Architectural reasoning in the conceptual phase - a case study in the oil and gas industry

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This is a pre-copyedited version of a contribution published in 2019 14th Annual System of Systems Engineering Conference (SoSE) published by IEEE. The definitive authenticated version is available online at IEEE Explore: 10.1109/SYSOSE.2019.8753863.

***Abstract* — This paper evaluates the use of architectural reasoning to explore the problem space in a system development project in the oil and gas industry. The suppliers in this industry have traditionally been tailor-making their systems for each delivery project. To improve the systems offering across the client and project portfolio, the suppliers must put more effort in the conceptual phase to explore the design space. Architectural reasoning is the process of transferring problem and solution know-how into a new systems architecture. In this paper we review literature on architectural reasoning in the conceptual phase, and on application in the oil and gas industry. To evaluate the use of architectural reasoning in the industry, we perform a case study in a subsea supplier company. From the case study, we are identifying a work-flow for architectural reasoning, utilizing the market needs, design, and domain knowledge to evolve the system. Evaluating the tools and working methods, we find that working in a multi-disciplinary team is key to support the reasoning process. We find that the team is utilizing the design and domain knowledge to improve the system architecture. However, the team lacks methods to make this knowledge explicit and to quantify the issues they are identifying.**

Keywords—architectural reasoning, conceptual design, oil and gas industry, case study

I. Introduction

Oil and gas suppliers are constantly working to improve their system offerings, by reducing the installation cost and schedule. Traditionally in this industry, the clients have been giving extensive and detailed requirements specifications. The specifications are often of poor quality and is a mix of requirements and prescribed solutions [1]. Reports from the industry show that the extensive requirements increase the cost as it requires customized system solutions, and do not enable suppliers to optimize their system offering across the client portfolio [2]. Currently, we see a shift of the industry, and the clients are more open to the supplier being a part of the development of the system solutions [3], "in press" [4].

With this shift, it opens for the supplier companies to rationalize their system solutions across their client and project portfolio. This requires supplier companies to have processes for supporting the conceptual phase to explore the design space. Systems architecting can support this exploration. Reference [5] describes systems architecting as a joint exploration of requirements and designs.

Architectural reasoning is the process of developing the system architecture. In this paper, we evaluate how architectural reasoning can support a supplier company in developing system solutions across their portfolio. First, we present a review of the existing knowledge of architectural reasoning and its importance in the conceptual design phase. We also look to the literature of implementation of systems architecture in the oil and gas industry. Next, we present a case study from a supplier company in the oil and gas industry. In this case study, we observe the use of architectural reasoning in an ongoing development project. We are describing the reasoning process the team are using and compare it to the existing literature. Finally, we describe the tools and working methods the team is using to support their reasoning and evaluate how the team perceive these tools.

II. Research Methodology

This paper contains two parts, a literature review and case study. The literature review is aiming to provide the understanding of architectural reasoning and its role in the conceptual phase. The second part of the paper presents a case study from the oil and gas industry. The case study is applying the research method industry-as-laboratory [6]. The first author is a part of a development team in the company and collecting data based on observations of the daily work. Further, we were using a survey to evaluate how the team was perceiving the methods and tools they were using. We were distributing the survey to all team members and got response from all of them.

In the survey we used a five-point Likert scale [7], with response alternatives *Strongly disagree (1)/ disagree (2)/ neither agree or disagree (3)/ agree (4) / strongly agree (5*). For all questions we gave the respondents the possibility to answer *not applicable* if they had not been involved or exposed to the given tool or method. The survey results presented in the paper are not including the *not applicable* responses.

To compare the methods relative to each other, we analyze the tendency using the median [8]. To evaluate the overall supportiveness of the methods, we use the Net Promotor Score (NPS) [9], considering strongly agree as a promoter, agree as neutral and neither agree or disagree, disagree, and strongly disagree as detractors.

III. Background

A. Systems architecture and architectural reasoning.

There is no unified definition of systems architecture, and the system engineering community is considering systems architecting more as an art [10]. ISO/IEC/IEEE defines systems architecting as *a process of conceiving, defining, expressing, documenting, communicating, certifying proper implementation of, maintaining and improving an architecture throughout a system's life cycle*.

Systems architecture can support the development project in exploring the needs and design of a system [10]. The importance of systems architecture is to enable a way to understand complex systems, to design and manage them and to provide long-term rationality of decisions made early in the project [11].

To support development of systems architecture, there exist several architectural frameworks. Architectural frameworks intend to provide a standard approach to architecture [12]. Reference [5] and [12] presents reviews of exiting architectural frameworks. In [12] the authors focus on the differences in the frameworks. They conclude that the one should adapt architectural framework to the goal and context.

Architectural reasoning is the process of developing the systems architecture. Reference [13] presents a schematic model for architectural reasoning, describing it as recursive process driven by system requirements, available domain knowledge and available design knowledge. In [14] the author gives a thorough introduction to architectural reasoning and what it means in an industrial setting. This work is based on the CAFCR framework [15]. The purpose of this framework is to support systems architecture.

The CAFCR framework decomposes the architecture into five views, *customer, application, functional, conceptual* and *realization*. Within each of the different views, the author suggests different sub-methods that can support developing the systems architecture. Among these methods is the key driver method. A key driver is defining the most important objectives of the customer, that is, *what does the customer want?* [16]. Using the key driver, the system architect can build a key driver graph, which provides a method to connect the customer key drivers to the system requirements. Another framework using key drives, is the FunKey framework [17]. In this method the author proposes to relate the function of the system to the key drivers and requirements by using a matrix to couple them.

B. Conceptual design phase.

The early phase of system design is the conceptual phase, in which one explores the business opportunities and needs, and develops high-level concepts [18]. The definition of the systems architecture occurs in the conceptual phase and is one of the key activities in this phase [19]. As new products are becoming more complex and multi-disciplinary, with shorter development cycles the role of the systems architecture in the conceptual phase is becoming more important [20].

In the early phase, it is important to make the right design decisions, as poor design choices could lead to late design changes, carrying the risk of cost overruns and schedule delays. In [21] the authors are listing some of the main reasons of poor design choices. This includes the lack of a common language and background for multiple engineering disciplines and that design choices based are on experience and intuition rather than quantitative arguments. Other work discussing challenges of multi-disciplinary development in the conceptual phase, also identify communication and decision making as critical issues [22] [23].

To improve the final system design, the developers need to consider and explore the problem domain in the conceptual phase [19]. One process to support this is the Boderc design methodology for high-tech systems [21]. The purpose of this framework is to support efficient evaluation of design choices over multiple disciplines. They split the method in three high-level steps. First step is *preparation of design*, identifying realization aspects of concern, key drivers, and requirements, and making core domain explicit. Next step is *select critical design aspects*, identifying tensions and conflicts and quantifying them. Last step is *evaluation of design aspects,* using models and measurements.

Reference [14] gives a similar flow from problem to solution, consisting of 4 steps, *problem understanding, analysis, decision,* and *monitor, verify and validate*. The first step is to create an understanding of the problem. To do this, one needs to explore both the problem and solution space. In the analysis step one should explore multiple propositions through systematic analyses. The next step is to make a decision by reviewing the analysis and to document and communicate this decision. Finally, the team should verify and validate the solution by measurements and testing.

C. Systems architecting in oil and gas industry

The oil and gas industry can have great benefit of systems engineering methods and techniques, but they must adopt it their own setting and needs [24]. Since early 2000 the cost level in the industry has been rapidly increasing. With the drop in the oil price it became challenging to develop profitable fields [25]. Tranøy et al. analyzed cost overruns in a supplier company in the oil and gas industry and found that the company spend sufficient effort in systems engineering [26]. They also concluded that the major reason for cost overruns was the poor identification of operational needs during early phase. Engen et al. evaluated the use of system engineering in the front-end engineering and design phase [3]. They identified shortcomings in the understanding of the needs in early phases and in documenting design decisions. To improve the system engineering process, they proposed to use informal models to document decisions. Solli investigated the use illustrative ConOps and found that this can improve the mutual understanding among the stakeholders and identify concern in early phase [27].

Another tool that can be effective and improve the system offering in the subsea industry is A3 Architectural Overviews (A3AO) [24]. Borches introduced the A3AO to support sharing of architectural knowledge [28]. In [29] the authors show the use of A3AO in combination with conceptual modelling for a workover system. They found that the A3AO connects the technical system to the business interest, which facilitate the discussion with the stakeholders. Reference [30] gives another example of implementation of A3AO. Here, the authors conclude that A3AO is a well-suited tool to improve communication and collaboration within industry. At the same time, they identify challenges related to implementing this in the industry. They find part of the organization reluctant to implementing and using A3AO, mainly due to the time spend on making the reports and the lack of integration with existing company tools. Reference

[31] support these finding, stating that the subsea industry often meets introduction of more formal methods by skepticism, and that they are perceiving the methods as time-consuming and not applicable.

IV. Case Study - Architectural Reasioning in Oil and Gas Industry

A. Introduction

In this case study, we focus on how architectural reasoning supports a multi-disciplinary team in a development project. The aim is to evaluate the use of architectural reasoning in an industrial setting. We are observing the daily work in a development project and the tools and methods supporting the team in their work. From our observations we identify a work flow for understanding the problem. To evaluate how the tools and working methods are supporting the architecting process, we did a survey among the team members. In the following section we present the case study and our findings.

B. The case

The case we are following, is a development project in a global supplier of equipment to the oil and gas industry. The purpose of the project is to evolve the system design, to reduce installed cost and schedule. The supplier company put together the development team by allocating engineers from different product disciplines and project groups. We call them the core team, with 14 members including the first author. Most of the members of the core team are co-located in an open office area, enabling daily discussions and knowledge sharing. In addition, the team has support from other business functions, such as manufacturing, supply, and costing. The team is following a lean product development process [32], but without any clear process for how to do systems architecting.

C. A work flow for initial phases of architectural reasoning in supplier company

When the team started their work, they were spending most of their time on understanding the problem. We observed that the engineers easily got down to the details of the solutions and were eager to "get going" with the design and engineering. This is similar to what the authors in [33], have seen in other development projects. They conclude that it is a challenge that *many engineers think in solution.*

As the team was progressing they understood that they should explore the problem and solution space more broadly. To do this the team was exploring the design and domain knowledge in the company to understand the issues and tensions of the existing system. In addition, they explored the market prospect to understand the needs for a new system solution. This data collection was supporting the team in understanding the problem. Next the team focused on selecting what they should prioritize to improve, to meet the overall target development project. To do this the team quantified the issues and needs they had identified during the problem understanding, using simple models. For the selected system issues, the team started to explore the design solution space. The phase of evaluating the design space is not within the scope of this paper.

In Fig. 1 we summarize the work flow the development team is using. It starts with a problem statement from the stakeholders. First step is *understanding the problem to solve,* where the team explores the problem and solution space to gain understanding of the problem.

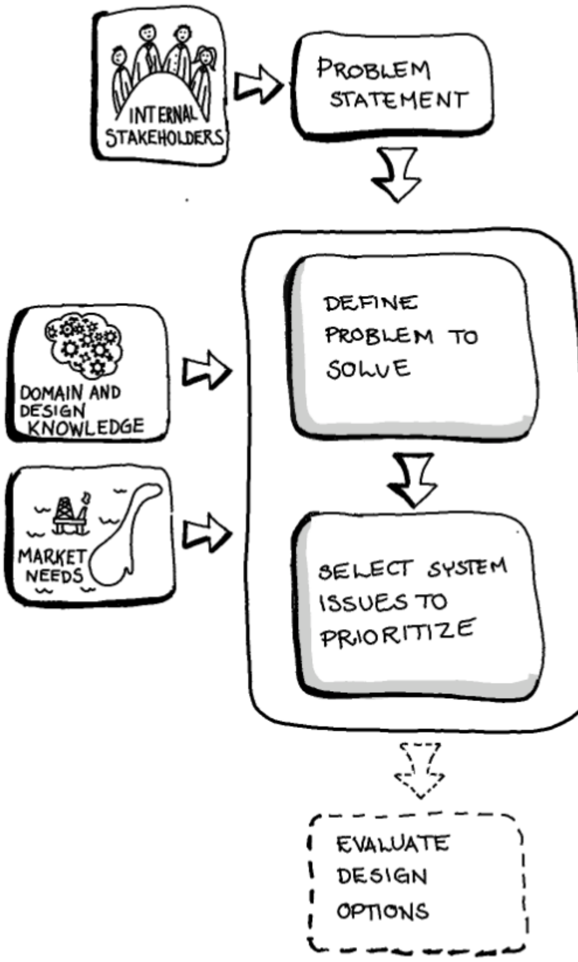

Fig. 1. The flow from stakeholder problem statement to selection of system issues to solve

This first step is comparable to what is the Boderc Method call *preparation phase* [21] and what Muller refers to as the *problem understanding* [14]. Next step is *select system issues to prioritize,* where the team analyzes the issues collected in the understanding phase and selects what is most important to solve the overall problem. This step has similarities to Boderc *select critical design aspects* and Mullers *analyze* step.

The left-hand side of Fig. 1 is showing the input data to the process. The team is utilizing the domain and design knowledge as well as the market needs to support their reasoning. This is equivalent to the schematic model describing architectural reasoning.

D. Methods and tools supporting the architectural reasoning in the supplier company

In the work with understanding the problem and selecting system issues to solve, the team used several tools and working methods. As the project follows the lean product development process, they are utilizing the **A3 problem-solving tool** [34]. The A3 report follows 6 steps to describe and understand the problem. The team is mainly using the left-hand side of the tool, which contains problem statement, background, current condition, and analysis. In the current condition and analysis, the team utilized simple models and problem-analysis tools to show the cause-and-effect relationship [34].

To gather data the team had a structured **workshop identifying the issues with the system today**. Firstly, they reviewed the functionality of the system before they identified the known issues with the major sub-systems and products. From this the team was able to identify the most important system issue to solve across the products and sub-systems. The outcome of this workshop was a power point slide illustrating the system issues identified in the workshop. To gather experience of how the market perceives the current system offering, the team had several **lessons learned workshops** bringing in key resources from previous development projects and tenders recently executed. These workshops were unstructured conversations, with the purpose of sharing knowledge. No one was documenting these workshops.

To extract the customer needs, the team performed a **market assessment**. Members from the team performed semi-structured interviews with the front-end managers and the system engineers in all ongoing field studies. The outcome from these interviews were a summary map showing all market prospects and data sheets visualizing the key technical data for each of the fields.

As part of the market assessment, the first author introduced **key drivers** to the development team. In all interviews the team was asking the system engineers to identify the top three key drivers for their study. Based on this and the information from the lessons learned workshop, we extracted the top three key drivers for each of the customers. In addition, we were identifying the **customer attitude,** weather they are open for change and willing to accept innovative solutions from the suppliers, or if they are more reluctant to change.

Using a survey, we asked the core team to evaluate how these tools and working methods have support the understanding of the problem and the selection the system issue to prioritize. We also asked the team to evaluate how working as a multi-disciplinary team has supported the reasoning process. Fig. 2 - Fig. 4 are presenting the result from the survey.

From the survey we see that the team is identifying working as a multi-disciplinary team as most supporting in both understanding the problem and selecting system issues. Research has shown that lack of multi-disciplinary knowledge is one of the key issues in conceptual phase. In [23] the authors highlight as an issue that the engineering education discipline oriented and that the engineers do not have sufficient knowledge of other disciplines. We observed that co-location of the multi-disciplinary team contributed to a knowledge sharing across disciplines and supported their understanding of the system. The survey result is supporting this observation, see Fig. 4.

The team is also finding the lessons learned workshops and the workshop identifying issues to be supportive in understanding the problem. This also follows the reasoning that sharing knowledge across domains is key to explore the problem domain. In selecting the system issues to focus on, the workshops get a close to neutral NPS score, which is natural as they are based on qualitative data.

The team is perceiving the market assessment and the key drivers as supportive in understanding the problem. However, looking at the NPS score, these get a close to neutral score. In selecting system issues the market

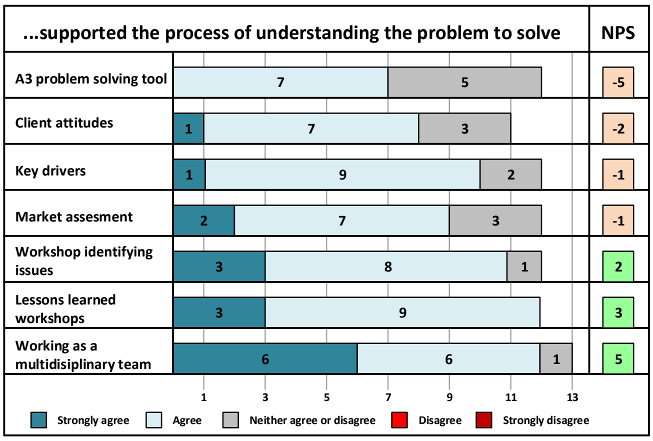

Fig. 1. Survey result - tools and techniques to support the understanding of the problem

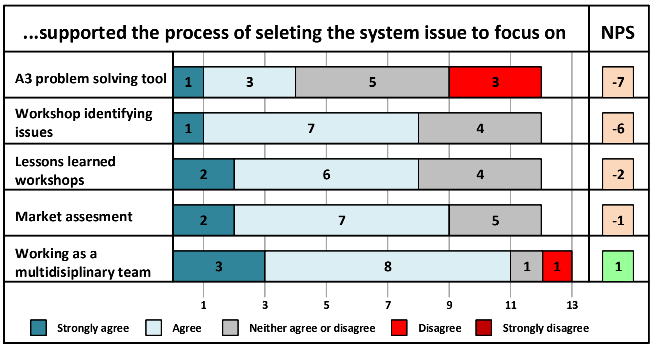

Figure 2: Survey result - tools and techniques to support the selection of system issue to prioritize

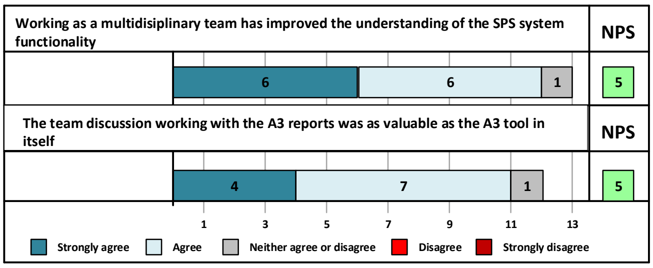

Figure 3: Survey result - general

assessment is among the most supportive, but again it has a close to neutral NPS score. In the daily work, we observed that the team was using the market assessment and the key drivers to communicate outside the team, to explain the reasoning and the decision made in the project to the stakeholders.

The tool getting the lowest score in both phases is the A3 problem-solving tool. This tool gets a poor NPS score, especially for supporting the selection of the system issues. Observations in the team showed that the team struggled to fit their problems into the format of the A3 problem solving tool. However, we observed that the work with the A3 triggered important discussion in the team that was valuable for the problem understanding. The survey result in Fig. 4 is supporting this observation, showing that most of the team members found the discussions when working with the A3 more valuable than the tool itself.

V. Discussion and further work

Architectural reasoning is the capability of developing a systems architecture and exploring and relating the needs and design of a system. Former research reveals the importance of doing architectural reasoning in the conceptual design phase to capture the system needs. The literature identifies several challenges leading to poor design decisions in the early phase. One of the key issue identified are the challenges with communication in multi-disciplinary teams.

The case study showed that the team perceives working multi-disciplinary as a key factor to understand the problem and select system issues. Sharing knowledge between the team members and with other resources in the company, is important to explore the problem domain. The use of informal workshops and discussions support communication and enables the team to understand different perspectives and quickly clarify misunderstandings. The challenge with this communication form, is that the team is sharing the knowledge orally without documenting it properly. As a result, knowledge gained in the discussions is not made explicit to those not involved. This limits the knowledge transfer.

We observed that the team followed a generic workflow for architectural reasoning, similar to those found in literature. But the team did not apply the associated tools and working methods for architectural reasoning. Instead, they choose tools and techniques based on their experiences. The survey showed that none of the tools is good enough to support the team in their reasoning process. The results from the survey and observations in the team shows that the team struggles to quantify the design issues and tension, to make the design decisions. This is coherent with challenges identified in literature, [21] [22] [23].

Systems requirement, design and domain knowledge drive the architectural reasoning process. In the case study we find that working in multi-disciplinary teams are effective to support the reasoning process. However, there is a lack of tools to effectively capture and communicate the architectural knowledge. A3AO, [28], is a tool to support knowledge sharing and it is shown that there are great benefits of using the tool in the oil and gas industry, [29] [30]. Still there are challenges with the use of A3AO, hindering a broader implementation of the tool in the industry, [30]. The case study also shows that it is a challenge to quantify issues and tension in current design, to ensure the development focus on the most important systems issues. The Boderc framework, [21], suggests the use of models and simulations to support this quantification. Reference [29] shows a case where they have implemented conceptual modeling in industry to quantify design issues and extract operational needs. Even though this case shows promising results, there is limited use of such models in the industry. Further work should investigate the use of conceptual models to support quantification of issues and sharing of knowledge in the industry, with the purpose to understand the success factors for implementing conceptual models in the industry.

From the literature review we identified key drivers, [16], as a method suitable for the development project. We introduced this method to the team. In the daily work we observed that the team members used the key drivers, and that it was supporting the communication with stakeholder. Yet in the survey the key drivers got a neutral NPS score. Further work should continue the evaluation of key drivers as a tool in the early phase work and evaluate how to evolve the method to fit the needs of the subsea industry.

VI. Conclusion

The oil and gas industry are immature in implementation of system engineering. This industry often perceives system engineering tools and processes as too formal and time consuming. Research within the oil and gas domain shows great benefits of implementing system engineering, [24]. At the same time, it shows that the industry must adopt the methods and techniques their setting and needs.

Since the downturn in the oil and gas industry in 2010, it has been an increasing focus on developing low-cost solution, "in press" [35]. This have led to a shift in the industry, and the suppliers is getting more involved in the conceptual phase of the development. To accommodate this, the suppliers needs to have processes for supporting the conceptual design phase to explore the design and problem space.

This paper provides a case study of how a major subsea supplier applies architectural reasoning in the early phase of a development project. From the case study, we identify two main challenges in the early phase work. These are sharing architectural knowledge, and quantifying tensions and issues. These observations coincide with the challenges identified in the literature, and other work points at conceptual modeling as a technique to meet these challenges. Future research should explore how the learnings from other industries could be adopted to be successfully implemented in the oil and gas industry.

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