Towards a Cross-Domain Modeling Approach in System-of-Systems Architectures

Boris Brankovic, Christoph Binder, Dieter Draxler, Christian Neureiter and Goran Lastro

Abstract Modeling a System is a challenging task, especially if more than one domain has to be considered. The scenario of *Cross-Domain Modeling* arises more and more in the future concerning *Smart Cities*, as the Electric Vehicle (EV) needs to be integrated into the Smart Grid (SG) and accordingly the Grid faces an emerging behaviour, regarding the energy-management. State of the art Frameworks like Smart Grid Architecture Model (SGAM), Automotive Reference Architecture Model (ARAM), or Reference Architecture Model Industrie 4.0 (RAMI 4.0) consider all these aspects and are used to model such systems, but the combination of these domains is still an issue. The Software Platform Embedded Systems (SPES) Framework provides a base for the modeling of systems belonging to certain domains and with proven modeling-theories a new approach towards the modeling of System of Systems (SoS)-Architectures is needed. Therefore, this paper concerns the problems of modeling SoS-Architectures and investigates the possibility to combine domains and to map them to the SPES-Framework.

1 Introduction

The constantly rising complexity in modern information systems is not a completely new topic, but has been a matter of science and research since several decades. To mention an example, the authors of [11] outline on how to deal with this complexity by exemplifying a system from a scientific perspective. Additionally, several approaches for measuring or modeling such a system, tailored to its development, are introduced. One of the main findings of their work and the underlying concepts proposed in [24] is the need for using a variety of diagrams in order to address

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all aspects of a complex system, but also create a mutual basis. Thus, the classification scheme introduced in [12] can be applied to classify a system based on its complexity. However, latest advances in technologies in the area of Internet of things (IoT) resulted in the emerging of new possibilities and products like Cyber-physical Systems (CPSs). This means, modern information systems not only form a system themselves, but constitute of multiple subsystems, making up the popular term of the so-called SoS. The traits proposed in [15] and [9] can be used when describing the peculiarities of such a SoS. Summarizing these aspects and the ones mentioned before, developing current and future systems is a challenging task including various individual issues. Hence, the concepts of Model Based Systems Engineering (MBSE) have proven to be a suitable methodology for approaching this problem. Supported by Model Driven Architecture (MDA), Domain Specific Systems Engineering (DSSE) is an example for such a comprehensive approach tailored to model-driven system development in the Smart Grid domain [17]. By doing so, it makes use of a specifically designed Domain Specific Language (DSL) and a corresponding development process [19]. Based on the findings of developing and using the DSL, a technology and knowledge transfer to other domains has been promoted. Thus, in [6], a methodology for model-based development of Industry 4.0 based systems is introduced, whereas [10] specifies all domain-specific features needed for modeling the system of an automotive vehicle. However, as proposed by [1], the amalgamation of the addressed domains with each other and several others is taking place under the so-called term *Smart Cities*. This is mainly supported by the ubiquitous data evaluation of IoT devices throughout the whole life-cycle in order to achieve their key functionalities. Moreover, this means that a smart component crosses multiple domains during its planning, development and utilization in the Smart City. An example for a method tailored to domain-independent engineering of systems has been provided with the introduction of SPES, as proposed in [21]. This model-driven approach enables MBSE on different viewpoints and multiple granularity layers. According to these considerations, this paper introduces a method for combining system architectures in the automotive, industrial and Smart Grid domain by using the concepts of SPES. Therefore, the first step to approach this is to map the layers of ARAM, the RAMI 4.0 and the SGAM to the viewpoints of SPES in order to create a common basis. The application and evaluation of this approach is assured by a real-world case study. For this scenario, a use case representing an EV is considered to be a suitable example, since the automotive architecture can be modeled according to ARAM, its manufacturing by using RAMI 4.0 and its behavior as well as integration into the Smart Grid with the help of SGAM. Therefore, this contribution is structured as following: In Section 2 an overview of SPES, ARAM, RAMI 4.0 and SGAM is given. Subsequently, the approach to address the problem statement is described in Section 3. The implementation itself is stated in Section 4, whose applicability is demonstrated in Section 5. Finally, in Section 6 the results of the conducted study are summarized and then a conclusion is given.

2 Related Work

2.1 Software Platform Embedded Systems (SPES)

The SPES Modeling-Framework is used for model-based development of systems. It addresses challenges that develop in application domains. Based on certain requirements, as well as fundamental principles defined in [21], it forms a core concept, which provides a new way of thinking while performing modelingactivities. An example would be meeting the characteristics of a specific system, while considering the requirements from the application domains. Therefore, two major approaches, *Abstraction-Layers* and *Views and Viewpoints*, are defined by the previously mentioned core concept, which form a two-dimensional engineering space, as proposed in [21]. The horizontal axis *Viewpoints* is separated into four sections, *Requirements Viewpoint, Functional Viewpoint, Logical Viewpoint* and *Technical Viewpoint*, each section provides different templates for modeling during the engineering process. The vertical axis *Abstraction Layers* provides the possibility to model a System under development (SUD) or a design element, on different abstraction layers.

2.2 Automotive Reference Architecture Model (ARAM)

Today's power grids are currently heading towards a major change. The introduction of communication technologies leads to the transformation towards the so called SG. Basically in SGs, sub-systems are geographically distributed, operational managerial and operational independent, heterogenic and interdisciplinary without a final state and with the ability to show emergent behavior. These, characteristics are defining a SoS [9]. In future, a bulk of those sub-systems are EVs, which in certain scenarios also might raise emergent behavior within the SG [16]. For this reason, when developing EV architectures, such systems need to be treated on an more holistic point of view with a strong connection to the SG. Therefore, such an extension of the system boundary leads to the introduction of new stakeholders into the development process of EV architectures. To enable interdisciplinary, model-based and domain specific systems engineering within the automotive domain the Automotive Reference Architecture Model framework has been developed [10]. The three-dimensional structure allows to model EV architectures on different points of view. The top most viewpoint is the Business Viewpoint. The requirements and functions are governed by the Function Viewpoint. Physical aspects of the system are modelled on the lower three layers. Whereas, the physical components are part of the Physical Viewpoint. The E/E architecture is framed by the E/E Viewpoint and the exchanged data objects are modelled in the Information Viewpoint.

2.3 Reference Architecture Model Industrie 4.0 (RAMI 4.0)

Similar to ARAM, the three-dimensional model has been mainly developed to create a common understanding and a mutual basis for enabling the discussion of systems based on Industry 4.0. The architecture itself is structured in *Life Cycle & Value Stream, Hierarchy Levels* and *Interoperability Layers* [13]. In more detail, the horizontal axis of RAMI 4.0 deals with the different states an asset may have during its time of usage. Thus, the aim is collecting data referring to the component throughout its whole life-cycle. In the second axis, the vertical integration within a factory is represented by the Hierarchy Levels. Well known under the term *automation pyramid*. Finally, the top-down arrangement of the layers enables the structuring of the system according to the feature of its components across six viewpoints. Thus, the Business Layer defines processes and boundaries of the system, resulting in the elaboration of requirements. Those requirements build the base for the future development of the system, in particular the specification of services displayed on the Function Layer. The Information Layer deals with handling all kind of data, whereas the Communication Layer contains connections and interfaces within the system components. Following this principle, the Integration Layer enables the digitalization of components by specifying Human-Machine Interfaces (HMIs). At last, the Component Layer implements the physical viewpoint and therefore enables the real-world representation of the component.

2.4 Smart Grid Architecture Model (SGAM)

The energy domain gained more and more importance over the past years. New challenges arise, as Distributed Energy Resources (DER) like Photo-Voltaic (PV) Systems, or Wind-Turbines, which are dispersed over the entire power grid, react sensibly to changes e.g. the weather. This highly dynamic characteristic puts current grids to the test and therefore a move towards a SG is needed. SGAM has been developed by the members of CEN, CENELEC and ETSI, in the context of the European Commission's Mandate M/490 [22]. It provides a Framework, which contains all necessary standards and information, needed for the development of a SG Architecture. The three-dimensional Model presented in [22], is based on the NIST Domain Model [20], the GWAC Interoperability Stack [23] and the automation pyramid. The dimensions contain the following elements, *Domain, Interoperability (Layer)* and *Zone*. The x-axis, described as *Domains*, contains five sections, which are present in a modern power grid. It breaks down a SG-System on the basis of the NIST Domain Model, where in contrast to that the y-axis, portrayed as *Zones*, illustrates the functionality on basis of the automation pyramid. To ensure a degree of interoperability between certain elements, five interoperability layers are established. These layers are derived accordingly to [23] and after [22] divided as follows: *Business Layer, Function Layer, Information Layer, Communication Layer* and *Component Layer*.

3 Approach

3.1 Agile Design Science Research Methodology

The *Agile Design Science Research Methodology (ADSRM)* fosters creative research by simultaneous development of both, the problem- and solution-space [8]. Basically, this approach allows to start from very uncertain requirements. The artifacts as well as the requirements are evolving in each iteration, whereas each iteration itself delivers a solution of the planned artifacts. The first input with respect to this research is an appropriate case study. The case study is the input for the requirements process, which delivers the requirements for each iteration loop. Based on these requirements, the artifacts are developed. Further, the artifacts are applied to model the case study, which further delivers in each iteration an architecture model of the case study. Through iterations the case study is modeled and therefore delivers input for the development of the artifacts itself. This step-by-step modeling is repeated until the artifacts and the model reaches a level, which allows the evaluation by domain experts. The final model and the artifacts are the input for the second stage of evaluation. Basically, the evaluation by domain experts is done based on the presentation of the artifacts and the model. The findings from the evaluation serve as input for the next iteration in the ADSRM. The process of charging an EV serves as case study for developing the artifacts. Further, charging an EV delivers input for modeling in each architecture domain. The automotive architecture can be modeled using ARAM, its manufacturing using RAMI 4.0. The integration into the SG together with the charging behavior can be modeled using the SGAM framework. Thus, also all three frameworks serve as main input for the task of requirements engineering. This task delivered a set of requirements, which need to be considered during the development. One main requirement is that the consolidation of the different domain frameworks to allow cross-domain modeling needs to be based on a framework, which is able to address the aspects within all three domains. This framework should serve as interface between the different other frameworks. Therefore, the main task of development with respect to ADSRM is to first map the frameworks coming from different domains on the SPES framework [7]. Based on this, the following main artifacts can be developed.

- Mapping between DSSE Frameworks and SPES.
- Interfaces between the different domain frameworks based on SPES.

3.2 Case Study

One input of the ADSRM is a suitable case study. Therefore, the chosen study is the charging system with respect to EVs charging at a Level II charging station, classified after the *Society of Automotive Engineers (SAE)*, with the development of the SAE J1772 standard [2]. A first model of a case study of the breaking system of an

EV has been implemented in [10]. To enable further considerations about charging an EV at a charging station, this case study has been extended. This includes an extension of the decomposition into additional sub-systems. In an conventional EV the main components for AC charging at a Level II charging station are usually a *On-Board Charger, Battery Management System (BMS), Inverter* and the *High Voltage Battery*. The components are connected to each other through electrical high voltage connections as well as communication connections such as CAN. As the *High-Voltage Battery* is crucial for EVs since it needs to fit along the other parts of the car, it therefore has an impact on the power grid during runtime and needs to be produced according to these aspects. Hence, the BMS is considered as main component in the proposed case-study. Typically the BMS acts as interface between the *On-Board Charger* and the *High-Voltage Battery*. Thus, the BMS is capable of detecting certain information about the cell-capacity. With this information one is capable of knowing how the *High-Voltage Battery* behaves in specific operational situations. To give an example herefore, a variety of battery packs exist, which are formed from different battery system structures [14]. Multiple cells are combined in order to achieve specific values, e.g. stored amount of energy, and with certain design parameters, provided by the BMS, it is possible to determine how a certain pack performs and where room for improvement exists.

4 Implementation

Mapping ARAM to SPES - As outlined in chapter 2.2, the ARAM framework is built upon five viewpoints [10]. The viewpoints are looking at the vehicle from different perspectives. As the SPES framework also allows modeling systems of the automotive domain, a mapping between the viewpoints of ARAM and SPES is possible. However, no one-to-one relation between the viewpoints can be established. As the Requirements Viewpoint of the SPES framework is basically for context, requirements, stakeholder and goals modeling, it is possible to map the Business Viewpoint of ARAM one-to-one on this viewpoint. The mapping of the Functional Viewpoint to SPES is much more challenging. As described in [10] the Functional Viewpoint considers the vehicle from the perspective of the functional architecture as well as of the logical architecture. But, within SPES those are part of two separate viewpoints. Thus, the ARAM Functional Viewpoint is split up and mapped to both of them. The functional architecture part of ARAM is mapped to the SPES Function viewpoint and the logical architecture part is mapped to SPES Logical Viewpoint. However, the most challenging is the one from the lower three viewpoints. As all three of them describe the system from a technical point of view, it is necessary to summarize them in the SPES Technical Viewpoint. Basically, the ARAM physical viewpoint is the main technical viewpoint in SPES. Further, as SPES is not restricted to the four main viewpoints, it is possible to define additional ones. This allows the mapping of the information and E/E viewpoint on the technical one through the definition of them as sub-viewpoints. To be able to model also mechanic and thermal related aspects, the authors of this paper also introduce a Mechanical and Thermal Viewpoint as sub-viewpoints to the Technical Viewpoint.

Mapping RAMI 4.0 to SPES - As previously explained, this framework also offers different layers dealing as viewpoints for dividing a system. However, since structuring a manufacturing system is a complex task entailing a lot of different challenges, RAMI 4.0 introduces six abstraction layers, containing an additional one in contrast to ARAM and SGAM. This means, the mapping of these layers to the SPES concepts needs to take care of several aspects. However, considering the first two layers is more or less straightforward. As explained in [5], the task of the Business Layer is to elaborate the requirements by specifying the system context as well as identifying the stakeholders. Consequently, this layer can be transformed to the Requirements Viewpoint one-to-one. The same principle can be applied to the Function Layer by mapping it to the equally called Function Viewpoint of SPES. This is the point where the mapping process becomes increasingly challenging. Since the Information and Communication Layer of RAMI 4.0 deal with exchanging the data and defining the interfaces or protocols for their exchange, this belongs to the development of the technical architecture, more precisely the Technical Viewpoint of SPES. However, with the third viewpoint defining the logical architecture of the system, the concepts of the RAMI Integration Layer seem to be suitable for its mapping. This is underlined by describing surrounding systems like the Information and Communication Technology (ICT) Infrastructure or HMIs. Finally, the Asset Layer is again part of the Technical Viewpoint due to containing components of the real world and their exact definition. Summarized, the transformation of RAMI 4.0 to SPES results in one-to-one mapping of the Business, Function and Integration Layer, while the remaining layers are combined to the Technical Viewpoint.

Mapping SGAM to SPES - According to section 2.4, the SGAM framework provides five interoperability layers [22], needed to enable a clear representation of the architecture model introduced by [23]. Therefore, these layers give insights into the decomposition of a Smart-Grid system, with a main focus on interoperability. Because the SPES framework considers modeling of systems in the energy domain, it is suitable for SGAM and thus a potential mapping of the mentioned layers onto the SPES Viewpoints can be realized. Although, the mapping between the layers and the viewpoints cannot be done one-by-one. SPES uses its specified Requirements Viewpoint as starting point for modeling a system, which generally is used to describe its context, requirements, needs of stakeholders and the modeling of certain goals. Concerning SGAM, a one-by-one mapping of the top-layer, defined as Business Layer, onto the Requirements Viewpoint can be performed. The underlying Function Layer in SGAM must be mapped onto the Functional Viewpoint and Logical Viewpoint of SPES. According to [19] the approach *Functional Analysis* decomposes primarily defined *High Level Use Cases (HLUCs)* from the Business Layer into *Primary Use Cases (PUCs)* and combines them with Logical Actors, which form the Function Layer. The explained approach is therefore located on the Functional Architecture as well as on the Logical Architecture. Another approach explained in [19], defined as *Architecture Development*, explains the transformation from the logical model to the technical, which covers the lowest three layers in SGAM. Thus, the mapping from the logical components onto the physical ones is done, which concerns inter alia the Information Layer, Communication Layer and the Component Layer. Because, the technical aspects are considered in this step, these layers can be mapped to the Technical Viewpoint of SPES.

Mapping Results - Summarized, Figure 1 outlines the relations of the SPES viewpoints and the corresponding domain-specific reference architectures. According to this figure, it is apparent that a one-by-one mapping of the Business Viewpoint, or Layer respective, of the considered frameworks ARAM, RAMI 4.0 and SGAM, can be realized.

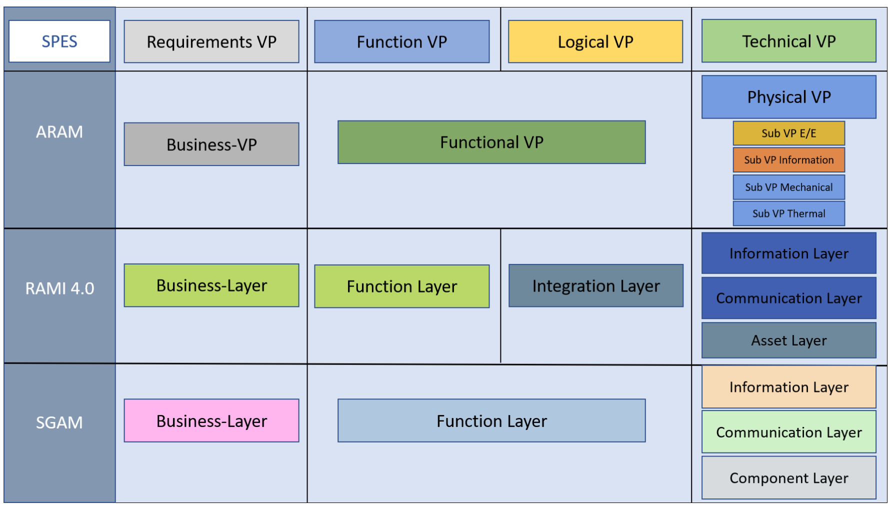

Fig. 1: Mapping of the Frameworks to SPES-Matrix.

As the given image defines the complete mapping between the mentioned domains, a potential common interface between the frameworks is identified. For a better understanding, this interface can be illustrated by a common Requirements Viewpoint i.e. the frameworks are internally connected through it. Therefore, each domain is represented as *Application Domain*, this principle was first introduced by [18], where each of these Application Domains (ADs) represents a certain system context. Further, these ADs are connected through Application Domain Interrelations (ADIs), which enable a holistic view on a SoS architecture (e.g. Smart City), consisting of multiple ADs, covering the architectural and functional aspect [18].

5 Application

As explained above, the goal is to evaluate the mapping by modeling the BMS of an EV with the help of SPES. First, modeling the EV architecture is done under consideration of the ARAM framework. This allows to create a model of the whole EV from the perspective of the automotive domain. Second, within the SG, EVs play an important role in certain use cases. For example, in power grids it is from high importance to keep the equilibrium between energy production and consumption. But, through the introduction of weather dependent energy production, such as wind turbines or photovoltaic systems, the equilibrium can be disturbed. One counter measure is for example to introduce load shifting through rate-based charging of EVs [3]. Such a demand side management scenario is modeled using SGAM. The charging behavior itself is modeled in behavioral diagrams, such as an activity diagram [4]. Last, the production of the single components of the EV,is modeled using the RAMI 4.0 framework. For example, the production of the *High-Voltage Battery* needs different resources and is done in an industry 4.0 production line. Within this, the complete value chain can be modeled, which further delineates the different states the *High-Voltage Battery* has along the time of usage. Basically, it starts with the idea by the input of certain design parameters. Those parameters, as specified in chapter 3, may come from the ARAM model of the EV, which might be for example the size and number of cells, provided by the BMS. Further, the production of the battery is also modeled with respect to the machines needed in a factory. According to these considerations, the modeled case study is explained in more detail in the following section.

Case Study Model - According to [21] the Requirements Process Model is chosen as suitable approach to define the Requirements Viewpoint. This viewpoint is seen by the mapping in chapter 4 as common interface with respect to the considered Frameworks ARAM, RAMI 4.0 and SGAM. The realization of the model is done with the Modeling-Software *IBM Rhapsody* [1], as it supports the SysML-Profile, needed for Systems-Engineering tasks. The Model regarding the case-study, deals with the charging-process of an EV at a Level II Charging Station with the main focus on the BMS. After the definition of the system-context and the goals, concerning the case-study, appropriate scenarios are needed, where each fulfills at least one defined goal. Those scenarios, are illustrated in Figure 2, where the main Use-Case, defined as HLUC, describes the overall scenario of the study. Based on this HLUC, a *Business Use Case* is specified, primary concerning the BMS and to derive meaningful Requirements from it.

[1] https://www.ibm.com/us-en/marketplace/rhapsody-designer-for-systems-engineers

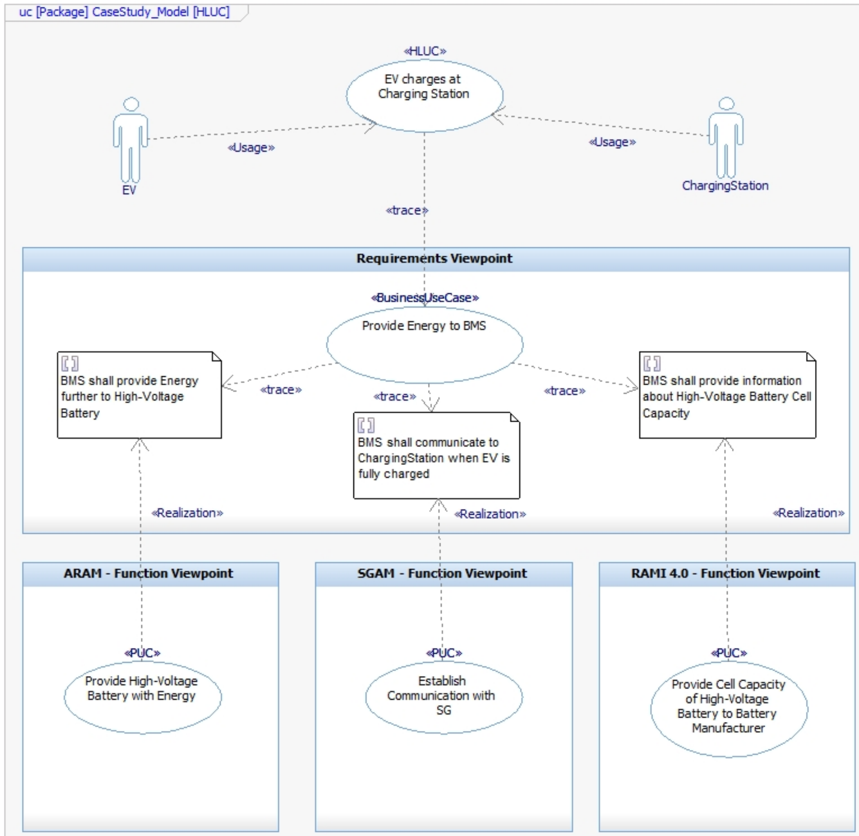

Fig. 2: Case Study Model illustrated with common Requirements Viewpoint.

Furthermore, regarding to the defined case-study, the Charging Station itself represents the architectural aspect of the model and as it is depicted in Figure 2, for each AD, a certain PUC is defined. These PUCs are fulfilled by this very Charging Station and represent the functional aspect. Depending on the domain, the PUCs are assigned to the corresponding Function Viewpoint. As proposed by [18], the information included in these PUCs is transported to services in the higher layers. Concerning SPES, the allocation from one viewpoint to another inducts an equal operation. In both cases, a traceability through the entire model is given by the aforementioned operational activity. Therefore, the PUCs can be used to enable a modeling across the considered domains and further for a decomposition into additional Sub-Systems. Hence, the refinement of certain Requirements, derived from the HLUC, is applicable to all levels of abstraction, as the Requirements Process Model remains the same.

5.1 Findings

The Case-Study Model in chapter 5 shows the application of a suitable model concerning the mapping results stated in chapter 4. Therefore, a modeling across domains is feasible by choosing a common Requirements Viewpoint and separating the considered domains into ADs. Further, the definition of PUCs makes it possible to address the according domain and to model the system, by considering the respective context, as the PUCs represent the functional aspect of the system and can be applied on all layers of abstraction.

6 Conclusions and Future Work

The presented approach outlines the first step towards cross-domain modeling of complex SoS under the term *Smart Cities*. This is done by making use of already established architecture frameworks regarded to domain-specific systems engineering. Thus, the goal is to combine the automotive architecture of an EV by using the ARAM as well as its manufacturing and integration into the Smart Grid according to RAMI 4.0 and SGAM. Therefore, first the respective reference architecture model needs to be analyzed in terms of its specific characteristics and its possibilities to delineate a system, which is stated in Section 2. This enables the elaboration of similarities and links between each model of the EV in order to define the corresponding interfaces. A suitable method for uniting those domain-specific approaches to work across domains is considered to be SPES. Therefore, in Section 4, the mapping of each architecture to the concepts of SPES is described in more detail and the interfaces to combine each other are defined. Subsequently, the result is evaluated by applying a real-world case study making use of an EV. The outcome of this work can contribute to various different follow-up projects inter alia the modeling of a Smart-City concerning different domains and with that the development of a suitable Framework.

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