business model canvas [25], and the value proposition canvas [26]. Having the base models for a value-oriented digital business we map these base service and product models to a digital business operating model. An operating model [32] strategically defines the necessary level of business process integration and standardization for delivering services and products to customers. From the value perspective of the business model canvas [25] results suitable mappings to enterprise architecture value models [17] with ArchiMate [23]. Finally, we are setting the frame for the systematic definition of digital services and associated products by modeling digital services and product compositions following semantically related composite patterns [10].

The primary motivation of successful organizations is to provide value to one or mode stakeholders, typically considering value for clients at first. This includes the modeling of value creation, capturing, and value delivery by using discrete value producing tasks. Classical concepts of value chains and value networks are seminal for lean value streams and for applying the current fundamental TOGAF series guide on value streams [24]. Porter's value chain modeling focuses on an economic perspective while value networks primarily shows participants involved in creating value.

Value streams, as in [24], models an end-to-end value view of value-adding activities as value stream stages from the customer's or stakeholder's perspective. Therefore, value streams enable digital business models which are closer to the definition and not the implementation of organizational core activities. Value streams are defined as compositions of value stages from the value-perspective for the addressed stakeholders.

From using value stream models and mappings we can summarize important benefits. Value stream models are the base for decision making helping to envision and prioritize the impact from strategic plans, for managing the stakeholders' engagement, and supporting the deployment of new business solutions. Business capabilities enable value stages and value streams, which are focused to the viewpoint of customers. Value streams provide a framework for better requirement analysis, case management, and supports modeling of digital services. Finally, value streams are focused on how business value is achieved for specific stakeholders, particularly for customers.

4 Micro-granular Architectures

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.

4.1 Internet of Things Architecture

The Internet of Things (IoT) [1, 22, 32] 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 [45] 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 [34] and adaptable digital systems.

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 [34] and adaptable digital enterprise architectures [57].

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 [29]. 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 [40].

A layered Reference Architecture for the Internet of Things is in [52] and Fig. 2, where layers can be implemented using suitable technologies.

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 [37]. 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 [11]. 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 24 × 7 timeframe, with deployment and auto-switching across cooperating

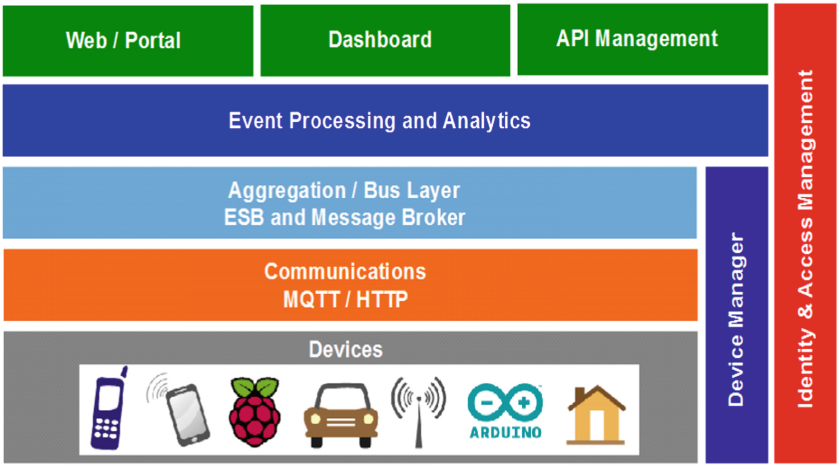


Fig. 2. Internet of things reference architecture [52].

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 [37] 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 [29] 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.

4.2 Microservices Architecture

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.

A lot of software developing enterprises have switched to integrate Microservice architectures to handle the increase velocity [2, 5]. 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.

The Microservices approach is spreading quickly. Defined by James Lewis and Martin Fowler, as presented in [5], 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) [5].

Microservices and Microservices Architectures (MSA), as in [2], 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 interrelationships, 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.

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.

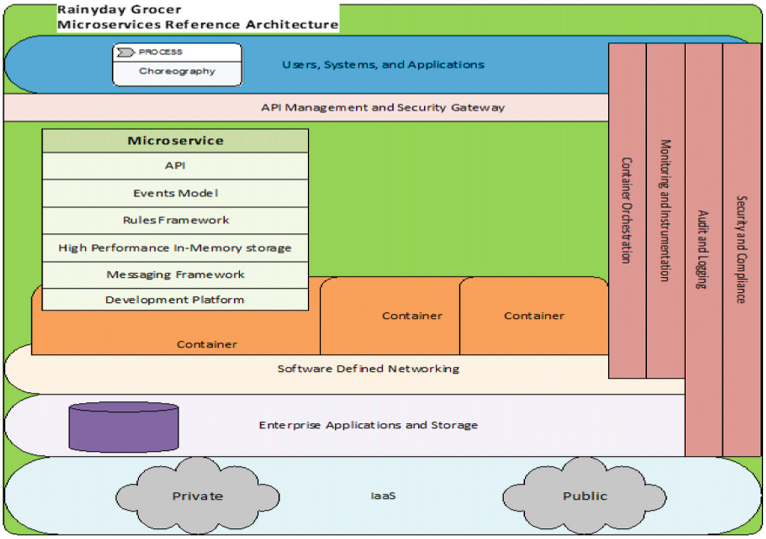


Fig. 3. Microservices reference architecture [2].

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 [20], 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 [20] 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.

5 Digital Enterprise Architecture

Enterprise Architecture Management [15, 27], as today defined by several standards like [22] and [23] 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 [35] and be both holistic and easily adaptable [5]. 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 [29, 52], mobile devices, or with Microservices [2, 20].

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 [13] models, which are supported by viewpoints and functions of an architecture management cockpit. DEA - Digital Enterprise Architecture Reference Cube provides an architectural reference model [57] 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 [22] and in [23]. The bottom-up composition of living architectural models fundamentally extends existing quite static standard frameworks like MODAF [18].

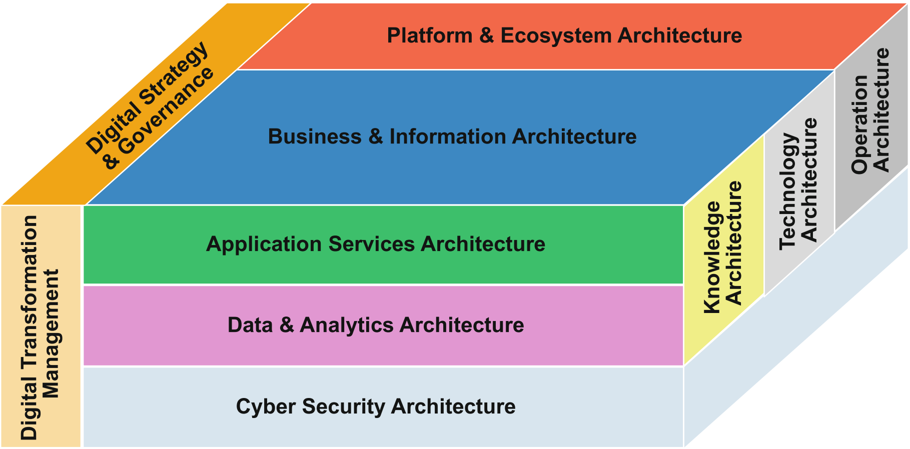


Fig. 4. Digital enterprise architecture reference cube.

DEA extends the research base in [53–58] and provides today in our current research ten integral architectural domains for a holistic architectural classification model, which is well aligned to embed also 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 [7, 31, 56] independent of different domains. The Open Group Architecture Framework TOGAF [22] 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 [23].

Metamodels and their architectural data are the core part of the enterprise architecture. Enterprise architecture metamodels [15] and [23] should enable decision making [57] 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., [47]).

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.

Architecture governance, as in [47], 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.

6 Architectural Composition Model

Digital transformation [31, 48, 50] 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 [5] 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 [56]. Our model structures (Fig. 5) are extensions of the Meta Object Facility (MOF) standard [21] 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

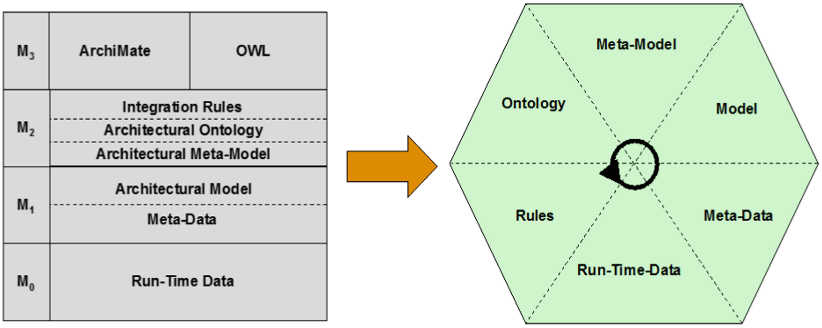


Fig. 5. Structure of EA-mini-descriptions [57].

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 [5] 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 [23]). The models can be seen as a structured representation of the lowest layer M0 [21].

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 [56], platforms, and application environments. Weil and Woerner introduces in [48] 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.

During the integration of DEA-Mini-Models as micro-granular architectural cells (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 [5] and [53–55]. Furthermore, it can be mostly be automatically synthesized by respecting the integration context from a growing number of previous similar integrations [56].

Being a bit closer to the architecture and design of systems, Trojer et al. coined in [39] 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.

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 [13] and [14], as in the following Section.

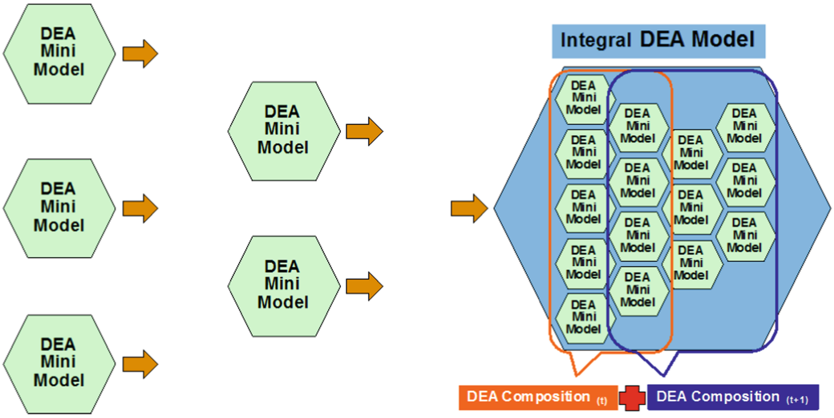
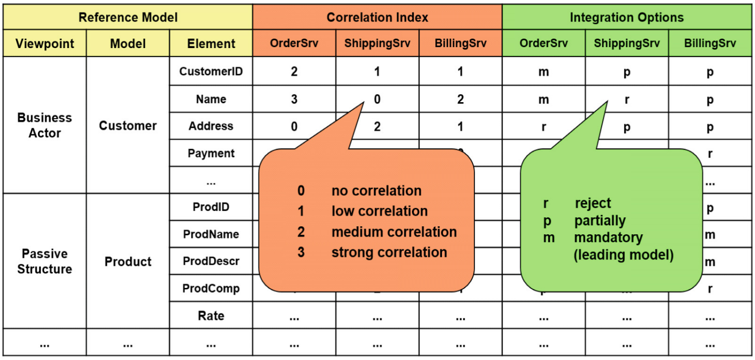


Fig. 6. Architectural federation by composition [57].

The Enterprise Services Architecture Model Integration (ESAMI) [53] (see Fig. 7) 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 [9], like *Architecture Description*, *Viewpoint*, *View*, and *Model*.



Reference Model			Correlation Index			Integration Options		
Viewpoint	Model	Element	OrderSrv	ShippingSrv	BillingSrv	OrderSrv	ShippingSrv	BillingSrv
Business Actor	Customer	CustomerID	2	1	1	m	p	p
		Name	3	0	2	m	r	p
		Address	0	2	1	r	p	p
		Payment						r
		...						...
Passive Structure	Product	ProdID						p
		ProdName						m
		ProdDescr						m
		ProdComp						r
		Rate	...	...	...	...	...	...
...	...	...	...	...	...	...	...	...

0 no correlation
1 low correlation
2 medium correlation
3 strong correlation

r reject
p partially
m mandatory (leading model)

Fig. 7. Correlation analysis and integration matrices [57]. (Color figure online)

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.

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.

We are currently extending model federation and transformation approaches [39] by introducing semantic-supported architectural representations, from partial and federated ontologies and associate mapping rules with special inference mechanisms.

Fast changing technologies and markets usually drive the evolution of ecosystems. Therefore, we have extracted the idea of digital ecosystems from [38] and linked this with main strategic drivers for system development and their evolution. Adaptation drives the survival of digital architectures, platforms, and application ecosystems.

7 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 [15, 27, 33] and integrate this idea with an original Architecture Management Cockpit [13, 14] for the context of decision-oriented digital architecture management for a huge amount of micro-granular architectural models from the open-world.

A cockpit presents a facility or device via which multiple viewpoints on the system under consideration can be consulted simultaneously. Each stakeholder who takes place in a cockpit meeting can utilize a viewpoint that displays the relevant information. Thereby, the stakeholders can leverage views that fit the particular role, like Application Architect, Business Process Owner or Infrastructure Architect. The viewpoints applied simultaneously are linked to each other such that the impact of a change performed in one view can be visualized in other views as well.

As shown in Fig. 8, the architectural cockpit [13] enables analytics as well as optimizations using different multi-perspective interrelated viewpoints on the system under consideration [54, 55]. 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. Additionally, we have to consider analytics and decision viewpoints in a close association with the architectural core information.

The ISO Standard 42010 [9] defines, how the architecture of a system can be documented through architecture descriptions. Jugel et al. [14] develops and introduces a special annotation mechanism adding additional needed knowledge via an architectural model to an architecture description.

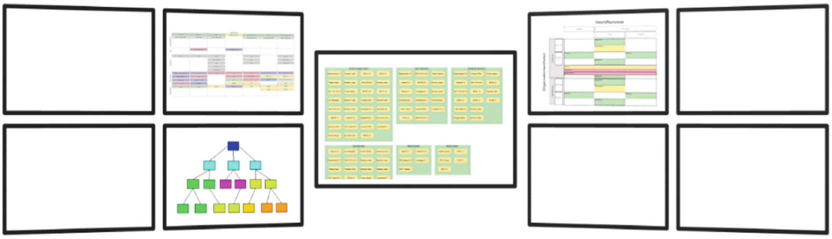


Fig. 8. Architecture management cockpit [13, 14].

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.

In addition, the fundamental work in **[**13**]** 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 [14]. Figure 9 illustrates the decision metamodel, as extension of [30], showing the conceptual model of main decisional objects and their relationships.

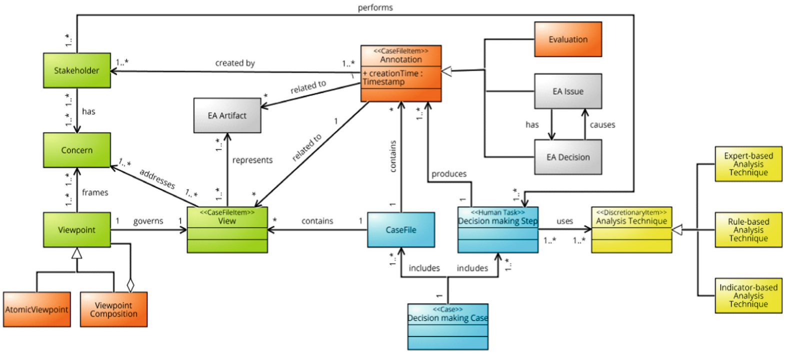


Fig. 9. Architecture decision metamodel [14].

According to the architecture management cockpit [13, 14], 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.

8 Evolution of Digital Services

The digital transformation [7, 35] highly increased the competitive pressure and urges enterprises to quickly develop new digitized products and services. Time to market is a key differentiator in digital transformation. The quicker a business is, the more successful it is likely to be. But more established businesses have delivered technology solutions to their employees and customers on lengthy release schedules that no longer make sense in today's accelerated environment.

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

Principally we can identify, as in [51], two broad perspectives of software evolution: First, software can be designed anticipating change by the original software developer to make evolution easier by predicting possible change perspectives of a new software. The main mechanism of proactive change is based on modularity structures of services. Secondly, software evolution can be handled during the maintenance phase by using special tools and methods. The intention here is to support understanding of software structures of the existing code, as fast and easy as possible.

The implementation of flexible and maintainable services strongly depends on service quality of services [12]. In the past, most quality of service indicators were designed for method-driven Web Services with SOAP. Today, many new services are designed in a resource-oriented way using REST or Microservices, to follow an easier technology-independent approach. Many of the existing quality indicators for Web Services can be mapped to resource-oriented services. Resource-oriented services can also be engineered using Microservices, as mentioned.

Decision analytics [55] provides increasingly complex and decision support, particularly for the development and evolution of sustainable enterprise architectures (EA), and this is duly needed. Tapping into these systems and techniques, the engineers and managers of the software and system architecture become part of a viable enterprise, i.e. a resilient and continuously evolving service-oriented architectures and systems that enable and drive innovative business models.

Main challenges of service computing for the next ten years guide a redefinition of service computing, which are postulated by [6]. The service computing manifesto (Fig. 10) maps out in a strategy that positions emerging concepts and technologies to support the service paradigm. The service computing manifesto recommends focusing on four main research directions by specifying both challenges and a research roadmap: service design, service composition, crowdsourcing based reputation, and the Internet of Things.

An important prerequisite for building and analyzing sound service systems and architectures is a formal understanding of the nature of services and their model-supported relationships. We have to currently consider a big change from traditional

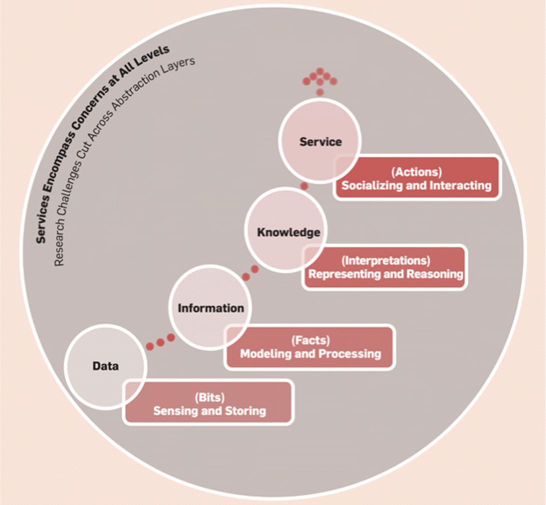


Fig. 10. Service evolution along the computing value chain [6].

closed-world software engineering approaches to the open-world of service systems with autonomous parts [6].

An important prerequisite for building and analyzing sound service systems and architectures is a formal understanding of the nature of services and their model-supported relationships. Cloud computing as a new service delivery model, which gives inspiration to integrate service computing and cloud computing. So, cloud computing is a main influencing factor for the service computing manifesto in [49], while other important influencers for service computing are mobile computing, big data, and social computing.

In the next wave of service composition [6], we have to integrate a fast growing and large set of non-WSDL-described services: REST services, Microservices, and partial services, like IoT or Android apps. In an open-world setting of big data existing static service selection, composition, and recommendation are inadequate and should be extended by large-scale Web and cloud service composition, big data driven service composition, and social network-based service compositions.

Trust [35] plays an important role for a functional service ecosystem. Crowd-sourcing provides effective means for collecting data through collaborations within communities. Reputation mechanisms and crowdsourcing in social networks support predicting credibility, which is important for derive trust. Artificial intelligence technologies, like deep learning [36], allow computers to behave in specific usage scenarios to behave like human beings.

Innovative models are required for the composition of Internet of Things (IoT) [2] and [29]. IoT poses two fundamental challenges: communication with things, and management of things. One additional challenge is that things are resource-constrained, making it practical impossible to combine IoT with heavy standards like, SOAP and BPEL. The IoT component model is further heterogeneous and multi-layered, typically with devices, data, services, and organizations. The IoT designed functionality is more dynamic and context-aware than in traditional settings.

The resulting fundamental IoT challenges [2] are related to continuously maintaining cyber personalities and context information for IoT devices, and continuously discovering, integrating, and reusing IoT and their data. Graph-based approaches and machine-learning techniques can facilitate discovery of hidden relationships between IoT and helping detecting correlations among IoT.

9 Conclusion

Based on our fundamental research question we have first set the context proceeding from digital transformation to a systematic value-oriented digital product and service modeling. To be able to support the dynamics of digital transformation with flexible software and systems compositions we have leveraged an adaptive architecture approach for open-world integrations of globally accessed systems and services with their local architecture models.

We contribute to the literature in different ways. Looking to our results, we have identified the need and solution mechanisms for a value-oriented integration of digital strategy models through suitable digital business models up to models for service-dominant products as part of a value-based digital enterprise architecture. We have developed a bottom-up integration approach for a huge amount of dynamically growing micro-granular systems and services, like mobile systems, Microservices or the Internet of Things. To integrate micro-granular architecture models from an open-world we have extended traditional enterprise architecture reference models and enhanced them with state of art elements from agile architectural engineering to support the digitalization of products, services, and processes. This is a major extension of our seminal work on reference enterprise architectures, to be able to openly integrate through a continuously bottom-up approach a huge amount of global available and heterogeneous micro-granular systems, having their own local architectures. Additionally, we have investigated current and next elements of service-oriented technologies to point to main influence factors, challenges and research areas for the evolution of enterprise architecture and the evolving discipline of the service economy.

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 and open issues in managing inconsistencies and semantic dependencies.

Future research addresses mechanisms for flexible and adaptable integration of digital enterprise architectures. Similarly, it may be of interest to extend human-controlled dashboard-based interaction and visualizations by integrating automated decision making by AI-based systems like, ontologies with semantic integration rules, and architectural data and model analytics with deep learning mechanisms as well as mathematical comparisons (similarity, Euclidean distance) and statistical methods.

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