Enterprise Architecture Management for the Internet of Things

Alfred Zimmermann[1], Rainer Schmidt[2], Kurt Sandkuhl[3],
Dierk Jugel[1,3], Michael Möhring[4] and Matthias Wißotzki[3]

Abstract: The Internet of Things (IoT) fundamentally influences today's digital strategies with disruptive business operating models and fast changing markets. New business information systems are integrating emerging Internet of Things infrastructures and components. With the huge diversity of Internet of Things technologies and products organizations have to leverage and extend previous enterprise architecture efforts to enable business value by integrating the Internet of Things into their evolving Enterprise Architecture Management environments. Both architecture engineering and management of current enterprise architectures is complex and has to integrate beside the Internet of Things synergistic disciplines like EAM - Enterprise Architecture and Management with disciplines like: services & cloud computing, semantic-based decision support through ontologies and knowledge-based systems, big data management, as well as mobility and collaboration networks. To provide adequate decision support for complex business/IT environments, it is necessary to identify affected changes of Internet of Things environments and their related fast adapting architecture. We have to make transparent the impact of these changes over the integral landscape of affected EAM-capabilities, like directly and transitively impacted IoT-objects, business categories, processes, applications, services, platforms and infrastructures. The paper describes a new metamodel-based approach for integrating partial Internet of Things objects, which are semi-automatically federated into a holistic Enterprise Architecture Management environment.

Keywords: Internet of Things, Enterprise Reference Architecture, Architecture Integration Method, Architecture Metamodel and Ontology

1 Introduction

One of the most challenging objects for our current discussion about the digital transformation of our society is the Internet of Things (IoT) [Wa14] and [Pa15]. The Internet of Things enables a large number of physical devices to connect each other to perform wireless data communication and interaction using the Internet as a global communication environment. Information and data are central components of our everyday activities. Social networks, smart portable devices, and intelligent cars, represent a few instances of a pervasive, information-driven vision of current enterprise systems with IoT and service-oriented enterprise architectures. Social graph analysis and management, big

[1] Reutlingen University, {alfred.zimmermann, dierk.jugel}@reutlingen-university.de
[2] Munich University, {rainer.schmidt@hm.edu}
[3] University of Rostock, {dierk.jugel@uni-rostock.de}
[4] Aalen University, {michael.moehring@htw-aalen.de}

data, and cloud data management, ontological modeling, smart devices, personal information systems, hard non-functional requirements, such as location-independent response times and privacy, are challenging aspects of the above software architecture [BCK13].

Service-oriented systems close the business - IT gap by delivering appropriate business functionality efficiently and integrating new service types coming from the Internet of Things [Gu13], [Sp09] and from cloud services environments [Be11], [OG11] and [CSA09]. As the architecture of Internet of Things systems becomes more complex, and we are going rapidly into cloud computing settings, we need a new and improved set of methodological well-supported instruments of Enterprise Architecture Management, which are associated with tools for managing, decision support, diagnostics and for optimization of impacted business models and information systems.

The current state of art research for the Internet of Things architecture [Pa15] lacks an integral understanding of Enterprise Architecture and Management [Ia15], [Jo14], [To11] and [Ar12] and shows an abundant set of physical-related standards, methods and tools, and a fast growing magnitude of heterogeneous IoT devices. The aim of our research is to close this gap and enhance analytical instruments for cyclic evaluations of business and system architectures of integrated Internet of Things environments. Novel technologies demand an increased permeability between "inside" and "outside" of the borders of the classic enterprise system with traditional Enterprise Architecture Management. In this paper we are concentrating on following concrete research questions:

RQ1: What are new architectural elements and constraints for the Internet of Things?

RQ2: What is the blueprint for an extended Enterprise Reference Architecture, which is able to host even new and small type of architectural description for the Internet of Things?

RQ3: How looks am mapping scheme for the Internet of Things Reference Architecture into a holistic and adaptable Enterprise Reference Architecture?

In this paper we make the following contributions and extend our service-oriented enterprise architecture reference model in the context of a new tailored architecture metamodel integration approach and ontology as fundamental solution elements for an integral Enterprise Architecture of the Internet of Things. We are revisiting and evolving our first version of ESARC–Enterprise Services Architecture Reference Cube [Zi11], [Zi13b]. Our research aims to investigate a metamodel-based model extraction and integration approach for enterprise architecture viewpoints, models, standards, frameworks and tools for the high fragmented Internet of Things. The integration of many dynamically growing distributed Internet of Things objects into an effective and consistent Enterprise Architecture Management is challenging. Currently we are working on the idea of integrating small EA descriptions for each relevant IoT object. These EA-IoT-Mini-Descriptions consists of partial EA IoT data and partial EA IoT models and metamodels. Our goal is to be able to support an integral architecture development, assessments, architecture diagnostics, monitoring with decision support, and optimization of the business, information systems, and technologies. We report about our work in progress research to provide a unified ontology-based methodology for adaptable digital enterprise architecture models from relevant information resources, especially for the Internet of Things.

The following Section 2 describes our research platform with fundamental concepts of the Internet of Things. The following Section 3 presents our holistic reference architecture for Enterprise Architecture Management. Section 4 revisits and extends previous research about architectural integration and federation methods. Finally Section 5 concludes our main results and provides an outlook for our work in progress.

2 The Internet of Things

The Internet of Things (IoT) fundamentally revolutionizes today's digital strategies with disruptive business operating models [WR04], and holistic governance models for business and IT [Ro06], in context of current fast changing markets [Wa14]. With the huge diversity of Internet of Things technologies and products organizations have to leverage and extend previous enterprise architecture efforts to enable business value by integrating the Internet of Things into their classic business and computational environments. Reasons for strategic changes by the Internet of Things [Wa14] are:

- Information of everything – enables information about what customers really demand,
- Shift from the thing to the composition – the power of the IoT results form the unique composition of things in an always-on always-connected environment,
- Convergence – integrates people, things, places, and information,
- Next-level business – the Internet of Things is changing existing business capabilities by providing a way to interact, measure, operate, and analyze business.

The Internet of Things is the result of a convergence of visions [At10] like, a Things-oriented vision, an Internet-oriented vision, and a Semantic-oriented vision. The Internet of Things supports many connected physical devices over the Internet as a global communication platform. A cloud centric vision for architectural thinking of a ubiquitous sensing environment is provided by [Gu13]. The typical configuration of the Internet of Things includes besides many communicating devices a cloud-based server architecture, which is required to interact and perform remote data management and calculations.

Sensors, actuators, devices as well as humans and software agents interact and communicate data to implement specific tasks or more sophisticated business or technical processes. The Internet of Things maps and integrates real world objects into the virtual world, and extends the interaction with mobility systems, collaboration support systems, and systems and services for big data and cloud environments. Furthermore, the Internet of Things is a very important influence factor of the potential use of Industry 4.0 [Sc15b]. Therefore, smart products as well as their production is supported by the Internet of Things and can help enterprises to create more customer-oriented products.

A main question of current and further research is, how the Internet of Things architecture fits in a context of a services-based enterprise-computing environment? A service-oriented integration approach for the Internet of Things was elaborated in [Sp09]. The core idea for millions of cooperating devices is, how they can be flexibly connected to form useful advanced collaborations within the business processes of an enterprise. The research in [Sp09] proposes the SOCRADES architecture for an effective integration of Internet of Things in enterprise services. The architecture from [Sp09] abstracts the heterogeneity of embedded systems, their hardware devices, software, data formats and communication protocols. A layered architecture structures following bottom-up functionalities and prepares these layers for integration within an Internet of Things focused enterprise architecture: Devices Layer, Platform Abstraction Layer, Security Layer, Device Management Layer with Monitoring and Inventory Services, and Service Lifecycle Management, Service Management Layer, and the Application Interface Layer.

Today, the Internet of Things includes a multitude of technologies and specific application scenarios of ubiquitous computing [At10], like wireless and Bluetooth sensors, Internet-connected wearable systems, low power embedded systems, RFID tracking, smartphones, which are connected with real world interaction devices, smart homes and cars, and other SmartLife scenarios. To integrate all aspects and requirements of the Internet of Things is difficult, because no single architecture can support today the dynamics of adding and extracting these capabilities. A first Reference Architecture (RA) for the Internet of Things is proposed by [WS15] and can be mapped to a set of open source products. This Reference Architecture covers aspects like: cloud server-side architecture, monitoring and management of Internet of Things devices and services, a specific lightweight RESTful communication system, and agent and code on often-small low power devices, having probably only intermittent connections.

The Internet of Thing architecture has to support a set of generic as well as some specific requirements [WS15], and [Pa15]. Generic requirements result from the inherent connection of a magnitude of devices via the Internet, often having to cross firewalls and other obstacles. Having to consider so many and a dynamic growing number of devices we need an architecture for scalability. Because these devices should be active in a 24x7 timeframe we need a high-availability approach [Ga12], with deployment and auto-switching across cooperating datacenters in case of disasters and high scalable processing demands. Additionally an Internet of Thing architecture has to support automatic managed updates and remotely managed devices. Often connected devices collect and analyze personal or security relevant data. Therefore it is mandatory to support identity management, access control and security management on different levels: from the connected devices through the holistic controlled environment.

Specific architectural requirements [WS15] and [At10] result from key categories, such as connectivity and communications, device management, data collection and analysis, computational scalability, and security. Connectivity and communications groups existing protocols like HTTP, which could be an issue on small devices, due to the limited memory sizes and because of power requirements. A simple, small and binary protocol can be combined with HTTP-APIs, and has the ability to cross firewalls. Typical devices of the Internet of Things are currently not or not well managed by device management functions of the current Enterprise Architecture Management.

Desirable requirements of device management [WS15] include the ability to locate or disconnect a stolen device, update the software on a device, update security credentials or wiping security data from a stolen device. Internet of Things systems can collect data streams from many devices, store data, analyze data, and act. These actions may happen in near real time, which leads to real-time data analytics approaches. Server infrastructures and platforms should be high scalable to support elastic scaling up to millions of connected devices, supporting alternatively as well smaller deployments. Security is a challenging aspect of this high-distributed typical small environment of Internet of Things. Sensors are able to collect personalized data and can bring these data to the Internet.

A layered Reference Architecture for the Internet of Things is proposed in [WS15] and (Fig. 1). Layers can be instantiated by suitable technologies for the Internet of Things.

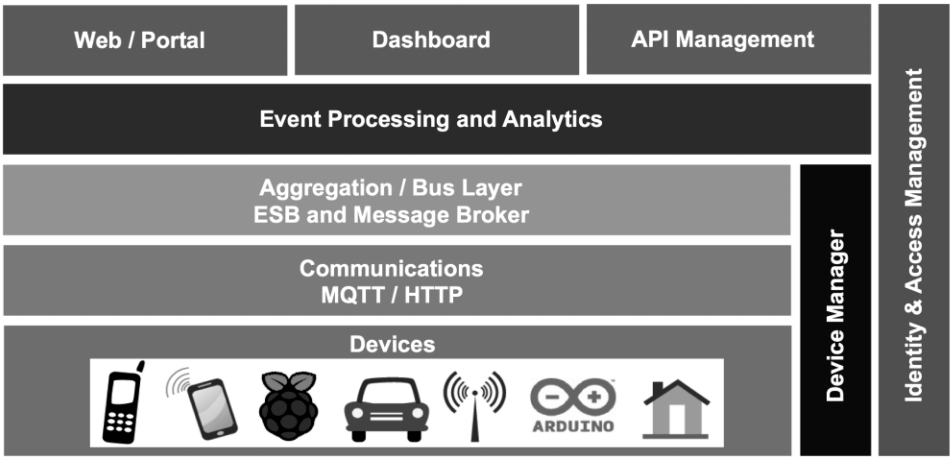

Fig. 1. Internet of Things Reference Architecture [WS15]

A current holistic approach for the development for the Internet of Things environments is presented in [Pa15]. This research has a close link to our work about leveraging the integration of the Internet of Things into a framework of digital enterprise architectures. The main contribution from [Pa15] considers a role-specific development methodology, and a development framework for the Internet of Things. The development framework contains a set of modeling languages for a vocabulary language to describe domain-specific features of an IoT application, an architecture language for describing application-specific functionality, and a deployment language for deployment features. Associated with this language set 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 [Pa15] defines elements of an Internet of Things architectural reference model like, IoT resources of type: sensor, actuator, storage, and user interface. Internet of Thing resources and their associated physical devices are differentiated in the context of locations and regions. A device provides the capability to interact with users or with other devices. The base functionality of Internet of Things resources is provided by software components, which are handled in a service-oriented way by using computational services.

3 Enterprise Reference Architecture

Our principal contribution is an extended approach about the systematic composition and integration of architectural metamodels, ontologies, views and viewpoints within adaptable service-oriented enterprise architecture frameworks for services and cloud computing architectures, by means of different integrated service types and architecture capabilities. ESARC - Enterprise Services Architecture Reference Cube, [Zi11], [Zi13b] and [Zi14] is an integral service-oriented enterprise architecture categorization framework, which sets a classification scheme for main enterprise architecture models, as a guiding instrument for concrete decisions in architectural engineering viewpoints. We are currently integrating metamodels for EAM and the Internet of Things.

The ESARC – Enterprise Services Architecture Reference Cube [Zi11] and [Zi13b] (see Fig. 1) completes existing architectural standards and frameworks in the context of EAM – Enterprise Architecture Management [To11], [Be12] and [La13], [Ar12] and extends these architecture standards for services and cloud computing in a more specific practical way. ESARC is an original architecture reference model, which provides a holistic classification model with eight integral architectural domains. ESARC abstracts from a concrete business scenario or technologies, but is applicable for concrete architectural instantiations.

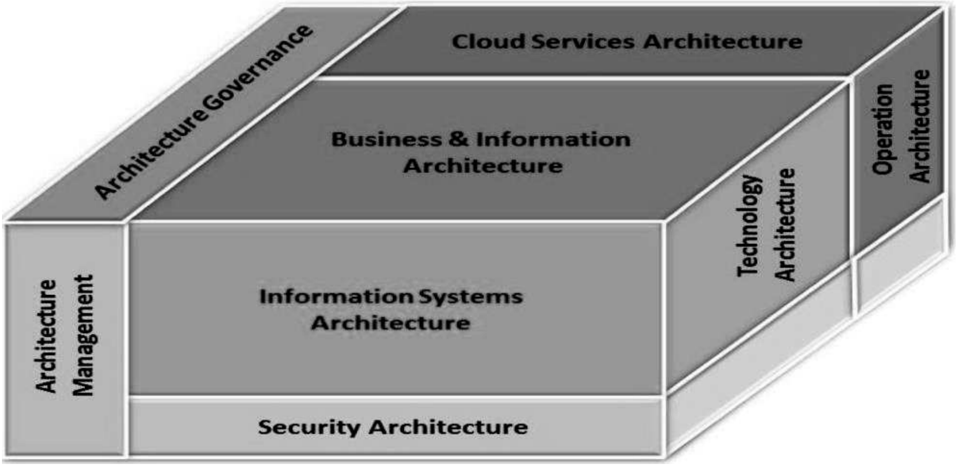

Fig. 2. Enterprise Services Architecture Reference Cube [Zi11], [Zi13b], [Zi14]

Metamodels and their architectural data are the core part of the Enterprise Architecture. Enterprise architecture metamodels [Ar12], [Sa10] should support decision support [JE07] and the strategic [SM13] and IT/Business [La13] 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.

Architecture Governance, as in [WR04] sets the governance frame for well aligned management practices within the enterprise by specifying management activities: plan, define, enable, measure, and control. The second aim of governance is to set rules for architectural compliance respecting internal and external standards. Architecture Governance has to set rules for the empowerment of people, defining the structures and procedures of an Architecture Governance Board, and setting rules for communication.

The Business and Information Reference Architecture - BIRA [Zi11], and [Zi13b] provides, a single source and comprehensive repository of knowledge from which concrete corporate initiatives will evolve and link. The BIRA confers the basis for business-IT alignment and therefore models the business and information strategy, the organization, and main business demands as well as requirements for information systems, such as key business processes, business rules, business products, services, and related business control information.

Today's development of cloud computing technologies and standards are growing very fast and provide a growing standardized base for cloud products and service offerings. Fig. 3 shows our integration scenario for an extended Cloud Computing architecture model from [Li11], [Be11], [CSA09], and [OG11b].

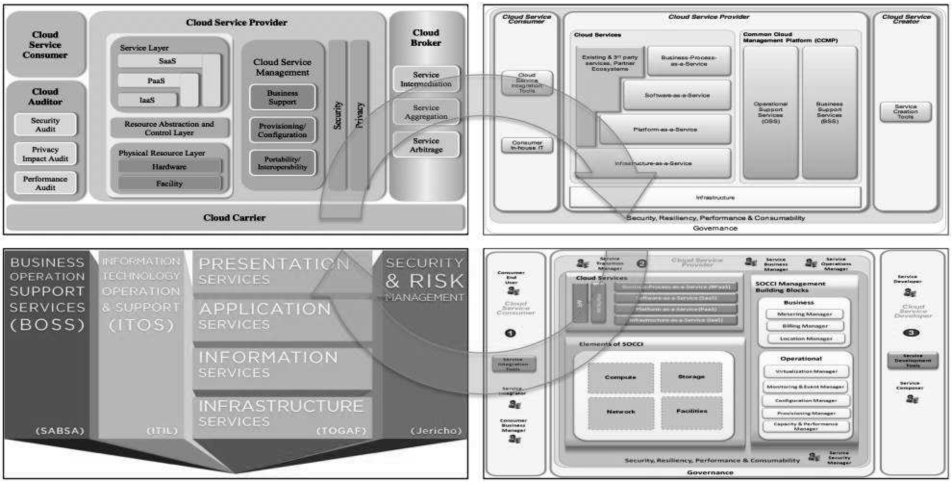

Fig. 3. Cloud Computing Integration [Li11], [Be11], [CSA09], [OG11]

4 Architecture Integration Method

Current work revisits and extends our basic enterprise architecture reference model from ESARC (Section 3) and [Zi13a] by federating Internet of Things architectural models (Section 2) from related scientific work, as well as specifications from industrial partners. Our originally developed integration model ESAMI – Enterprise Services Architecture Metamodel Integration – [Zi13b] serves as a method for integrating base models from enterprise architecture standards, like [To11], [Ar12], architectural frameworks [EH09], [EAP15], [DoD09], [MOD05], and [NAF07], metamodels from practice and from tools. ESAMI is based on correlation analysis, having a systematic integration process. Typically this process of pair wise mappings is quadratic complex. 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.

The architectural model integration [Zi13a] and [Zi13c] works considering following steps: analyze concepts of each resource by using concept maps; extract viewpoints for each resource: Viewpoint, Model, Element, Example; initialize the architectural reference model from base viewpoints; analyze correlations between base viewpoints and architectural reference model; determine integration options for the resulting viewpoint integration model; develop the synthesis metamodel from base metamodels; consolidate the architectural reference model according the synthesis metamodel, and finally readjust correlations and integration options; develop the ontology of the architectural reference model; develop correspondence rules between model elements; and develop patterns for architecture diagnostics and optimization.

First we have to analyze and transform given architecture resources with concept maps and extract their coarse-grained aspects in a standard way [Zi13a], [Zi13c] by delimiting architecture viewpoints, architecture models, their elements, and illustrating these models by a typical example. Architecture viewpoints are representing and grouping conceptual business and technology functions regardless of their implementation resources like people, processes, information, systems, or technologies. They extend these information by additional aspects like quality criteria, service levels, KPI, costs, risks, compliance criteria a. o. We are using modeling concepts from ISI/IEC 42010 [EH09] like Architecture Description, Viewpoint, View, and Model. Architecture models are composed of their elements and relationships, and are represented using architectural diagrams.

The integration of a huge amount of dynamically growing Internet of Things objects is a considerable challenge for the extension and dynamically evolution of EA models. Currently we are working on the idea of integrating small EA descriptions for each relevant IoT object. These EA-IoT-Mini-Descriptions consists of partial EA-IoT-Data, partial EA-IoT-Models, and partial EA-IoT-Metamodels associated with main IoT objects like IoT-Resource, IoT-Device, and IoT-Software-Component [Pa15], and [WS14]. Our research in progress main question asks, how we can federate these EA-IoT-Mini-Descriptions to a global EA model and information base by promoting a mixed automatic and collaborative decision process [Ju15]. For the automatic part we currently extend model federation and transformation approaches [Br10], [Tr15] by introducing sematic-supported architectural representations, e.g. by using partial and federated ontologies [Kh11] and associated mapping rules - as universal enterprise architectural knowledge representation, which are combined with special inference mechanisms.

5 Conclusion and Future Work

We have developed a metamodel-based model extraction and integration approach for enterprise architecture viewpoints, models, standards, frameworks and tools for EAM towards integrated Internet of Things. Our goal is to support a holistic Enterprise Architecture Management with architecture development, assessments, architecture diagnostics, monitoring with decision support, and optimization of the business, information systems, and technologies. We intend to provide a unified and consistent ontology-based EAM-methodology for the architecture management models of relevant Internet of Things resources, especially integrating service-oriented and cloud computing systems for digital transforming enterprises as well.

Referring to our research questions, we looked at:

RQ1: What are new architectural elements and constraints for the Internet of Things? First we have delimited main architectural elements for the Internet of Things and adopted and included an IoT reference model from the state of art. We defined in that way our conceptual architectural elements of our "outside" world, which have to be considered for integration with the "inside" model for an integrated Enterprise Architecture.

RQ2: What is the blueprint for an extended Enterprise Reference Architecture, which is able to host even new and small type of architectural description for the Internet of Things? We have defined with the Enterprise Reference Architecture our holistic and adaptable framework of architectural domains, viewpoints, and views.

RQ3: How looks am mapping scheme for the Internet of Things Reference Architecture into a holistic and adaptable Enterprise Reference Architecture? With the correlation-based integration method we have defined a flexible methodology for the integration of architectural elements by using an extendable architecture reference model. Our approach introduces the new concept of EA-IoT-Mini-Descriptions. Many of the typical high-level model-based integration decisions could not be done during run time at the deployment-level. Given the high number of IoT elements in dynamically complex environment such strong EAM claim would require strong evidence of the feasibility.

From our research in progress work on integrating Internet of Things architectures into Enterprise Architecture Management results some interesting theoretical and practical implications. By considering the context of service-oriented enterprise architecture, we have set the foundation for integrating metamodels and related ontologies for orthogonal architecture domains within our Enterprise Architecture Management approach for the Internet of Things. Architectural decisions for Internet of Things objects, like IoT-Resource, Device, and Software Component are closely linked with the code implementation. Therefore, researchers can use our approach for integrating and evaluating Internet of Things in the field of enterprise architecture management. Our results can help practical users to understand the integration of EAM and Internet of Things as well as can support architectural decision making in this area. Limitations can be found e.g. in the field of practical multi-level evaluation of our approach as well as domain-specific adoptions.

Future work will include conceptual work to federate EA-IoT-Mini-Descriptions to a global EA model and enterprise architecture repository by promoting a semi-automatic and collaborative [Sc15] decision process [JS14], [Sc14] and [JSZ15]. We are currently extending our model federation and transformation approaches with elements from related work, like [Br10], [Tr15]. We are researching about semantic-supported architectural representations, as enterprise architectural knowledge representations, which are combined with special inference and visualization mechanisms.

References

[Ar12] The Open Group: Archimate 2.0 Specification. Van Haren Publishing, 2012

[At10] Atzori, L. et al.: The Internet of Things: A survey. In Journal of Computer Networks 54, 2010, pp. 2787-2805

[BCK13] Bass, C., Clements, P., Kazman, R.: Software Architecture in Practice. Addison Wesley, 2013.

[Be11] Behrendt, M., Glaser, B., Kopp, P., Diekmann, R., Breiter, G., Pappe, S., Kreger, H., and Arsanjani, A.: Introduction and Architecture Overview – IBM Cloud Computing Reference Architecture 2.0. IBM, 2011.

[Be12] Bente, S. et al.: Collaborative Enterprise Architecture. Morgan Kaufmann, 2012.

[Br10] Breu, R. et al.: Living Models – Ten Principles for Change-Driven Software Engineering. In Int. Journal of Software Informatics, Vol. 5, No. 1-2, 2010, pp. 267-290

[CSA09] CSA Cloud Security Alliance: Security Guidance for Critical Areas of Focus In Cloud Computing V2.1", 2009.

[DoD09] DoDAF 2009. *DoDAF Architecture Framework*. Version 2.0, Volume 1, Department of Defense USA, 28 May 2009.

[EH09] Emery, D., Hilliard, R.: Every Architecture Description needs a Framework: Expressing Architecture Frameworks Using ISO/IEC 42010. IEEE/IFIP WICSA/ECSA, 2009, pp. 31-39

[Fa12] Farwick, M. et al.: A Meta-Model for Automated Enterprise Architecture Model Maintenance. EDOC 2012, pp. 1-10

[Ga12] Ganz, F. et al.: A Resource Mobility Scheme for Service-Continuity in the Internet of Things. GreenCom 2012, pp. 261-264

[Gu13] Gubbi, J. et al.: Internet of Things (IoT): A vision, architectural elements, and future directions. Future Generation Comp. Syst. 29(7), 2013, pp. 1645-1660

[Ia15] Iacob, M.-E. et al.: Delivering Business Outcome with TOGAF® and ArchiMate®. eBook BiZZdesign, 2015

[Iso11] ISO/IEC/IEEE 42010: Systems and Software Engineering – Architecture Description. Technical Standard, 2011.

[JE07] Johnson, P., Ekstedt, M.: Enterprise Architecture – Models and Analyses for Information Systems Decision Making, Studentliteratur, 2007

[Jo14] Johnson, P. et al.: IT Management with Enterprise Architecture. KTH, Stockholm, 2014.

[JS14] Jugel, D., Schweda, C.M.: Interactive functions of a Cockpit for Enterprise Architecture Planning. In: International Enterprise Distributed Object Computing Conference Workshops and Demonstrations (EDOCW), Ulm, Germany, 2014, pp. 33-40

[JSZ15] Jugel, D., Schweda, C.M., Zimmermann, A.: Modeling Decisions for Collaborative Enterprise Architecture Engineering. In: 10th Workshop Trends in Enterprise Architecture Research (TEAR), held on CAISE 2015, Stockholm, Sweden, 2015.

[Kh11] Khan, N. A.: Transformation of Enterprise Model to Enterprise Ontology. Master Thesis, Linköping University, Sweden, 2011.

[La13] Lankhorst, M. et al.: Enterprise Architecture at Work: Modelling, Communication and Analysis. Springer, 2013.

[Li11] Liu, F. et al.: NIST Cloud Computing Reference Architecture. NIST special publication, 2011.

[MD05] MODAF 2005. *MOD Architectural Framework*, Executive Summary, Version 1.0, 31 August, Ministry of Defense UK, 2005.

[NAF07] NAF 2007. *NATO Architecture Framework*. Version 3, 2007.

[OG11] Open Group 2011. Service-Oriented Cloud Computing Infrastructure (SOCCI) Framework. The Open Group, 2011.
[Pa15] Patel, P., Cassou, D.: Enabling High-level Application Development for the Internet of Things. In CoRR abs/1501.05080, submitted to Journal of Systems and Software, 2015.
[Ro06] Ross, J. W. et al.: Enterprise Architecture as Strategy – Creating a Foundation for Business Execution. Harvard Business School Press, 2006.
[Sa10] Saat, J. et al.: Enterprise Architecture Meta Models for IT/Business Alignment Situations. IEEE-EDOC Conference 2010, Vitoria, Brazil, 2010.
[Sc14] Schmidt, R. et al.: Towards a Framework for Enterprise Architecture Analytics. In Proceedings of the 18th IEEE International Enterprise Distributed Object Computing Conference Workshops (EDOCW), Ulm / Germany, 2014, pp. 266-275
[Sc15] Schmidt, R. et al.: Social-Software-based Support for Enterprise Architecture Management Processes. International BPM 2014 Conference Workshops, Eindhoven, 2014, LNBIP, Springer 2015.
[Sc15b] Schmidt, R. et al.: Industry 4.0 - Potentials for Creating Smart Products: Empirical Research Results. 18th Conference on Business Information Systems, Poznan 2015, Lecture Notes in Business Information Processing, Springer, 2015 , forthcoming.
[SM13] Schmidt, R., Möhring, M.: Strategic alignment of Cloud-based Architectures for Big Data. Proceedings of the 17th IEEE International Enterprise Distributed Object Computing Conference Workshops EDOCW Vancouver, Canada, 2013, pp. 136–143
[Sp09] Spiess, P. et al.: SOA-Based Integration of the Internet of Things in Enterprise Services. ICWS 2009, pp. 968-975
[To11] The Open Group: TOGAF Version 9.1. Van Haren Publishing, 2011.
[Tr15] Trojer, T. et. al.: Living Modeling of IT Architectures: Challenges and Solutions. Software, Services, and Systems 2015, pp. 458-474
[Wa14] Walker, M. J.: Leveraging Enterprise Architecture to Enable Business Value With IoT Innovations Today. In Gartner Research http://www.gartner.com/analyst/49943, 2014.
[WR04] Weill, P., Ross, J. W.: It Governance: How Top Performers Manage It Decision Rights for Superior Results. Harvard Business School Press, 2004.
[WS15] WSO2 White Paper: A Reference Architecture for the Internet of Things. Version 0.8.0 http://wso2.com, 2015.
[Zi11] Zimmermann, A. et al.: Capability Diagnostics of Enterprise Service Architectures using a dedicated Software Architecture Reference Model. In IEEE International Conference on Services Computing (SCC), Washington DC, USA, 2011; pp. 592–599
[Zi13a] Zimmermann, A. et al.: Towards an Integrated Service-Oriented Reference Enterprise Architecture. ESEC / WEA 2013 on Software Ecosystem Architectures, St. Petersburg, Russia, 2013, pp. 26-30
[Zi13b] Zimmermann, A. et al.: Towards Service-oriented Enterprise Architectures for Big Data Applications in the Cloud. EDOC 2013 with SoEA4EE, 9-13 September 2013, Vancouver, BC, Canada, 2013, pp. 130-135
[Zi13c] Zimmermann, A. et al.: Metamodell-basierte Integration von Service-orientierten EA-Referenzarchitekturen. Informatik 2013, September 16-20, Koblenz, Germany, Lecture Notes in Informatics, 2013.
[Zi14] Zimmermann, A. et al.: Adaptable Enterprise Architectures for Software Evolution of SmartLife Ecosystems. In: Proceedings of the 18th IEEE International Enterprise Distributed Object Computing Conference Workshops (EDOCW), Ulm / Germany, 2014, pp. 316-323