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Design Decisions in the Architecture Development of Advanced Systems: Towards traceable and sustainable Documentation and Communication

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Abstract

Future technical systems, so-called Advanced Systems (AS), will be significantly more capable than current ones, but also more complex. This increase in complexity needs to be addressed during the development of AS, which resembles an ongoing complex problem-solving process (PLP). In PLP, documenting and communicating decisions is paramount. A major result of PLP decision making is the system architecture, which defines the basic concepts and properties of the system. Documenting and communicating these design decisions properly is especially important since they allow later changes to remain traceable and organizationally sustainable. These activities are also relevant for learning and sustainably saving knowledge. Developers however lack the appropriate tools to do so, and thus often report in unstructured natural language and via different channels. Virtual collaboration platforms such as Microsoft Teams could significantly help documenting and communicating design decisions during the PLP. They are ideal for storing information such as decision rationales and for communicating them to different project stakeholders without changing systems. Nevertheless, developers still lack methodological guidelines and simple technical support for using them in the context of architecture development. As a first step, we therefore held semi-structured group interviews with various company representatives to identify problems in communicating and documenting design decisions and to evaluate solutions with employees. We found that developers lack

uniform documentation processes and templates. In addition, they see documenting and communicating design decisions not as a significant part of their work, but nevertheless complain about incomplete and missing communication of these decisions. In this paper we report in detail our findings and use them to develop preliminary support methodology for documenting and communicating design decisions on collaboration platforms. The proposed methodology consists out of 4 phases: the identification, documentation, communication, and management of relevant design decisions. It includes tools and guidance to support developers in their daily work.

Keywords: Systems Engineering (SE), Documentation Management, Communication, Decision Making

1 Introduction

Manufacturers of technical, mechatronic systems integrate an increasing amount of software and electronics into their future, so-called Advanced Systems (AS). This integration makes AS superior to current, hardware-based systems in several ways (Dumitrescu et al., 2021). Not only will AS be highly interconnective, autonomous, interactive, and socio-technically integrated, they will also allow a whole range of internet- and platform-based services. These new features however will also increase the complexity of the systems themselves on the one hand, and their development on the other hand (Dumitrescu et al., 2021; Gausemeier et al., 2019). The development of AS basically resembles an ongoing problem solving process (PLP) (Bender & Gericke, 2021; Haberfellner et al., 2019; VDI 2221-1, 2019). In solving a wide variety of problems, developers are constantly faced with a large number of decisions: For example, they decide on the appearance, functionality, or user interfaces of individual system elements that have multiple dependencies on the overall system (Walden et al., 2015). The PLP is generally divided into the target searching, the solution searching, and the solution selection (Bender & Gericke, 2021; VDI 2221-1, 2019). In the third part of this process - the solution selection - the described decision process of the developers takes place. One result of PLP decision making is the system architecture, which defines the basic concepts and properties of the system (ISO/IEC/IEEE, 2011). It enables a picture of the basic operating principles, requirements and general interrelationships of the elaborated solution of the decision process (Haberfellner et al., 2019).

In PLP, documenting these design decisions is paramount (Albers et al., 2016; Haberfellner et al., 2019). It enables traceable individal decision-making in the development process. Good documentation of decisions makes subsequent detailing and changing easier or possible at all (Haberfellner et al., 2019). Furthermore, documenting these decsions properly is essential since they enable learning and continuous reflection of the PLP as well as the derivation of best practices (Albers et al., 2016; VDI 2221-1, 2019). In addition to documenting, communicating or submitting the decisions results is also an important activity in this process. Because of the increasing complexity of the individual development tasks, a strong collaboration of individual developers is required in their work (Gausemeier et al., 2013; Hardwig & Weißmann, 2021; Kröger & Marx, 2020). In many cases, the documentation serves to communicate the decisions made to other people and teams. Different communication techniques exist (Rupp, 2021). Despite its relevance, the most popular form of documentation is still based on informal language. Thus, knowledge in different contexts is often documented in natural language in the form of prose (Kurrle, 2017; Pohl & Rupp, 2015). The use of natural language results in knowledge being documented in stylistically very different ways. This contradicts desired quality criteria or required formalities for documentation (Rupp, 2021). This leads to design

decisions being reasoned very differently or only insufficiently (Zdun et al., 2013). In addition, many developers have difficulty with systematic, formal documentation (Zörner, 2015). As a result, there are often gaps in the documentation (Bender & Gericke, 2021). Especially in the case of complex AS, lacking documentation quickly leads to the loss of an overall view of the system under development (Rupp, 2021).Virtual collaboration platforms could significantly help documenting and communicating design decisions during the PLP. They provide a virtual environment where much of the collaboration can take place. By linking the work of individual employees, they enable company-wide exchange and flexible, network-based collaboration (Hardwig & Weißmann, 2021; Mordi, 2021). Having in mind that teams working less and less in the same place and interdisciplinarity and distributed product development increases, collaboration platforms find a wider and wider use in the development of AS (Dumitrescu et al., 2021; Nicklich & Sauer, 2019). Collaboration platforms offer different functions. For example, they can be used as a knowledge base, for real-time chat, or as a video conferencing tool (Kröger & Marx, 2020; Rossmann et al., 2016). Thus, they are suitable to store information such as rationales of a decision and thus to document it without changing the system. Developers however still lacking approaches or methodological procedures to use collaboration tools for this purpose. This is, among others, a result of a recent study of several research institutes in the field of engineering (Dumitrescu et al., 2021).

As a first step, the authors' research objective is to gain principal understanding of the problems involved in documenting and communicating design decisions in practice and to work out the associated technical and process-related challenges in more detail. Based on this analysis, the authors' research in the second step aims to develop a systematic support methodology that enables comprehensible and sustainable documentation and communication of design decisions in the architectural development of AS in collaboration platforms.

2 State of the art

2.1 Architectural design decisions and design rationale

System architecture represents a central element in the development of AS. It provides a picture of the fundamental operating principles, the requirements, and the general interrelationships of the solution to be developed (Haberfellner et al., 2019). In this context, the system architecture can basically be understood as a sum of important design decisions within the development process (Jansen & Bosch, 2005; Zörner, 2015). For the term "design decisions", no precise definition can be found in the literature for the development of system architectures. For this paper, the authors therefore orient themselves to publications from the field of software architecture development due to the thematic similarity. According to Jansen and Bosch (2005) a design decision is *"a description of the architectural additions, subtractions, and changes to the software architecture, rationale, and design rules, design constraints, and additional requirements that (partially) realize one or more requirements for a particular architecture"*. Different types of design decisions can be distinguished. For example, Kruchten (2004) proposes a subdivision of design decisions into the classes of existence decisions, property decisions, and executive decisions. Existence decisions are decisions in which the individual artifacts or system elements of a system architecture are defined. In property decisions, overarching properties or qualities of the system are defined. Executive decisions do not relate directly to the design elements or their properties, but to, for example, the business environment, the design of the development process, or the choice of technologies and tools (Kruchten, 2004). Regardless of its nature, once a design decision has been made, it is a fundamental decision that is difficult to take back in the further course of development (Zörner, 2015). A central

component of the design decision is its justification. The justification documents the motives or rationales why a corresponding design decision was made. It includes the problems and alternative solutions. It also contains the arguments for or against the proposed alternatives and the selected solution (Alkadhi, 2018; Jansen & Bosch, 2005; Lee & Lai, 1991). The justification can serve several purposes. A key aspect for a traceable development process and sustainable knowledge management in the organization is the fact that documenting the justification supports communication within the development organization and enables continuous reflection and tracking of improvement proposals (Albers et al., 2016; Zörner, 2015).

2.2 Approaches to document architecture decisions

To support developers in documenting design decisions and associated rationales, metamodels, methods, and tools have been proposed by the Architectural Knowledge Management community since 2004, especially for the field of software architecture development (Ali Babar et al., 2009). Most of this work focuses on capturing design decisions and their associated rationales retrospectively. Various templates have been developed for this purpose (Zimmermann et al., 2015). The aim of these templates is to enable developers to systematically document design decisions by means of a predefined structuring and thus to formalize the contents of the documentation. The scope and characteristics of the templates differ. According to the template of the ISO/IEC/IEEE 42010:2011, for example, the rationales of design decisions are documented extensively and in detail (ISO/IEC/IEEE, 2011). In contrast, the Y-template proposed by Zdun et al. (2013) allows for simple and quick documentation of the design decision by completing a sentence template. Although some of these presented approaches have been known for a long time in software architecture development, they have not yet been used much in practice (Zimmermann et al., 2015). In system architecture development, such approaches have not yet been found in the literature at all. Furthermore, previous approaches hardly consider the fact that the collected, documented knowledge often must be applicable in practice in multiple projects in different organizations (Zimmermann et al., 2015). For this reason, the authors pursue the approach of simplifying documentation and making it more easily accessible across the organization by integrating decision documentation into collaboration platforms.

2.3 Communication in collaboration platforms

The increasing complexity of tasks in the development of AS requires greater collaboration between individual developers in their work (Gausemeier et al., 2013; Hardwig & Weißmann, 2021; Kröger & Marx, 2020). In scientific discussions, the term collaboration is used to describe a particularly intensive form of cooperation in which social units (teams, companies, etc.) use resources in joint work and decision-making processes to achieve a result that cannot be easily achieved through division of labor (Bedwell et al., 2012; Camarihna-Matos & Afsarmanesh, 2008). To support this collaboration, collaboration platforms have been increasingly used in recent years. For example, the number of daily users of MS Teams a collaboration platform from Microsoft increased from 20 million in November 2019 to 115 million in November 2020 (Microsoft, 2021; Microsoft Switzerland, 2020). A reason for this development is certainly the change in the working world in the context of the Covid-19 pandemic. However, it can be assumed that collaboration platforms will continue to be used with the same frequency in future (Jackson et al., 2022). Collaboration platforms offer their users a virtual place where a large part of the collaboration can take place. With their help, the work of individual employees can be linked, and flexible, network-based collaboration made possible (Hardwig & Weißmann, 2021, p. 204). Despite their strong and rapid spread in practice, there are currently only a few approaches or methodological procedures in the literature on how communication in

collaboration platforms can be systematically structured. This applies in particular to approaches to documenting collaboration content such as design decisions in engineering. A recent study by several research institutes in the field of engineering underscores this statement (Dumitrescu et al., 2021). The study examined the current state of performance and future trends in engineering and surveyed more than 130 experts and executives from industry and academia. The respondents indicated that the multitude of communication channels currently in use makes structured documentation difficult. According to the respondents, there is also a lack of a methodical approach to structuring collaboration opportunities and approaches to documenting relevant decisions. Therefore, several respondents call for a cloud-based collaboration platform that addresses the activities of interdisciplinary product development (Dumitrescu et al., 2021).

3 Research methodology

The state of the art has shown that metamodels, methods and tools already exist, particularly in the field of software architecture development, which support developers in documenting design decisions. However, these approaches are still rarely used in practice (Zimmermann et al., 2015). No approach could be found to document and communicate design decisions in collaboration platforms. Thus, the authors address the following research questions:

Research Question 1: What are technical, process-related, or other problems that hinder good documentation and communication of design decisions in system architecture development in practice?
Research Question 2: How can documenting and communicating design decisions be improved by using collaboration platforms?

To answer research question 1 semi-structured group interviews were held. Due to the limitations of the Covid-19 pandemic, the interviews were conducted digitally. The tools "Conceptboard" and "Microsoft Teams" were used, to support the interviews, as they are easily accessible for all participants. The use of the named tools results in advantages such as time flexibility, increased motivation to participate, integration of all employees, and spatial independence (Arkorful & Abaidoo, 2015). A total of 10 participants from different companies were interviewed. It was ensured that the interviewees had experience in product or architecture development of AS. The terms design decisions, communication and documentation were defined in advance. This allows a uniform understanding of the questions to be assumed. The group interviews focused on the two topics of problem identification and solution selection.
First, the following questions were asked / discussed:

1. What problems arise in the documentation and communication of design decisions or changes?
2. What are the three most common reasons for missing or incomplete documentation in your company?
3. What tools and methods are currently used to document and communicate design decisions or changes?

To generate data about the current solution selection process, participants were next asked the following questions:

4. What is the current process for communicating and documenting design decisions?
5. What tools and methods are currently being used specifically to prevent inadequate documentation and communication of design decisions?
6. What goals should be met with a documentation and communication concept?

The results of the semi-structured interviews were evaluated in the form of a qualitative content analysis. During the group interviews the answers were documented using the digital whiteboard tool “Conceptboard”. The results were then clustered inductively and grouped into categories. The obtained results served as a starting point for the development of the methodological support.

4 Results

4.1 Semi-structured group interviews

The following figure shows the clustered problems in documenting and communicating design decisions (see figure 1). The clustered problems were assigned to the categories of documentation, communication & transmission, motivation & methodological knowledge, and tools to gain a better overview. In the following, the main answers to the individual questions that were frequently named by the participants are explained in more detail.

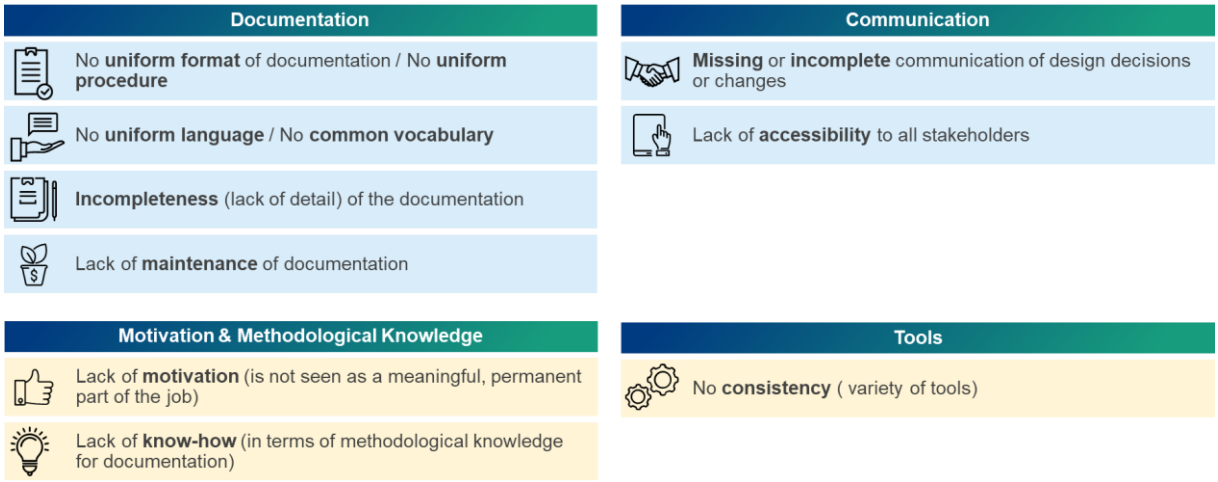

Figure 1: Clustered interview results of problem identification

In the first part of the group interviews, the participants were asked specifically about challenges and problems in documenting and communicating design decisions. The participants tended to answer the first question in this context with insufficient, inconsistent, and complex documentation. It was stated that developers are using different tools for documenting design decisions. Participants reported that there is no common storage location and no uniform language for documenting. Other problems that have named are intransparent design decisions and inconsistent or missing communication. In the participants’ opinion, developers do not or only partially communicate design decisions to stakeholders. They also consider interdisciplinary agreements to be more difficult. The three most common reasons, according to the participants, for missing or incomplete documentation and communication are low prioritization, user-unfriendliness, and delayed documentation. In the participants' view, documenting and communicating design decisions is not high prioritized by developers. This would lead to the fact that these activities are seen as secondary and the added value of detailed documentation not being present in the minds of those responsible. In their opinion user-unfriendliness is demonstrated by the fact, that it is difficult or impossible for people from outside the field to understand the content. Furthermore, the existing documentation is not self-explanatory or incomplete. There are no uniform guidelines. As a result, participants find it often impossible for third parties to familiarize themselves independently into the documented content or to understand what is documented. According to the participants, both collaborative tools and storage options such as Microsoft Office and Jira are currently used, as well as

unstructured documentation in text form. In the second part of the group interviews, the participants were asked about specific requirements for methodological support for documenting and communicating design decisions. In response to the fourth question, a (sometimes strong) commitment to existing standards was mentioned. Also mentioned were various forms of team meetings in which, among other things, weaknesses and risks are evaluated. The answer to the fifth question indicates a tendency that developers are searching for tools that support a uniform language. It was stated that for this reason developers are already partially using the UML language (Authors' comments: Unified Modelling Language), which allows members of different areas in a company to use a homogeneous and formal language. The participants strongly defined user-friendly, uniform documentation and transparent and traceable communication and decisions as the main goals of a documentation and communication concept. To document design decisions user-friendly and uniform, the participants request a comprehensible, complete, and understandable documentation. Stakeholders shall also be systematically involved and notified about any design decision made. It is particularly relevant for the participants that design decisions, rationales and communication is transparent. They find it important that interdisciplinary communication with non-topic employees should work. The traceable presentation of design decisions can also ensure the "reuse" of design decisions in future project teams.

4.2 Preliminary Methodology: Documenting and Communicating Design Decisions

As shown in the semi-structured group interviews, there is a need to improve the documentation and communication of design decisions in the architecture development of AS in the individual companies. The documentation is often in natural language and unstructured. Furthermore, a variety of currently used documentation and communication tools as well as different storage locations make structured, comprehensible, and sustainable documentation and communication in the organization difficult. The systematic support methodology for traceable and sustainable documentation and communication of design decisions in the architecture development of AS is intended to support developers through a defined procedure and the provision of tools such as templates. By integrating the methodical approaches into a collaboration platform, a central technical tool shall be used that enables uniform communication channels and storage locations.

The approach of the methodology is presented and discussed in the following (see figure 2). In practice not all the large number of everyday design decisions can be documented with a reasonable amount of effort. For this reason, in the first step relevant design decisions will be identified. Documenting effectively should ensure fast decision-making processes, since they are a success factor of product development (Chen et al., 2010). With the help of a tool for decision-making, which contains e.g., defined criteria and guiding questions, developers shall easily identify relevant design decisions. In the second step developers shall be supported in documenting design decisions uniform and systematically in collaboration platforms. For this purpose, a documentation concept shall be developed, which describes as a central element how design decisions shall be documented. As part of the concept, methodological tools such as documentation templates shall be developed. These shall then be integrated into collaboration platforms. Communicating design decisions is also an important part of the methodology (see step 3). The communication concept is intended to help developers communicate design decisions to relevant stakeholders in a targeted, cross-disciplinary, and role-specific manner in collaboration platforms. The last step of the procedure deals with the management of design decisions within the collaboration platforms. Developers shall be supported with an appropriate management concept for reviewing or changing design decisions once they have been documented.

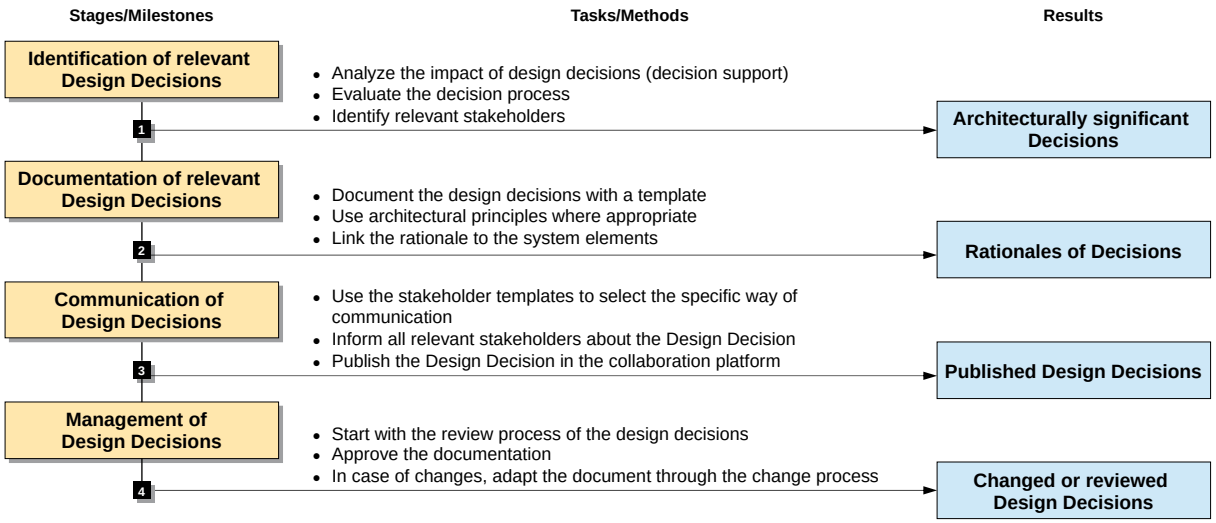

Figure 2: Procedure steps of the preliminary support methodology to document and communicate design decisions

5 Discussion and outlook

The presented support methodology for traceable and sustainable documentation and communication of design decisions will be elaborated in further research. Existing methodological approaches from e.g., software architecture development and requirements management will be analyzed, and appropriate principles extracted as methodological building blocks. As shown in the interviews, developers are often not motivated to document design decisions. For this reason, future research will focus on designing the methodology as effortless as possible to ensure that the approach cloud be integrated into developers' everyday work. In this context, existing solution approaches from agile work design, where similar problems occur (Theunissen et al., 2022), will be analyzed. It should be noted that such an approach or tools should primarily serve systematic technical documentation and communication and should not be overloaded; in particular, controversial decisions or ambiguities can still be clarified in direct (informal) exchange, according to sociological findings (Nicklich & Sauer, 2019). The findings of the structured group interviews are gaining an initial understanding of the technical and process-related challenges in documenting and communicating design decisions in product development. It should be however noted that the sample size of the interviews is relatively small. Generalized quantitative statements about the collected challenges are therefore not yet possible. Future research plans to expand on the insights gained in further interviews. To ensure that the presented support methodology is user-friendly, and benefit oriented, it will be validated in a corporate context.

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