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# Intelligent Decision Management for Architecting Service-Dominant Digital Products

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**Abstract**

New business opportunities appeared using the potential of the Internet and related digital technologies, like the Internet of Things, services computing, artificial intelligence, cloud, edge, and fog computing, social networks, big data with analytics, mobile systems, collaboration networks, and cyber-physical systems. Companies are transforming their strategy and product base, as well as their culture, processes and information systems to adopt digital transformation or to approach for digital leadership. Digitalization fosters the development of IT environments with many rather small and distributed structures, like the Internet of Things, Microservices, or other micro-granular elements. Digitalization has a substantial impact for architecting the open and complex world of highly distributed digital services and products, as part of a new digital enterprise architecture, which structure and direct service-dominant digital products and services. The present research paper investigates mechanisms for supporting the evolution of digital enterprise architectures with user-friendly methods and instruments of interaction, visualization, and intelligent decision management during the exploration of multiple and interconnected perspectives by an architecture management cockpit.



*Keywords:* Digital Products and Services; Digital Architecture; Interaction and Visualization; Intelligent Decision Management

## 1. Introduction

Today's organizations and enterprises are deeply influenced by the Internet and digital transformation aiming to reinvent themselves or transform their strategy, culture, products, services, capabilities, processes, and their

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information systems to adopt digitalization [11], [6]. Data, information, and knowledge are fundamental core resources of our everyday activities and are driving the digital transformation of today's global society. New services and smart connected products expand physical components by adding information and connectivity services using the Internet.

Digitalization [6] and Digitization [21] define the process of digital transformation, which are promoted by current technological trends: 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 essential business enablers for the digital transformation. Digital services and products amplify the essential value and capabilities, which offer exponentially expanding opportunities. Digitalization enables human beings and autonomous objects to collaborate beyond their local context using digital technologies. The exchange of information enables better decisions of co-creating humans, as well as of intelligent digital systems and services.

Enterprises are complex and integrated systems of processes, organizational units, resources and technologies with a multitude of interdependencies. Enterprise architecture management (EAM) [9] aims at providing an integrated view on these aspects of an organization to support the alignment of business and IT, optimization scenarios, quick adaption to environmental changes and other purposes. Since enterprise architectures are complex structures, it is difficult to keep track, transparently decide and to work out relevant characteristics. Both business and technology are connected to digital transformation by complex relationships between architectural elements, which directly affect the integrated view of a digital architecture [11] for digital products and services and their related digital governance. Enterprise architecture management (EAM) [9] organizes, build and utilize distributed capabilities for the digital transformation [11], [27].

Unfortunately, the current state of art and practice of enterprise architecture lacks an essential understanding of a fast and flexible adaptation of architectures and related decisions when integrating a magnitude of micro-granular digital systems and services, like Microservices and Internet of Things. Our goal is to extend previous approaches of static closed-world enterprise architecture management to fit for the flexible and adaptive digitalization by introducing new methods and instruments for decision-oriented collaborative architectural engineering for digital enterprise architectures.

A useful interaction and visualization combine a suitable way of representing information with a careful selection of relevant information. Therefore, the elicitation of what information is relevant to address the stakeholders' concerns is crucial. Work in the area of information logistics showed that information demands depend on the tasks and responsibilities (concerns) of an organizational role [8]. Thus, the critical precondition for achieving demand-oriented information supply is to understand the roles and stakeholder concerns and their information demands. Although visualizations are often used in practice for decision-making in enterprise architecture management, their capabilities often leave much to be desired [7]. Visualizations are often static and therefore cannot be changed interactively with changed information demands. The configuration is also often very complex and requires expert knowledge.

Therefore, our current research paper investigates the following central question:

*What is a suitable intelligent decision management approach with multi-perspective mechanisms of interaction and visualization of digital architectures for supporting flexible digital services and products?*

First, we will set the architectural context for digital transformation and the targeted service-dominant digital products. Then we present our digital architecture approach. In the following section, we are giving insights into our intelligent decision management approach pointing to visualization and interaction methods, which we implemented and practically evaluated as a sophisticated central compliance cockpit. Finally, we conclude in the last section our research findings and mentioning our future work.

## 2. Service-Dominant Digital Products

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 [11] are software-intensive [21] and therefore malleable and usually service-oriented [3]. Digital products can increase their capabilities by accessing Cloud-Services and change their current behavior [27].

Digitization fosters the development of IT systems with many, globally available, and diverse, rather small and distributed structures [27], like the Internet of Things [1] or Microservices [14]. A lot of software developing enterprises have switched to integrate Microservice architectures to handle the increased velocity. Therefore, applications built this way consist of several fine-grained services that are independently scalable and deployable.

In the beginning, Digitalization was considered a primarily technical term [26]. Thus, many technologies are preconditions of Digitalization [11]: Cloud Computing, Big Data often combined with advanced analytics, social software, and the Internet of Things [1]. New technologies like Artificial Intelligence [20] with Deep Learning [5], [22] support digitalization efforts. They allow intelligently automated activities that are traditionally exclusive to human beings.

Digitized products and services [21] support the co-creation of value together with the customer and other stakeholders in different ways. First, there is permanent feedback to the provider of the product. The internet connection of the digitized product allows collecting data permanently on the usage of the product by the customer. Second, the data provided by a large number of digital products can offer new insights, which are not possible with data from a single device. Current research argues that digital products and services are offering disruptive opportunities [12] for new business solutions, having new smart connected functionalities.

The business and technological impact of Digitization [21] has multiple aspects, which directly affect digital architectures of service-dominant digital products [25]. Unfortunately, current modeling approach for designing proper digital service and product models suffers from using uncorrelated and diverse modeling approaches and structures, with issues in integral value-orientation of necessary composed services and systems.

High-quality digital models should follow a specific value and service perspective. However, 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 properly aligned service and product model representations. The present contribution shows a newly introduced value-oriented model composition approach by linking digital strategies with digital business models for digital services and close aligned products through an extended multi-perspective digital enterprise architecture model.

Value is commonly associated with the worth of a digital service or product [17], [24] and aggregates potentially required attributes for successful customer experiences, such as meaning, desirability, and usefulness. The concept of value is essential 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.

The current conceptualization of value as a service-based view is offered by [24] and [13] considering a conceptual framework of service-dominant (S-D) logic [24] 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 today's value view. Since the work of Adam Smith [23] and the development of economic science the value-in-exchange as a measure for a 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 simple use of the value perspective considering customer experience and customer satisfaction as critical value-related concepts.

Characteristics of value modeling for a service ecosystem were elaborated by [24]. Value has essential 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 changing context within a service ecosystem. Value is co-created through 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 the new 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 precisely known customer at design time and should be realized later when using these digital services and associated products.

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 first digital strategy frameworks, like in [2], in loosely association with traditional strategy frameworks. 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 [17], and the value proposition canvas [18]. 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 [26] strategically defines the necessary level of business process integration and standardization for delivering services and products to customers.

The business model canvas [17] is the blueprint for mappings to enterprise architecture value models [13] with ArchiMate [16]. Finally, we are setting the frame for the precise definition of digital services and associated products by modeling digital services and product compositions, following semantically related composite patterns [4].

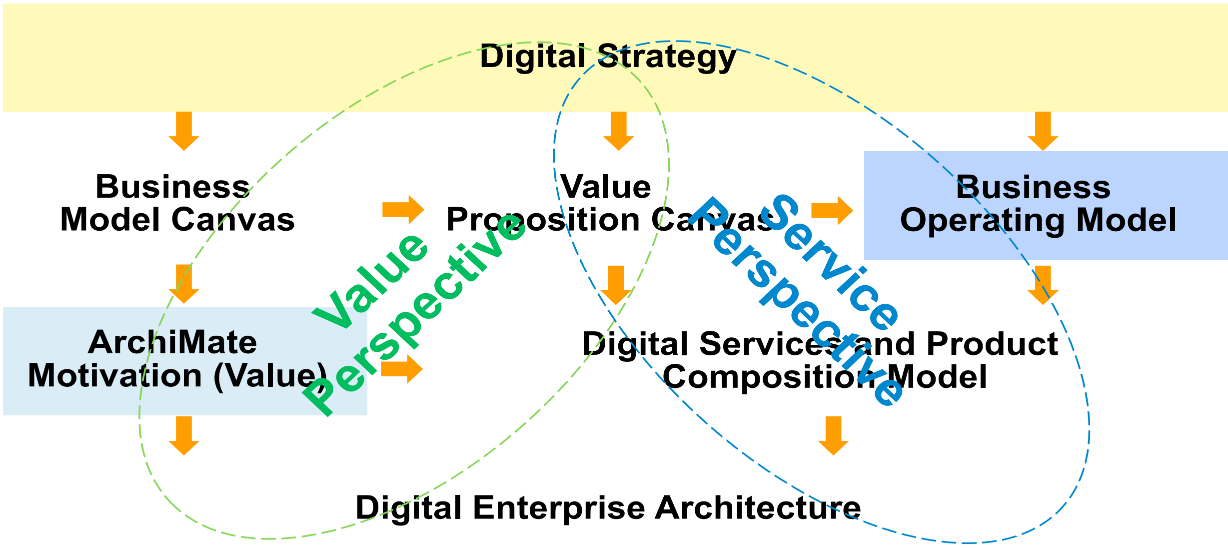


Fig. 1. Integrating Value and Service Perspectives.

Our thesis is that Digitization embraces both a product and a value-creation perspective. Standard industrial products are static. We 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. Digital products are upgradeable via network connections. Also, their functionality can be extended or adapted using external services. Therefore, the feature of digital products is dynamic and adjustable 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.

## 3. Digital Architecture

Digitalization promotes massively distributed systems, which rely on the development of IT systems with many rather small and distributed structures, like the Internet of Things, mobile systems, cyber-physical systems, and others. Additionally, we have to support digitalization by a dense and diverse amount of different service types, like microservices, REST services, and put them in a close relationship with distributed systems, like the Internet of Things. The change from a closed-world modeling perspective to more flexible open-world composition and evolution of system architectures [27] defines the moving context for flexible systems, which are essential to enable the digital transformation. Adaptivity has a strong impact on architecting digital services and products. The implication of architecting micro-granular systems and services considering an open-world approach fundamentally changes the modeling contexts, which are classical and well defined by quite static closed-world and all-times consistent and less complex models.

Digital transformation [6], [21] and digital disruption [12] create many events that may impact enterprises and organizations. Resilient enterprise architecture management plays an essential role in fostering strategies and capabilities for resiliency by providing methods and tools for flexible designing enterprises architectures. It may address enterprises but also selected parts of enterprise architecture such as services and processes. Resilient Services are services that provide additional meta-services in addition to their core functionality to cope with disruptive events. E.g., airlines reschedule passengers of delayed flights. Resilient Processes provide event handlers to cope with external events and are thus capable of leading back the control flow on the desired track even in the case of adverse events. Their decision points use data from a multitude of internal and external sources allowing them to detect and react to changes in the environment.

Resiliency is the capability of enterprises and their information systems [11] to cope with fast and real-time changing events. Resiliency is the ability of an IT system to provide, maintain and improve disturbed services even when changes occur. Resiliency is a new capability because of combining a multitude of different perspectives on different abstraction levels such as organizational resiliency, information system resiliency, cyber resiliency, network and technology resiliency, as well as organizational resiliency. Resiliency refers to an entity's ability to deliver the intended outcome despite adverse cyber events continuously. Resiliency includes response and recovery and developing resilient-by-design systems. Resiliency requires constructive and organizational approaches with a strong focus on a managed environment for enterprise architectures of information systems and services.

Enterprise Architecture (EA) [9] is since years a well-motivated discipline of enterprise and IT governance. Enterprise Architecture has since more than one decade as a discipline with a scientific background and useful decision supporting functions and models for forward-thinking enterprises and organizations. Enterprise Architecture aims to model, align and understand significant interactions between business and IT to set a prerequisite for a well-adjusted and strategically oriented decision-making framework for both digital business and digital technologies.

Digital Enterprise Architecture Reference Cube (DEA) extends the research base from [27] and provides today in our current research ten integral architectural domains for a holistic architectural classification model (Fig. 2), which is well aligned to embed also micro-granular architectures for different digital services and products. DEA abstracts from a particular business scenario or technologies, because it is applicable for concrete architectural instantiations to support digital transformations [6], [11] independent of different domains.

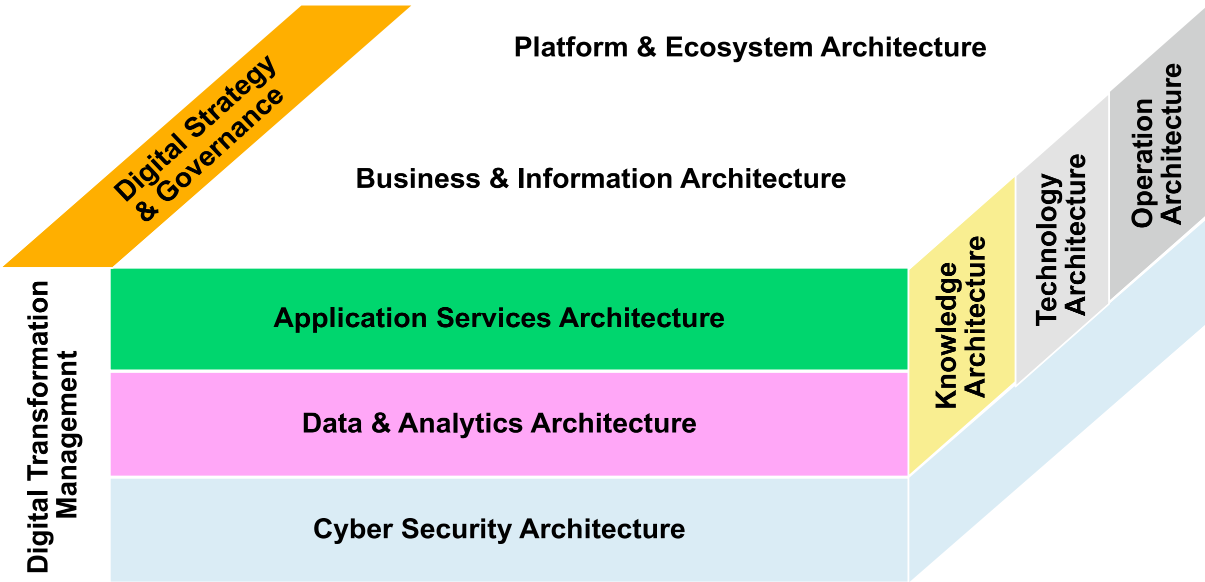


Fig. 2. Digital Enterprise Architecture Reference Cube.

The Digital Enterprise Architecture Reference Cube (DEA) supports by a holistic view metamodel-based extraction and bottom-up integration methods and techniques by integrating micro-granular viewpoints, models, standards, frameworks and tools into a consistent digital enterprise architecture model. DEA frames these multiple elements of a digital architecture into basic configurations of digital architecture by providing an ordered base of architectural artifacts for associated multi-perspective decision processes.

Enterprise Architecture Management [9], as today defined by several standards like [15] and [16] uses a quite large set of different views and perspectives for managing current IT. A practical architecture management approach for digital enterprises should additionally support the digitization of products and services [21] and be both holistic and easily adaptable [27]. Furthermore, a digital architecture sets the base for the digital transformation enabling new digital business models and technologies that have a large number of micro-structured digitization systems with their micro-granular architectures like IoT [1], mobile devices, or with Microservices [14].

Architecture governance, as in [27], defines the base for well-aligned management practices through specifying management activities: plan, define, enable, measure, and control. Digital governance [11] 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 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 plenty of various micro-granular structures, like the Internet of Things or Microservices.

## 4. Intelligent Decision Management

While integrating a massive amount of micro-granular architectural models and objects as part of open digital architecture, we are currently extending our research base about architecture decision management by integrating AI methods for partially automating repetitive or similar decision situations. Due to advances in several areas of automation AI [20], [5], [22] receives today much of attention, especially in areas like decision making which are not well covered by traditional algorithmic approaches. In our current research, we are setting the extended focus on integrating the classical symbolic AI with machine learning and deep learning approaches and apply these for architectural decision support. Currently, we are extending our previous research on expert systems with mechanisms for explanation and reasoning based on rules, horn clauses and ontologies. Additionally, we are working on integrating deep learning mechanisms with traditional semantic support methods for the automatically bottom-up integration of similar architectural model elements into a comprehensive and transparently explainable digital architecture [27].

Our current paper 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 [9], [27] and integrate this idea with an original Architecture Management Cockpit [7], [8], as in Fig. 3, for the context of decision-oriented digital architecture management for a considerable amount of micro-granular architectural models from the open-world.

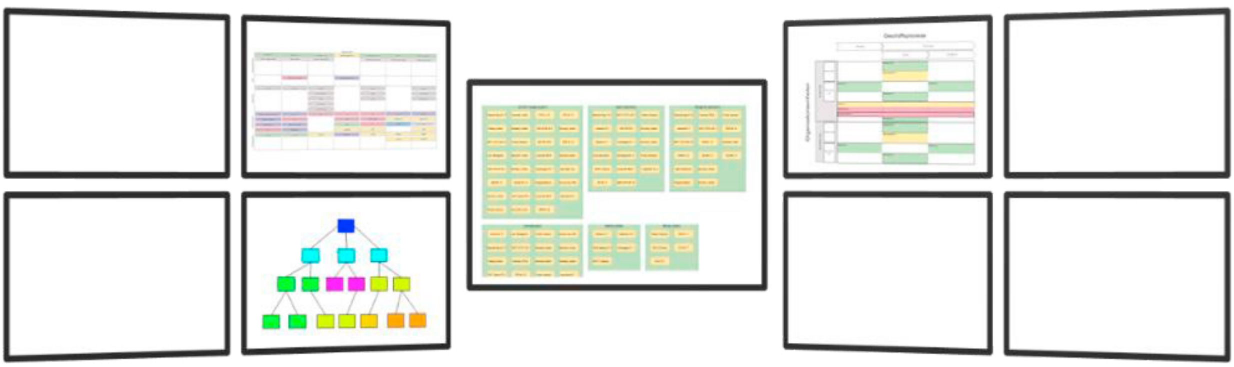

Fig. 3. Architecture Management Cockpit.

The Architecture Management Cockpit [7] enables analytics as well as optimizations using different multi-perspective interrelated viewpoints on the system under consideration [8]. Multiple perspectives of architectural models and data result from a magnitude of architectural objects, according to the dimension categories of a digital enterprise architecture. Additionally, we have to consider analytics and decision viewpoints for the architectural core information.

The ISO Standard 42010 [8] defines, how architecture descriptions model the architecture of a system. Jugel et al. develop and introduces a unique annotation mechanism adding additional needed knowledge via an architectural model to an architecture description. The original work in **[8]** 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 [7]. Fig. 4 illustrates the decision metamodel, like our extension of [19], showing the conceptual model of main decisional objects and their relationships. According to the architecture management cockpit [7], [8], 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. Following [7] we have defined the concept of Decision Process, as a logical sequence of activities to solve one or more identified problems.

The concept Activity represents the individual activities of the process. Since these Activities take place with social participation, at least one Stakeholder links to an activity, who executes the particular activity. The Stakeholder concept results from ISO Standard 42010 [8].

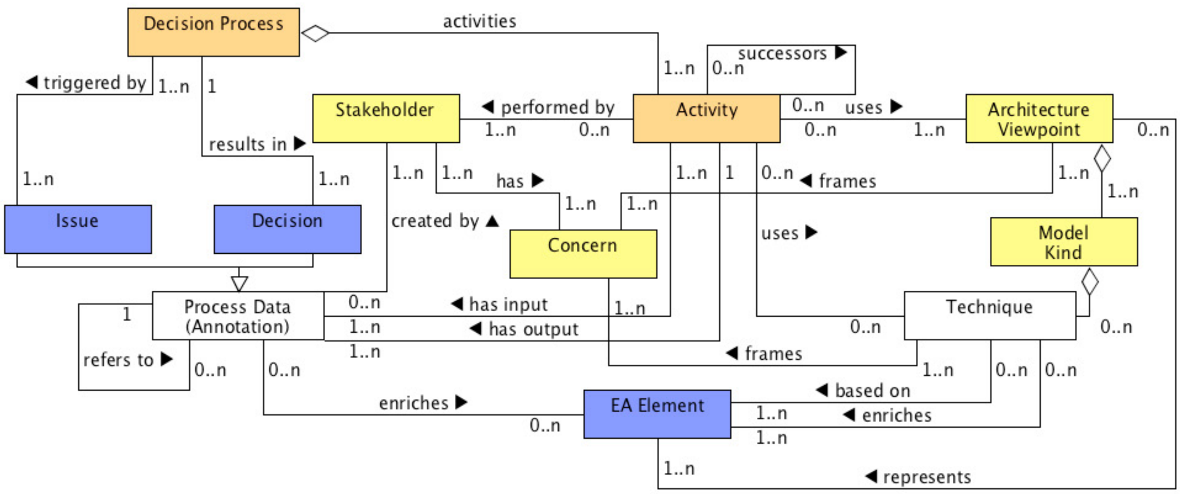


Fig. 4. Architecture Decision Metamodel.

Architecture Viewpoints are used to visually represent parts of the enterprise architecture in a stakeholder-oriented way, while Techniques contain detailed recommendations of actions or algorithms for automated execution of specific tasks.

## 5. Architecture Compliance Cockpit

The use case of a Control Compliance Cockpit [8] of a global operating insurance company exemplarily shows some viewpoints giving a comprehensive picture of selected 'cyber risks' about the company – covering cybersecurity and enterprise architecture related risks. The risk assessment results concerning globally mandated control objectives for mitigating cyber risks are visualized in a web-based cockpit environment, whose main user interface is anonymously presented in Fig. 5. The user interface visualizes risk rates of company's operating entities

(OEs) using a world map, identifying 'Country OEs' with the corresponding countries and also adding non-country-specific OEs ('Global OEs') to the visualization.

The World Map Viewpoint serves as an entry point for user visualizations and interactions. The Control Compliance Cockpit presents various Control Objectives and Assessment Techniques and combines them with the various stakeholders' concerns. The viewpoint allows adding a layer representing a selected Control Objective via a color-coding. The legend at the bottom of the visualization reflects the scoring system of the respective Assessment Technique ranging from 'very good' (dark green) to 'very bad' (red), adding two more colors for the Measurements 'not available' (dark gray) and 'not in focus' (light gray). The latter color indicates countries in which there is no operating OE. The slider on the right side of the visualization directly influences the thresholds specified in the Assessment Technique. When these thresholds are adapted, the Assessment Technique re-calculates the scoring, and the color-coding is adapted. Via this mechanism, 'what-if' analyses support subject matter experts.

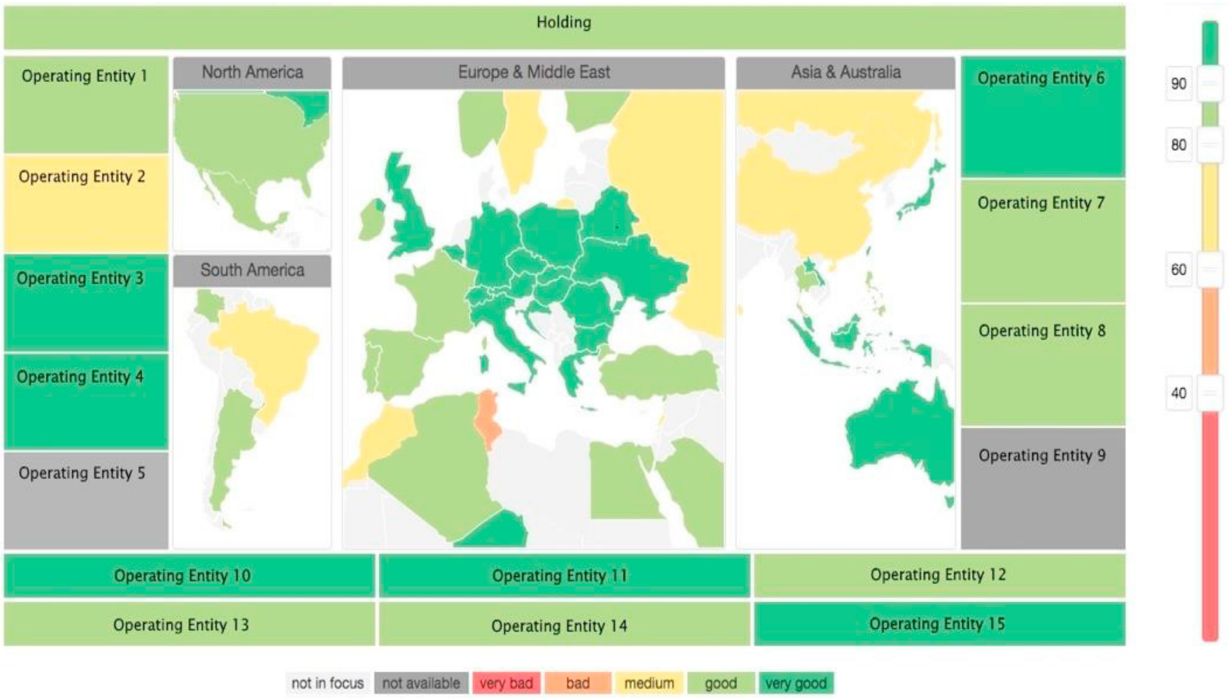


Fig. 5. Control Compliance Cockpit.

The number of internet-facing vulnerabilities (ExtV) visualizes, for instance, the number of vulnerabilities exposed via internet-facing IP addresses, taking into account the severity of the vulnerability and the time, for which this vulnerability was exposed. The number of internal vulnerabilities (IntV) provides a corresponding assessment for the vulnerabilities being exposed to IP addresses being available from the internal network. The assessment techniques used are directly based on results from a technical vulnerability scanner.

IT Ageing and IT Debt relate to structuring concepts of the Enterprise Architecture, typing the Control Objective to the 'areas' in which the non-compliance was measured. Examples of such structuring elements are different hierarchical types of IT Domains: Infrastructure Domains reflect prevalent operating environments for the IT, e.g. data center, workplace and mobile, and Technical Domains reflect typical use cases for 'commodity' IT, e.g., operating system, database system, and application server.

IT Ageing computes the distribution of IT assets over the releases of used technology. A 'left-hanging' distribution is thereby considered an indication of aging, a 'right-hanging' distribution for the actuality of the current IT asset concerning that technology. , in turn, is assigned to an IT Domain reflecting its prevalent operating environment and use case. IT Debt is expressed in the amount of money needed to migrate from non-standard technologies to their conventional counterparts. IT Debt computes the distribution of IT assets of a standard to non-standard technologies.

Assessment Techniques are categorized by the way their corresponding Measurements are determined. In particular for grouped high-level Control Objectives no direct assessments may exist, but their results may be derived from more granular Measurements. In line with this, we differentiate two types of Assessment Techniques: Direct Assessment Techniques acquire results by self-assessments or using technical tools for measuring, and Derived Assessment Techniques calculate results based on the results of already performed assessments.

Based on these values the results of following two high-level Assessment Techniques are derived. Cyber Security Attack Exposure (CSAE) provides a cumulated view on the exposure to cybersecurity-related attacks resulting from organizational, procedural and technical vulnerabilities that can potentially be exploited by an attacker. The value of an OE's measurement is derived from the assessments of constituting control objectives. The score of the measurement is determined by applying a minimum operation to the scores of the constituting Assessment Techniques, reflecting a worst-case assumption concerning exposure.

Arc Debt provides a cumulated view on potential costs and disadvantages that result from non-compliance to Global Architecture Standards and missing investments into IT rejuvenation. The value of the OE's measurement is derived from the assessments of constituting control objectives. The Architectural

Debt for an IT Domain combines operating environments (as the top-level) and use cases (at the child-level), e.g. ‘operating system on workplace’. The value is determined by applying a summation over the values of the constituting Assessment Techniques.

The number of internet-facing vulnerabilities, the number of internal vulnerabilities and the Cyber Security Attack Exposure all consider the OE as a whole, making them Direct Control Objectives. The Architectural Debt with constituting IT Ageing and IT Debt are conversely Typed Control Objectives bound to the EA concepts IT Domain and Technology which are assessed for any instance of these concepts, e.g., the above IT Domain ‘operating system on workplace’.

## 6. Conclusion

Based on our research question we have first set our context for the current context of digital transformation for service-dominant digital products. To be able to support the dynamics of digital transformation with flexible software and systems compositions we have leveraged an adaptive digital architecture for open-world integrations of globally accessed intelligent systems and services with their local architecture models. The new main results of our current paper include methods, mechanisms, and an exemplary use case for interaction, visualization and intelligent decision management of digital enterprise architecture with related intelligent systems and digital services. Furthermore, we have demonstrated the feasibility of our research and the enterprise architecture cockpit through large projects and validations, like the architecture compliance cockpit for key partners from science and practice.

To integrate micro-granular architecture models from an open-world, we have extended traditional enterprise architecture reference models and enhanced them with state-of-the-art elements from agile architectural engineering to support the digitalization of products, services, and processes. Our approach is a significant extension of our seminal work to be able to integrate micro-granular systems with local-defined architectures.

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. Additionally, we are working on introducing a capability view to serve as a single point to integrate other models and views of the Digital Enterprise Architecture Reference Cube.

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