Evolution of the Automotive Reference Architecture Model towards a Domain-Specific Systems Engineering Approach

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***Abstract*—Due to the rising complexity in the automotive domain a suitable modeling framework to facilitate development as well as interdisciplinary communication is needed. In the domain of smart grids, the Smart Grid Architecture Model (SGAM) framework turned out to be a suitable tool for coping with complexity whilst providing cross-disciplinary understanding. A similar approach exists for the automotive domain: the Automotive Reference Architecture Model (ARAM) framework. As opposed to other automotive frameworks, this one offers interoperability with the smart grid framework, which simplifies cross-domain collaboration. During the development of ARAM, the Software Platform Embedded Systems (SPES) methodology gained momentum. This methodology can be considered an architectural model while the automotive framework can be considered an analysis model, according to the domain-specific systems engineering approach. In order to follow this approach, a transformation between the two models must be possible. This work-in-progress paper aims at presenting first approaches of an adapted version of the ARAM framework, proposing a reworked structure that is compatible with both, SGAM and SPES.**

***Index Terms*—Automotive Reference Architecture Model (ARAM), Automotive Framework, Model-based Systems Engineering (MBSE), Domain-Specific Systems Engineering (DSSE)**

I. Introduction

Nowadays, the development of cars is more complex than ever before [1]. Hardware as well as software components of cars are becoming increasingly complex [2]. Moreover, the environment in which cars operate changes continuously, considering for example electric vehicles, which interact with the smart grid [3]. Even combustion-engine cars are becoming smarter by communicating with their surroundings, for instance with traffic lights [4]. As a result of these trends, the stakeholder audience alongside their concerns changes or rather widens which demands interdisciplinary communication.

A well-suited method to cope with this rising complexity is the utilization of models. Hence, the discipline of systems engineering was extended towards a model-based approach resulting in model-based systems engineering (MBSE). In order to combine both, an MBSE approach and a method to facilitate interdisciplinary communication, a suitable framework must be established. In the domain of smart grids, which faces similar issues, a framework was created that proved valuable for this purpose: the Smart Grid Architecture Model (SGAM) which is a standardized three-dimensional architecture framework for the domain of smart grids [5]. Regarding the domain of automotive, Draxler et al. [6] analyzed four similar approaches of automotive frameworks and created a framework thereafter: the Automotive Reference Architecture Model (ARAM) framework. Considering the domain-specific systems engineering (DSSE) modeling stack [7], such a domain model can be considered an *analysis model*. As vehicles cannot be considered isolated systems anymore—due to connections to other domains like smart grid—the goal of this framework was to incorporate existing research regarding automotive frameworks whilst providing interoperability to SGAM, thus, ensuring cross-domain understanding. Moreover, an SGAM-based model is not suitable for the modeling of a vehicle. Nevertheless, electric vehicles are a part of the smart grid. Providing a modeling approach for modeling vehicles in a way that is similar to the SGAM-based approach enables interoperability between these two domains. However, during the research conducted in the context of the first concept the SPES framework [8], a framework for modeling approaches regarding cyber-physical systems (CPS), gained more attention in the automotive domain. This framework can be considered an *architectural model*, according to the DSSE modeling stack. Since a transformation between analysis and architectural model must be conducted for a holistic DSSE approach, a possible mapping of the ARAM layers to the SPES viewpoints had to be reserached on.

The aim of this paper is to give an overview of the current state of a revised ARAM. On the one hand, this evolution takes the SPES framework into consideration. On the other hand, in contrast to the first conceptual approach, this framework will also provide the possibility of modeling a car as a whole, from technical components through to high level business aspects.

II. Related Work

In the following sections, information about the underlying concept of DSSE as well as the previous research on automotive frameworks is given.

A. Domain-Specific Systems Engineering

In the context of MBSE approaches, the Systems Modeling Language (SysML) is frequently used as a modeling language. However, stakeholders coming from a less technical background do not necessarily have the expertise in using or understanding this general-purpose language (GPL). When it comes to a modeling language suitable for MBSE approaches, the modeling language should be precise enough from a technical perspective [9] but also simple enough to facilitate understandability among a wide range of stakeholders [10].

The discipline of domain-specific systems engineering (DSSE) deals with the challenge of combining these aspects: an MBSE approach that enables a holistic and simple understanding of the system as well as a basis for a detailed engineering approach providing dependability by design [7]. Therefore, a 3+1-layered modeling stack is introduced by Neureiter et al. [7], which is influenced by the structure of the Model-Driven Architecture (MDA) [11]. Hence, on the upper two layers it provides a separation of concerns by defining an *analysis model* and an *architectural model*. The former is used to describe the system of interest on a high level, utilizing a domain-specific language (DSL)—a language tailored to a specific domain—as modeling language, facilitating understandability for all involved stakeholders. The latter takes the outcome from the analysis model and identifies components on a more precise, technical level. For this layer, the SPES methodology, as described by Pohl et al. [8], is suggested to be used in combination with the modeling language SysML. Therefore, a transformation from the approach used on the level of the analysis model towards the SPES framework must be possible. Afterwards, the identified technical architecture is handed over to the lower levels of the modeling stack for the creation of a detailed design, resulting in the final implementation [7].

One widely accepted example for the analysis model can be found in the domain of smart grids: the SGAM [5] alongside its DSL, introduced in [12]. However, the question arises, whether a similar framework does exist in the domain of automotive.

B. Automotive Frameworks

Draxler et al. [6] considered the question of a concept similar to SGAM in the domain of automotive by conducting research on existing automotive frameworks and performing an evaluation therefrom. The analyzed frameworks are: the Automotive Architecture Framework (AAF) [1], the Architectural Design Framework (ADF) [13], the Architectural Framework for Automotive Systems (AFAS) [14] and the Volvo Cars Architecture Framework (VCAF) [15]. Each of those approaches does not only consider the vehicle as closed system but also incorporates aspects from the value chain. Moreover, several viewpoints, stakeholders, concerns, and model kinds are presented in accordance with architectural descriptions following the ISO/IEC 42010 [16]. However, since none of the mentioned approaches is designed to be interoperable with the SGAM, the initial concept of the ARAM framework was created. Due to the fact, that the SPES framework gained more attention since the development of the first version of the introduced automotive framework, a mapping of the ARAM framework to the SPES framework was already suggested by Draxler et al. [6], however, not researched on yet.

Combining the research of DSSE, which frames the overall approach, an SGAM-based model as analysis model of the DSSE modeling stack, SPES, as a basis for the architectural model, and the evaluation of the above-mentioned automotive frameworks – in addition with the work conducted for the initial framework – a new version of ARAM is being developed. The current results of this development are outlined in the following sections.

III. Current State of Development

The goal of this framework is—in accordance with the analysis model of the DSSE modeling stack—to facilitate an overview of the system architecture on a rather high abstraction level. This framework therefore acts as a bridge between the business interests and the technical realization of the system under development (SuD). The business goals can be outlined and traced towards and through a technical realization without overloading the level of the analysis model with too much technical detail. Hence, this framework provides a communication basis between business-oriented and technically-oriented stakeholders. The current structure of the revised automotive framework is influenced by the SPES methodology. Since ARAM is located on the modeling-stack level of the analysis model and SPES on the level of the architectural model that follows underneath, this automotive framework should be defined in a way that it is compatible with SPES. Thus, an analysis model can be transformed to an architectural model as seamlessly as possible. Therefore, the structure of the framework was inspired by the SPES viewpoints. This was achieved by adapting the interoperability layers of ARAM, as explained in the following section.

A. Interoperability Layers

The main principle of this framework are the five interoperability layers, as depicted in Figure 1. They provide different

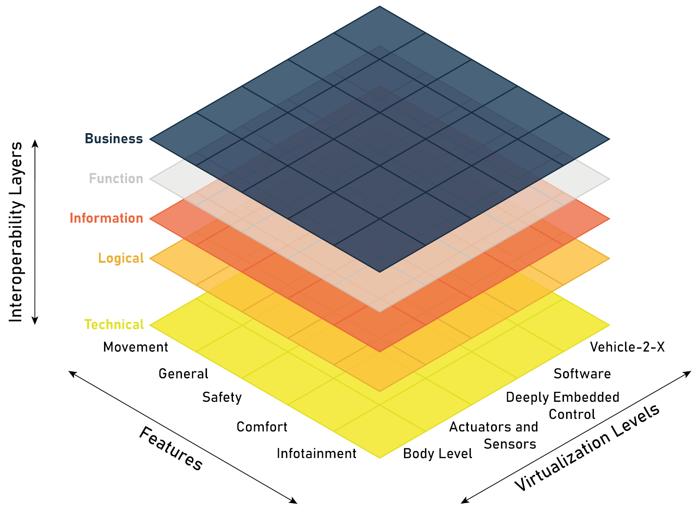

Fig. 1. Automotive Reference Architecture Model, current version

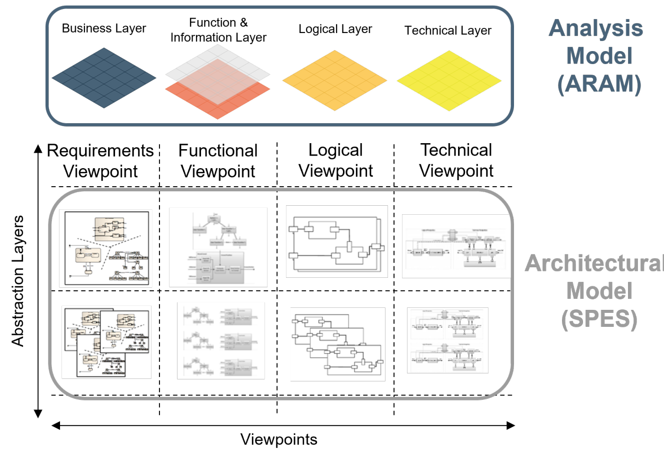

Fig. 2. Mapping between ARAM and SPES, SPES graphic adapted from [8]

views of the respective SuD. Nevertheless, the ARAM framework allows for traceability throughout all five layers. The origin of these layers lies in the GridWise Architecture Council (GWAC) interoperability stack [17], which is also used in the SGAM framework.

The topmost layer is the *Business Layer*. It provides a business view of the SuD and describes the involved business actors as well as their interest in the system. After these business goals are identified, they are mapped to use cases from a system's perspective.

After the use cases have been specified, the functionality of the system can be designed. This is done on the *Function Layer* which provides a view of the system regarding the functionality that must be fulfilled in order to cover the envisioned business goals. The traceability between business and function layer is established by refining the use cases from the business layer on the underlying function layer. Afterwards, the functionality of the refined use cases can be specified. This also includes the definition of communicating entities as well as the information exchanged between them.

The information that is exchanged between entities is detailed on the next layer: the *Information Layer*. On this layer, not only the communicating entities are further refined. Also, the exchanged information is specified in the form of data. A similar approach regarding the SGAM framework was published by Vereno et al. [18].

Based on the identified communicating entities on the information layer, a first draft of the logical, solution-neutral architecture can be designed. This is done on the *Logical Layer*.

Finally, the logical architecture can be realized as technical architecture on the *Technical Layer*, resulting in an architecture that is close to a real-world implementation. As ARAM is located on the level of the analysis model of the DSSE modeling stack, the technical architecture is still on a rather high abstraction level and therefore serves as a starting point for a detailed architectural model of the SuD. Since different departments usually develop different components, the usage of this framework provides more transparent knowledge of how these components are interoperating with each other as well as how they are physically connected. A more detailed model of each separate component can than be created using—following the DSSE modeling stack—the SPES framework together with the SysML. The current design of the framework's layers intends to facilitate this transformation between ARAM and SPES, as the layers of ARAM can easily be mapped to the SPES viewpoints. This mapping is visualized in Figure 2.

B. Features Axis

As it is stated in [15], an important aspect is the separation of concerns, for instance when it comes to the domains inside a car, like infotainment or safety. Hence, two of this framework's three axes are dedicated to the aspect of separation of concerns. The first axis that is introduced is the *Features Axis*. The current state of development regarding the categorization of this axis is the following:

- **Movement**: This feature classifies components that are related to the lateral or longitudinal movement of a vehicle, such as tires or the engine.
- **General**: This section considers regulatory aspects of cars, depending on the legislation of the respective country. The name currently acts as a placeholder and therefore will still be defined during future research.
- **Safety**: The safety section of the features axis is used to group physical components of the car that are related to passenger safety, for instance airbags. Research on security and safety by design is still being conducted.
- **Comfort**: This section classifies components of the car that are purely related to the comfort of passengers, such as heated seats for instance.
- **Infotainment**: Components for information purposes like the speedometer, radio, warning lights, and displays are assigned to this section.

Since the order of these categories cannot be determined clearly, this framework only provides a recommendation for the sequence. The final order is left to the end-users' judgement. During future research the introduced categories will still be consolidated by means of case studies and feedback from industry.

C. Virtualization Levels

Concerning the third axis, a separation of concerns regarding levels of virtualization is suggested. This axis allows a classification of components regarding their level of virtualization; from physical to virtual components and gradations in between. The different levels are:

- **Body Level**: physical components of the car, such as wheels, chassis, or seats
- **Actuators and Sensors**: actuators and sensors of the vehicle
- **Deeply-Embedded Control**: components that act as a bridge between physical and virtual elements
- **Software**: software components of the vehicle
- **Vehicle-2-X**: elements related to the communication with the environment

Opposed to the features axis, the order of the virtualization levels can be determined clearly. By utilizing these two axes, which span a plane, components can be assigned to a feature and virtualization level, allowing for separation of concerns in these two categories.

Overall, ARAM could be used to model an architecture of the entire vehicle on a high abstraction level or just subcomponents of the vehicle. If a more detailed definition of certain aspects is desired by the users, the introduced framework can also be used over multiple abstraction levels, similarly to the SPES methodology.

IV. Discussion, Conclusion & Future Work

Based on the existing research on the automotive framework ARAM, the aim of this paper was to introduce an approach towards a refined automotive framework. This evolution leads to a first proposal towards a holistic DSSE approach in the automotive domain by enabling a transformation from the analysis model, in the form of the proposed framework, towards the architectural model, in the form of the SPES framework. This will facilitate communication between business-oriented and technically-oriented stakeholders, paving the way for interdisciplinary development of highly complex systems. A current version of the newly defined automotive framework was presented in this paper. However, future research still demands an evaluation of the newly designed interoperability layers. The seamless transformation between analysis and architectural model as well as the categorization of the features axis must be verified by means of, for instance, case studies. Moreover, the revision of the DSL based on the ARAM framework is also relevant for this demonstration. In order to provide tool integration of this ARAM-based DSL, a modeling-toolbox, similarly to the SGAM Toolbox[1], will be developed. Further research will also be conducted regarding aspects like safety, cyber-security, model verification, and requirements engineering. This research will also lead to a continuous advancement of the functionalities provided by the ARAM Toolbox.

[1]https://sgam-toolbox.org

Acknowledgment

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 gratefully acknowledged.

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