Using a model-based engineering approach for developing Industrial Internet of Things applications

Christoph Binder
Center for Secure Energy Informatics
Salzburg University of Applied Sciences
Urstein Sued 1, A–5412 Puch, Austria
christoph.binder@fh-salzburg.ac.at

Katharina Polanec
Center for Secure Energy Informatics
Salzburg University of Applied Sciences
Urstein Sued 1, A–5412 Puch, Austria
kpolanec.itsb-m2019@fh-salzburg.ac.at

Franz Schweiberer
Center for Secure Energy Informatics
Salzburg University of Applied Sciences
Urstein Sued 1, A–5412 Puch, Austria
fschweiberer.itsb-m2017@fh-salzburg.ac.at

Christian Neureiter
Center for Secure Energy Informatics
Salzburg University of Applied Sciences
Urstein Sued 1, A–5412 Puch, Austria
christian.neureiter@fh-salzburg.ac.at

Goran Lastro
Center for Secure Energy Informatics
Salzburg University of Applied Sciences
Urstein Sued 1, A–5412 Puch, Austria
goran.lastro@fh-salzburg.ac.at

Arndt Lüder
Otto-v.-Guericke University
Universitätsplatz 2
D-39106 Magdeburg, Germany
arndt.lueder@ovgu.de

***Abstract*—A new trend in the manufacturing sector, better known by the term "Industry 4.0", will influence all areas and increase the complexity of production processes, product development, maintenance and disposal. The integration of information and communication technologies (ICT) and the advantages of the Industrial Internet of Things (IIoT) will result in automation processes aiming to optimize efficiency or reduce expenses. However, this results in the emergence of on-demand manufacturing as well as the provision of personalized goods and services, produced in the context of shortened innovation cycles. However, the downside of this trend is the uprising complexity that appears when engineering such systems. Thus, the Reference Architecture Model Industry 4.0 (RAMI 4.0) has been developed by several German associations in order to cope with the complexity of such cross-disciplinary systems. However, at the current point of view, this framework is exhibiting a gap between the architectural model and actual industrial applications. Thus, this paper introduces an approach proposing Round-trip Engineering (RTE) of previously modeled industrial system components. In order to do so, first the information and communication architecture is modeled according to the specifications of RAMI 4.0 and by utilizing OPC UA. Subsequently, the modeled components are generated and applied with the help of FREDOSAR, an open-source system architecture aimed for the application in such a complex system. In the end, data exchange between RAMI 4.0 and the industrial application is established by realizing a bi-directional interface, which is evaluated with a typical industrial case study.**

***Index Terms*—System Architecture, OPC UA, Industrial Internet of Things (IIoT), Reference Architecture Model Industrie 4.0 (RAMI 4.0), Round-trip Engineering (RTE)**

I. Introduction

Advancing digititalization is reaching the manufacturing sector with all its suppliers, machine and plant manufacturers and other production companies [1]. The future vision of on-demand manufacturing and the provision of individual or personal goods and services pushes a lot of companies to integrate results from the progress of research and development [2]. This trend, summarized by the term "Industry 4.0", therefore characterizes the ongoing integration of decentrally arranged products coming from the Information and Communication Technology (ICT) area, with the goal to optimize production by automating its processes [3], [4]. Thus, as so-called Cyber-physical System (CPS) inherits all peculiarities for expediting this transformation, they try to achieve the best result for themselves. Nevertheless, as multiple stakeholders and their requirements accumulate in such a complex production system, not only the single production units need to focus on their primary goal, rather the overall purpose of the system has to be considered [5]. This means, the most important task ensuring this trend is to secure the communication between all single system components in a standardized and efficient way [6], [7].

First steps to achieve this goals have already been set by approaches in the area of Model Based Systems Engineering (MBSE). For example, the Reference Architecture Model Industrie 4.0 (RAMI 4.0) is providing a suitable reference architecture providing different viewpoints on such complex systems [8]. Already used in several industrial projects and applied by prestigious German associations, this reference architecture is considered to be a common basis for engineering future industrial systems, underpinned by its standardization. However, although RAMI 4.0 offers great opportunities for manufacturing their complexity, it is still difficult to describe real applications according to its specifications. It follows that several approaches trying to understand the reference architecture and modeling industrial use cases with its help are already existing. One example is the so-called RAMI Toolbox, a piece of software providing a Domain Specific Language (DSL) and a particular development process regarding the characteristics of RAMI 4.0 [9]. Even though used in multiple industrial projects, the transfer from modeling the system towards its actual implementation is still unknown territory.

Therefore, this paper introduces an approach for modeling the communication infrastructure of a complex industrial system and subsequently transforms the modeled information into real system components. This is done by utilizing one of the most promising technologies in this area, the Open Platform Communication Unified Architecture (OPC UA). This technology is considered to be the future standard concerning industrial communication and is therefore a suitable method for applying MBSE. Therefore, in the first step, the modeling environment as provided by the RAMI Toolbox needs to be adapted for enabling the development of system elements according to this standard, which is mainly done in the Information and Communication Layer of RAMI 4.0. Then, a specific interface using this information and converting it for application in real industrial components has to be developed, which are intended to be utilized and applied in an actual manufacturing environment. However, as setting up such a scenario is a difficult task entailing a lot of resources, the virtual environment of the Free Educational Open System Architecture (FREDOSAR) is taken for use in this specific scenario. Nevertheless, a real-world use case is serving as a blueprint and applied for implementing this approach.

In order to address the mentioned consideration, this contribution is structured as following: In Section II RAMI 4.0, FREDOSAR, OPC UA and model-based Round-Trip Engineering (RTE) is explained in more detail. The next section deals with illustrating the applied approach, while the actual implementation of the mentioned aspects is stated in Section IV. Additionally, the application according to the industrial use case is demonstrated in Section V. Finally, in Section VI the results of the conducted study are summarized and a conclusion is given.

II. Related Work

A. RAMI 4.0

The main goal of RAMI 4.0 is the creation of a common base for stakeholders, products, machines and plants in an industrial system. Based on the reference architecture, visualized in Figure 1, potentials for improvement or individualized products can be elaborated when modeling such a complex automation system. Thereby, all stakeholders included in the life-cycle of the system should build a common understanding and enabling a mutual perspective. In order to do so, the design principles *separation of concerns* as well as *divide and conquer* are used for structuring complex processes into manageable parts. According to the just mentioned issues, RAMI 4.0 itself provides a three-dimensional layout, each axis providing a different viewpoint on the system. Thus, the "Life Cycle & Value Chain" axis considers the life-cycle of such a system and its participants in each of the single phases, which reach from prototypes up to actual implementations. The second axis, the so-called "Hierarchy Levels", describes a standardized way for exchanging information between different abstraction sectors and is thereby derived from the well-known automation pyramid. At last, the architecture axis is realized by six different interoperabilty layers. More precisely, the Business as well as the Function Layer provide information for elaborating the business analysis, while the two middle layers deal with creating the system architecture.

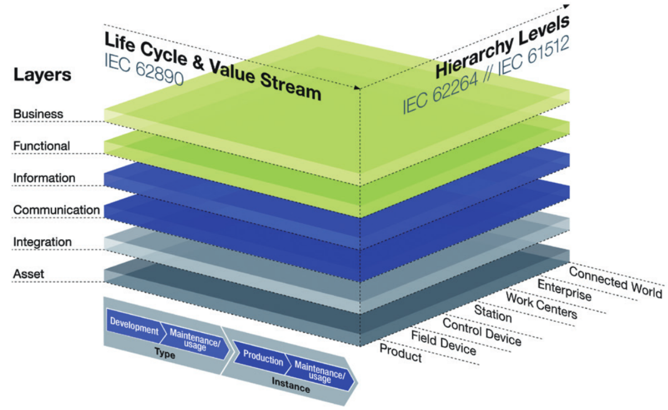

Fig. 1. Reference Architecture Model Industrie 4.0 (RAMI 4.0) [10]

The two bottom layers, the Integration and the Asset Layer enable a more precis description of the system components themselves and thereby realized the design & development of such an industrial system.

B. Fredosar

By applying the classification of [11], the Smart Grid can be classified as System of Systems (SoS). Concepts like MBSE attempt to not only deal with the rising complexity of such systems, but also ensure Privacy and Security by Design. Approaches on how to apply those MBSE methods in development of domain-specific system architectures have been introduced for instance by [12].

In more detail, the development of an architecture called FREDOSAR is introduced by [13]. FREDOSAR is an open system architecture developed for applications in such complex systems and SoS, as illustrated in Figure 2. Primarily, FREDOSAR focuses on Security by Design and Model Based Approaches. For the implementation, a Service-oriented Architecture (SOA) using Java and OSGi has been chosen. The architecture of FREDOSAR is divided in layers, the most important one being the core layer, as it defines core functionalities like, for instance, communication and relevant interfaces. Those functionalities are extended by the management layer. Some of the tasks handled by this layer are module management, configuration and observation of the FREDOSAR bundles as well as providing updates during runtime for service properties. Services for mapping, messaging and data storage are covered by the service layer. In order for new services to reach autonomy, the service layer follows a process in which service extensions have to implement existing core interfaces. With FREDOSAR being an open systems architecture, a fundamental part is to augment the ongoing implementation process by new technology-specific services. Hence, extensibility is another feature treated by the service layer. The application layer is responsible for FREDOSAR applications (FRAPPS), which are case studies, realized as Proof of Concept (PoC), such as outlined in [14].

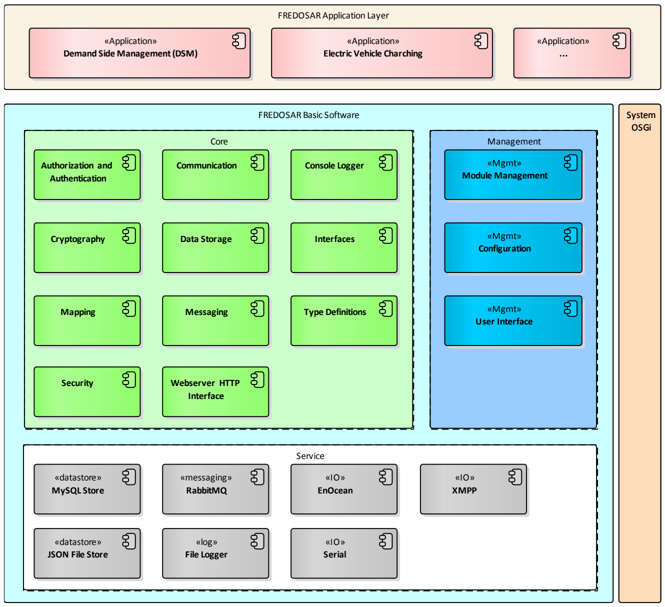

Fig. 2. Fredosar Architecture

As abovementionend, FREDOSAR focuses on security, among other things. Therefore, a bundle with a focus on authentication and authorization is part of the architecture. It can either be used for external communication like user authentication and authorization or internal communication. Regarding internal communication, a module authorization service is responsible for listing applications and their respective communication service permissions. If an application tries to achieve permission for using one of the communication services, the user has to permit or deny this request via the user interface. Another security related service, is the crypto service. It is in charge of cryptographic methods, key store handling and certificate procedures. Hashing functionalities, like RSA and AES encryption are supported by this service as well.

C. Model-Based Round-Trip Engineering

The concept of MBSE defines a model to be the foundation of the overall Systems Engineering (SE) process. Therefore, multiple SE activities can be supported, some of them being for instance detailed requirements definition as well as validation and verification. Moreover, the flawlessness and quality of system design is promoted. Risks in requirements definition, systems design, integration and testing can be reduced as well. Another part of MBSE are simulations, mainly of behavioral diagrams, to verify the model's completeness and flawlessness. This can be achieved through automatic code generation based on those behavioral diagrams. The resulting software can then be executed on target hardware [15].

An important aspect of such model to code transformations is bidirectionality, to keep the code consistent with the model and vice versa. On the one hand, if the model is changed, the code, that has been generated prior, should adapt accordingly. On the other hand, if the generated code is changed, the model is expected to adapt as well. However, this process would require a permanent, bidirectional connection, which is rather complex and therefore often not worth realizing. A different, more feasible approach is RTE. In RTE this connection is not maintained, it is rather realized by creating the code from the model and the other way round [16].

The RTE process is not only usable for model to code generations, but also for model to model transformations. However, the goals in model transformations are the same as in code generations. Source and target need to be consistent. Changes to one model, due to maintenance or altered requirements, should also be adapted in the other model. A challenge of Model RTE was outlined by [17]: Transformations between a source and a target model can not always be executed one to one, as either the source or the target model may include aspects, that cannot be mapped to the other. Hence, an attempt has been made to find a formal definition for partial and non-injective transformations in RTE. Overall, their research came to the conclusion, that the outlined challenge in Model RTE is highly complex, since prior to the transformation process, the semantics of model changes must be defined. For that reason, changes between models might have to be restricted in scale.

D. Open Platform Communications Unified Architecture

In recent years, OPC UA has been chosen to be a standardized communication interface for automation processes. By introducing the respective information models of this architecture, a uniform representation of data and services has been enabled, which spans across manufacturing sectors. This is secured by providing methods for standardized, asynchronous as well as distributed communication, which is applied by client-server architecture. Moreover, the provision of so-called data points, described with metadata, ensures that each client could possibly communicate with each server.

In terms of security, a three-layer model is introduced. In the user-layer, authentication is used for guaranteeing security while certificates are used in the application-layer. Furthermore, the transportation is secured by using TLS-encryption. By doing so, a OPC UA server provides information about data points, methods, subscriptions or other data to the clients, which is structured as a tree. Nevertheless, typical application areas of OPC UA are Manufacturing Execution System (MES) or Enterprise Resource Planning (ERP) systems, since vertical communication between office and shop-floor as well as horizontal communication is enabled. The main advantage is thereby, that each kind of information is available anytime and everywhere for all authorized applications within the system.

III. Approach

Industry 4.0, also known as the fourth industrial revolution, has a high impact on the complexity of manufacturing and production processes as well as on the development, maintenance and disposal of products. The key element of Industry 4.0 is communication. CPS are visioned to be interconnected and share information to trigger actions. Not just production facilities will be part of such CPS, but also the products themselfes. Products will then be able to submit their current production state as well as required production stages to reach the product's end state. All this presupposes the integration of the Internet of Things (IoT) resulting in an Industrial Internet of Things (IIoT), which can be considered as complex SoS [18]. Hence, RAMI 4.0 was developed to manage and handle the resulting complexity. For instance, it allows data, functionalities and communication systems of the integration layer, which are not in accordance with Industry 4.0, to be replaced with Industry 4.0 conform systems prior to mapping it to the coresponding higher layers of RAMI 4.0. The RAMI 4.0 communication layer covers the interconnection and communication between assets. This includes inter alia the asset's ability to autonomously negotiate characteristics like bitrate, quality and security during the setup of communication channels [8].

By using the RAMI 4.0 Toolbox in Enterprise Architect (EA), consistent syntax and semantic can be used to model the assets and other components resulting in digital twins. While connecting those digital twins, traceability within the RAMI 4.0 model is created. By following this approach, possible negative impacts on functionalities or interfaces, caused by changes on the model's assets, can already be detected during the design and development phase. However, due to heterogenous information and data models in automation's runtime components and environments, the resulting model cannot directly be transfered to production facilities and machinery. Consequently, the goal of this approach is to directly integrate the model with an application. For the data exchange between the modelling environment an industrial applications, a gateway system is required. The gateway system is in charge of reading the exported data of the model and afterwards transfering it to the application. Since OPC UA is evolving as standardized industrial communication, an OPC UA server is developed to serve as gateway service between the modeling environment and the industrial application. FREDOSAR provides an architecture for Smart Grid, Smart Home, IoT and Industry 4.0 applications and allows a dynamic composition of services and applications, since it is based on the Apache Felix OSGi framework. Therefore, the gateway system is derived from the FREDOSAR framework. The case study used for this approach is created on the Agile Design Science Research Methodology (ADSRM), which extends the Design Science Research Process (DSRP) by the concepts of agile development of informationsystems. As a case study, the production process of a production facility is modelled and transfered to a FREDOSAR application by following a unidirectional RTE approach.

IV. Implementation

A. OPC UA Modeling

The first step enabling the realization of previously modeled system components is to generate the model itself. Thus, as OPC UA is the technology of choice for modeling and applying the system element, a suitable environment needs to be provided. This is done by adapting the DSL of the RAMI Toolbox so that symbols forming the semantics as well as the syntax OPC UA are available for illustrating industrial systems. However, as this standardized communication interface has mainly been introduced for representing exchanged data and used services, the Information as well as the Communication Layer of RAMI 4.0 appear to be the right viewpoint for realizing this. Therefore, the following adaptions have been made in order to enable the modeling of OPC UA with the RAMI Toolbox.

First, the Information Layer makes use of different data representation methods, data model standards or technologies. More precisely, this viewpoint represents the connections between the single system elements and the container for exchanging the data. This could be XML, JSON or any other format. Furthermore, information about the exchanged data is modeled via so-called Tagged Values, which can be considered as attributes. Each modeling element thereby contains these attributes and stores information about the sent or received data, while the data itself is modeled in the Tagged Values of the connection. Furthermore, a similar principle is applied in the Communication Layer. Thus, the main difference is that in this case the connection type comes into focus. For example, wireless or wired technologies can be used as well as the used protocol like Ethernet or FTP is depicted in the mentioned viewpoint. The needed OPC UA information is again stored in the respective attributes. However, as this is explained in more detail in the next section, this will not be discussed in-depth in this paragraph.

B. Fredosar Integration

In order to establish the interconnection between the model and the FREDOSAR framework, a specific gateway-system has been implemented. More precisely, several communication bundles have been developed in order to realize OPC UA and Message Queuing Telemetry Transport (MQTT) services. On the one hand MQTT has been implemented on the basis of the Microsoft Azure cloud computing platform, while the OPC UA communication is ensured by providing servers as well as clients, which is done with the help utilizing the ProSys OPC UA SDK for Java. By doing so the bundles are created based on the previously modeled architecture. This means, the information contained in the Information and the Communication Layer is exported and imported in the respective bundle. In more detail, the single data is read from the Tagged Values and structured into an XML editable format, which is subsequently converted into a FREDOSAR embedded bundle. As the names assume, OPC UA bundles thereby deal with realizing servers and clients, while the messaging bundles take care of the communication issues. In order to secure RTE, the gateway-system furthermore works bi-directional and thus overwrites the Tagged Values of the Digital Twins according to its physical representations. Again, the application of the described process is underpinned by its application as part of the mentioned case study within the next section.

V. Application

Prior to transferring the model to an industrial application, a case study needs to be modeled. For this approach, the process of a production facility was used. Customer A orders a defined quantity M1 of the product P1 from the manufacturer B. the product P1 is manufactured in the production facility PA. This case study was modeled according to RAMI 4.0 by using the RAMI 4.0 Toolbox and EA. Subsequent, the modeled layers are outlined from the top layer to the bottom.

Following this principle, the Business Layer describes the business relations and requirements concerning the manufacturing of product P1 for customer A by manufacturer B. As depicted in Figure 3, Customer A expects a flawless product, fulfilling the offered quality. Manufacturer B expects an optimized production process. Customer A submits a request to the manufacturer and receives an offer. Thereafter, the customer places an order, followed by the production and delivery of the desired product. The order includes all necessary data, for instance label and quantity of the product, that is needed for the further process. The business processes are split up into separate company processes, called High Level Use Case (HLUC). During the manufacturing process of product P1 for instance the purchasing department, storage facility and production are involved. The HLUCs are then separated into functional requirements, such as technology and quality specifications.

Within the Functional Layer, the requirement's functions as well as their implementation are defined. For instance, considering the requirement 'Heat up and Mix Product P1', the function 'heat up' needs to be specified, by defining which energy sources are used and in which container is the product being placed during the heating process. For a more detailed description, the use cases can be modeled using behavioral diagrams, which later serve as base for source-code generation. Information and data exchanged by the components of the process is defined in the Information Layer. The information flow between modeling environment, or rather gateway system, and data points of the automation is compactly described within this layer. Source of the data is the current order, which includes inter alia label and quantity of the product, or other production parameters, that can be defined directly within the model, as demonstrated in Figure 4.

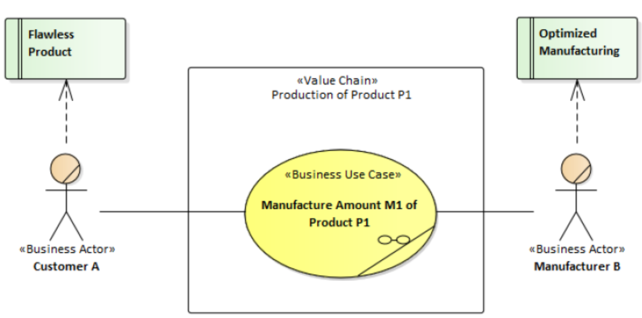

Fig. 3. Business Layer

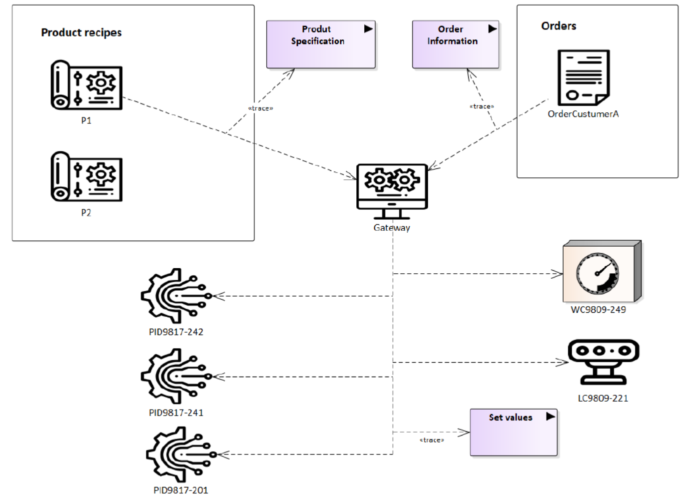

Fig. 4. RAMI 4.0 Information Layer Diagram

The Communication Layer defines the used communication technologies, depicted in Figure 5. For the data exchange between modeling environment and gateway service, FTP is used. The communication between gateway and automation device is realized via OPC UA communication. An FTP connection is needed additionally for the transmission of CNC programs, since neither the gateway, nor the automation device supports communication via OPC UA. All functions and functional requirements need to be assigned to Industry 4.0 conform digital twins of the assets. The digital twins are integral parts of the architecture. This assignment is modeled within the Integration Layer. The connections used for modeling the logical architecture indicate dependencies and associations between the elements. Communication and data exchange is, as aforementioned, defined within Information and Communication Layer. Finally, all digital objects are assigned to their real counterparts within the Asset Layer. In the next step, the modeled information is exported and transferred into physical elements with the help of the previously developed gateway-system. As aforementioned, the OPC UA server is implemented in FREDOSAR, because this framework supports OSGi bundles. The advantage about OSGi bundles, is that new bundles can be added and existing ones can be changed or deleted during the application's run-time. In this case, the OPC UA bundle provides services, which are registered within the framework, so that other bundles are able to access and use those provided services.

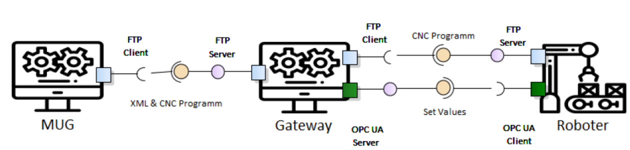

Fig. 5. RAMI 4.0 Communication Layer Diagram

By doing so, prior to connecting the model with the industrial application, skeletons for communication bundles for OPC UA and MQTT are provided in Java. As FREDOSAR inherits a Communication Service, this can be implemented for developing a new communication service. Additionally to the communication architecture, a bundle contains information about transmitted data and communication details. In this example, this information is contained within the model, especially within the Information and Communication Layer, which is exported and embedded to the OSGi bundle as well. By adding and registering the newly developed services, other permitted bundles have access to it. Concluded, the thereby resulting bundle can be integrated and registered with the FREDOSAR environment and thereafter has full access to the OPC UA and MQTT services that were registered before.

VI. Conclusion & Future Work

Industrial systems continuously grow more and more complex, resulting from current and future trends applied by the IIoT or CPS. In order to deal with this complexity a rising number of projects focus on MBSE, which is seen as a suitable way to develop such a system considering all stakeholders and providing multiple viewpoints. Resulting from this evolution, widely applicable methodologies like RAMI 4.0 and the corresponding toolbox emerge. However, as those approaches mostly look good on paper without providing any practical usability, the transfer between the model and the actual applied system needs to be given. Therefore, this paper provides an approach for transferring previously modeled data into real system components. As OPC UA is the methodology advertised at most providing a standardized communication interface, this technology is used for creating the mentioned interface. This means, the first step is to adapt the RAMI Toolbox in order to enable the description of industrial models and the interconnection of multiple CPS based on OPC UA. Furthermore, a interface exporting the modeled information and transferring it to actually applied components has to be developed, which also creates the required OPC UA structure. Consequently, the resulting system elements are applied in an actual environment for securing their functionality and validate their applicability. However, as setting up an actual industrial OPC UA scenario would exceed the scope of this paper, the FREDOSAR framework is utilized as a reference implementation realizing an IoT based Industry 4.0 application. By doing so, a real-world case study is used and applied in this work.

The approach mentioned in this paper can be refined by several enhancements, which need to be considered in follow-up projects. At the current point of view, the information is read from the model and subsequently transformed into XML based bundles. In order to improve automation potential and the acceptance of this process, the source code should be directly modeled within the system architecture with the help of the RAMI Toolbox. This will furthermore enable the application of more sophisticated RTE by extending the bi-directional interface for automatically synchronizing model and implementation. Furthermore, as far as standardization issues are confirmed, a unique representation of the Asset Administration Shell (AAS) would increase the interconnectivity of machines manufactured independently across organizations.

Acknowledgment

The support for valuable contributions of LieberLieber Software GmbH and successfactory consulting group is gratefully acknowledged. The financial support by the Austrian Federal Ministry for Digital and Economic Affairs and the National Foundation for Research, Technology and Development and the Christian Doppler Research Association as well as the Federal State of Salzburg is also gratefully acknowledged.

References

[1] H. Zeyn, *Industrialisierung der Additiven Fertigung: Digitalisierte Prozesskette-von der Entwicklung bis zum einsetzbaren Artikel Industrie 4.0*. Beuth Verlag, 2017.

[2] M. A. Pisching, M. A. Pessoa, F. Junqueira, and P. E. Miyagi, “Pfs/pn technique to model industry 4.0 systems based on rami 4.0,” in *2018 IEEE 23rd International Conference on Emerging Technologies and Factory Automation (ETFA)*, vol. 1. IEEE, 2018, pp. 1153–1156.

[3] R. Kestel, *Variantenvielfalt und Logistiksysteme: Ursachen—Auswirkungen—Lösungen*. Springer-Verlag, 2013.

[4] U. Dombrowski, P. Krenkel, and M. Hermann, “Ganzheitliches informationsmanagement im kontext von industrie 4.0,” *ZWF Zeitschrift für wirtschaftlichen Fabrikbetrieb*, vol. 113, no. 12, pp. 869–872, 2018.

[5] P. Adolphs, “Smart products / innovative produktentwicklung: Referenzarchitektur als grundlage für neue produkte zur cloud-basierten kommunikation,” *Industrie 4.0: Potenziale erkennen und umsetzen,*, pp. 109–127, 2017.

[6] F. Pauker, S. Wolny, S. M. Fallah, and M. Wimmer, “Uml2opcuatransforming uml class diagrams to opc ua information models,” *Procedia CIRP*, vol. 67, pp. 128–133, 2018.

[7] K. Suri, J. Cadavid, M. Alferez, S. Dhouib, and S. Tucci-Piergiovanni, “Modeling business motivation and underlying processes for rami 4.0-aligned cyber-physical production systems,” in *2017 22nd IEEE International Conference on Emerging Technologies and Factory Automation (ETFA)*. IEEE, 2017, pp. 1–6.

[8] R. Heidel, M. Hankel, U. Döbrich, and M. Hoffmeister, *Basiswissen RAMI 4.0: Referenzarchitekturmodell und Industrie 4.0-Komponente Industrie 4.0*. Beuth Verlag, 2017.

[9] C. Binder, C. Neureiter, and G. Lastro, “Towards a Model-Driven Architecture Process for Developing Industry 4.0 Applications,” *International Journal of Modeling and Optimization*, vol. 9, no. 1, pp. 1–6, 2019.

[10] Bitkom, VDMA, ZVEI, “Umsetzungsstrategie Industrie 4.0, Ergebnisbericht der Plattform Industrie 4.0,” *ZVEI*, 2015.

[11] R. Haberfellner, O. de Weck, E. Fricke, and S. Vössner, “Systems engineering–grundlagen und anwendung. 12,” *Auflage. Zürich: Orell Füssli*, 2012.

[12] C. Neureiter, G. Eibl, D. Engel, S. Schlegel, and M. Uslar, “A concept for engineering smart grid security requirements based on SGAM models,” *Computer Science - Research and Development*, pp. 1–7, 2014.

[13] M. Fischinger, C. Neureiter, C. Binder, N. Egger, and M. Renoth, “Fredosar: Towards a security-aware open system architecture framework supporting model based systems engineering,” in *8th International Conference on Smart Cities and Green ICT Systems (SMARTGREENS)*. Heraklion, Crete - Greece: SciTePress, 2019, pp. 108–115.

[14] M. Fischinger, N. Egger, C. Binder, and C. Neureiter, “Towards a model-centric approach for developing dependable smart grid applications,” in *2019 4th International Conference on System Reliability and Safety (ICSRS)*. IEEE, 2019, pp. 1–9.

[15] J. M. Borky and T. H. Bradley, *Effective model-based systems engineering*. Springer, 2018.

[16] A. Kleppe, *Software language engineering: creating domain-specific languages using metamodels*. Pearson Education, 2008.

[17] T. Hettel, M. Lawley, and K. Raymond, “Model synchronisation: Definitions for round-trip engineering,” in *International Conference on Theory and Practice of Model Transformations*. Springer, 2008, pp. 31–45.

[18] A. Gilchrist, “Industry 4.0: The Industrial Internet of Things,” pp. 87–118, 2016.