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A Study on Architectural Decision-Making in Context

Iris Groher
Johannes Kepler University Linz
Linz, Austria
iris.groher@jku.at

Rainer Weinreich
Johannes Kepler University Linz
Linz, Austria
rainer.weinreich@jku.at

***Abstract*—Design decisions are made throughout the design process of a new software system or the evolution of an existing system. The context in which a system is developed influences these decisions themselves and the way they are made. There are only a few empirical studies regarding architectural decision-making or concerning how the decision-making process is executed. In this paper, we report an analysis of expert interviews regarding architectural decision-making to gain insight into how decision-making is organized in different organizational contexts. We base our analysis on interviews conducted in a previous study, where we talked to 25 software architects, team leads, and senior developers from 22 different companies in ten different countries about architectural decision-making and documentation. In this paper, we specifically analyze the interview transcripts with regard to the decision-making process. We identified eight different categories of main factors influencing how, when, and by whom decisions are made. We also present decision-making scenarios and relate them to the discovered influence factors. Results show that, apart from organizational factors, individual factors and cultural factors seem to have about the same influence as business and project factors. Company size and domain do not influence the decision-making process as much as one might expect.**

***Keywords*—decision-making process; influence factors; architectural design process; expert survey**

I. Introduction

About 10 years ago, software architecture was defined as the composition of a set of design decisions [1]. Design decisions are made throughout the design process of a new system or the evolution of an existing system. To prevent knowledge vaporization, software architecture knowledge management (SAKM) has emerged as major research topic within software architecture research. SAKM deals with capturing, sharing, and reusing architectural knowledge, including design decisions and their rationale [2].

Design decisions are not made in isolation. Architects work in many different contexts, which impacts not only the decisions themselves but also the decision-making process (when, how, and by whom decisions are made). For example, in a start-up company developing mobile games, the decision-making process might look completely different than in large companies operating in the banking domain. Architects working in an agile environment make their decisions differently from architects working in an organization with strictly defined hierarchies following a plan-driven process.

Other studies have already identified factors that influence design decisions (e.g., [3], [4], [5], [6]). In [3] and [4] the study participants were asked to rate the importance of influence factors identified in existing literature, and they also identified additional factors mentioned by the participants. In [3] constraints on the design, design benefits, and certainty of design were rated highest in terms of usage frequency. What has not yet been explored is how the actual decision-making process is influenced by the context, in which the architect works. Exploring how different context-related factors influence the decision-making process can help to identify best practices for making decisions. The study presented here is a first step towards investigating how context currently influences decision-making and which techniques and practices for architectural decision-making are currently used in practice.

We recently conducted an expert survey with 25 software architects, software team leads, and senior developers from 22 companies in 10 different countries, each more than 13 years of experience in software development on average [4]. In this previous study regarding kinds of design decisions and factors influencing them, we analyzed the interviews with respect to design-decision documentation and classification. We also rated the importance of factors influencing design decisions based on the experts' opinions.

In the study presented in this paper we reanalyze the interview with regards to factors influencing the decision-making process. In particular, we wanted to gain insight into what are potential influence factors for the architectural decision-making process and how decision-making is organized in different contexts. We took as a basis the transcripts of the 25 expert interviews conducted in our previous study and recoded them to obtain information on the architectural decision-making process. For the codification of the interviews, we used a theory-guided approach based on our research questions. After coding all interviews, we performed an in-depth analysis of the results to answer the research questions. This was possible because during the interviews we had asked questions about decision classification and documentation for answering the research questions in our previous study, and we also had asked questions about how, when, and by whom decisions are made for answering the research questions in this study.

The contribution of our work is threefold. Firstly, we identify different categories of potential influence factors on the architectural decision-making process. Secondly, we identify different ways of architectural decision-making in practice by reporting the decision-making scenarios mentioned in the interviews. Thirdly, we present some insights and lessons

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learned from this analysis. In particular, we look at how the identified influence factors relate to the decision-making scenarios in order to explore how the context the architect is working in influences architecting.

The remainder of this paper is structured as follows. In Section II, we present the research objectives and research questions. In Section III, we describe the research approach and the study design. In Section IV, we present the results of the study by answering the research questions. Lessons learned are discussed in Section V. Threats to validity are presented in Section VI. In Section VII, we discuss related work on studies about decision-making in practice and on potential factors that influence it. The paper concludes with a summary of the main findings in Section VIII.

II. Objectives and Research Questions

The main objective of this study is to understand how design decisions are made in practice and how the design process is organized in different contexts. As part of this objective, we first wanted to understand which factors influence the decision-making process and when, how, and by whom decisions are made, depending on the context in which the architect works. In particular, we want to answer the following two research questions:

RQ1: What are potential influence factors for the architectural decision-making process?

The first aim of this study is to gain more information regarding factors that potentially influence the decision-making process. We limit our analysis to factors influencing the decision-making process, ignoring factors potentially influencing the decisions themselves because such factors have already been discussed in previous studies [3] [4].

RQ2: How is the architectural decision-making process organized in different companies?

The second aim of this study is to shed light into when, how, and by whom decisions are made in practice. We identify different ways of architectural decision-making typically used in practice by discussing decision-making scenarios identified in the interviews.

III. Study Design

The study was performed applying qualitative research based on expert interviews [7].

A. Sampling

We targeted software engineers, lead developers, and software architects from different companies in Europe and the United States. In particular, we sought individuals who had more than three years of professional experience in software architecting and development. In total, we interviewed 25 experts from 22 different companies in 10 different countries (Austria, Germany, Switzerland, France, Finland, Czech Republic, The Netherlands, Denmark, UK, and the United States) with expertise in industrial and enterprise software system development. All study participants were male, and all had at least a master's degree in computer science or related fields, such as electrical engineering, mechanics, technical physics, or business informatics. Six participants had a PhD, and 19 participants had a master's degree. In total, the participants had graduated from 20 different universities in Europe and the United States.

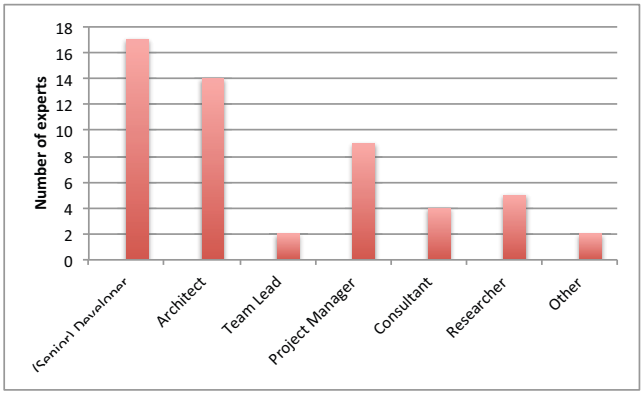

Fig. 1. Roles and Functions of Survey Participants in their Careers [4]

The professional experience of the participants in software engineering ranged from 3 to 27 years, with an average of more than 13 years. They worked in teams of size varying between 3 and 200 developers, with an average of about 35 people involved in their projects. The duration of the projects discussed by study participants ranged from 3 months to 10 years, with an average of 3.8 years. Figure 1 shows the roles and functions the study participants had in the projects they discussed during the interviews. Most people worked as developers and architects, but more than 30% of the participants also had some experience in project management. About 20% of the participants have worked as consultants and researchers at some point in their career; a few have also worked as team leads or had other roles. The study participants have worked in many different areas and domains during their careers: industrial and process automation, enterprise systems, ERP systems, business process management, information systems, embedded systems, real-time systems, web-based systems, service-oriented systems, automotive systems, mechatronic systems, bioinformatics, telecommunications, banking, finance, e-commerce, mobile applications, location-based services, and software development environments.

B. Interview Guide and Interview Process

We conducted the interviews using an interview guide with open questions according to [8]. The interview guide remained the same as in our previous study; it can be found in [4]. It was divided into three parts containing 16 questions. In the first part, we asked the participants about their background and working context, including their education, previous work and projects, and their roles in these projects. The second part contained questions about the decision-making and documentation process. In the third part of the interview, we presented decision categories and decision influence factors from existing literature to the participants and asked them about the frequency and importance of such decisions in their previous projects.

The interviews were conducted personally or via VoIP by the authors and recorded with consent using a Dictaphone or

a VoIP call recorder. The interviews took between 27 and 72 minutes per expert, about 46 minutes on average.

C. Data Analysis

For data analysis, we followed the process model for deductive categorization suggested by Mayring [9]. The data analysis process was performed using the four-eyes principle. In the first step, the data obtained from the interviews are prepared for further analysis. This includes transcribing the interviews from the recorded audio files. About one-third of the interviews were in German (Austrian) dialect and were transcribed by the authors. About two-thirds of the interviews were in English and were transcribed by a professional transcription service. All transcripts were checked for correctness and completeness by both authors.

In the next step, we defined initial categories for the coding of the interviews. We used a theory-guided approach based on our research questions, defining the following main categories: *Who makes decisions?*, *When are decisions made?*, *How are decisions made?*, and *Influence factors*. The category system has been iteratively extended by subcategories during the analytical process. Newly emerging categories and their encoding rules were repeatedly discussed by both authors.

Who makes decisions? This category is used to gather information about the people and roles involved in the decision-making process.

When are decisions made? This category is used to shed light on when decisions are typically made. We collect statements about the development process and about specific points in time when decisions are made or which events trigger decision-making.

How are decisions made? This category captures information about how decisions are made. For example, we were interested in whether decisions are made during discussions with colleagues, during meetings, or based on experiments and prototypes. In this category, we also capture information about whether different kinds of decisions are treated differently.

Influence factors. This category is used to collect different types of factors that influence the decision-making process. During codification, we iteratively extended this category with subcategories to group related influence factors.

The information collected in the Influence Factors category is used to answer the first research question (RQ1). Information from the other categories (who makes decisions, when, and how decisions are made in different contexts) is used to answer the second research question (RQ2).

The third step includes the assignment of codes to the transcribed data through a detailed reading of each interview transcript. In this step, the category system was iteratively revised and refined (deductive categorization). The final category system is thus developed incrementally through multiple feedback loops over the course of coding all interviews. Codification was performed with the MAXQDA toolkit[1]. In total we assigned 655 text fragments to 59 categories. On average, an interview contained 26 assignments.

[1]MAXQDA Tool, http://www.maxqda.de

We analyzed the data within each main category using a combination of summarization and structuring, following Mayring [9]. The summarization step aims to reduce the dataset and is already performed during codification. The result is a list of categories, in which each category contains one or more text fragments from different interviews. We then adapted and restructured the category system within each main category. This structuring step aimed to define common categories from related categories in order to analyze specific aspects such as the influence factors for decision-making.

IV. Study Results

We discuss the study results with respect to the two research questions presented in Section II. First, we present and discuss the identified potential factors influencing the architectural decision-making process, thus addressing RQ1. Next we report the different decision-making scenarios identified in the interviews, thus addressing RQ2. We present the statements made by the experts in italics to distinguish them from our interpretation.

A. RQ1: Influence factors

We grouped the potential influence factors we identified into eight main categories: *Company Size*, *Business Factors*, *Organizational Factors*, *Technical Factors*, *Cultural Factors*, *Individual Factors*, *Project Factors*, and *Decision Scope*. The main categories and their subcategories are depicted in Figure 2. Below, we describe these categories in more detail.

1) Company size: As part of our interviews, we collected general information regarding the work context of the study participants. This included the size of their companies in terms of the number of employees. Since larger organizations typically require a more complex structural organization and also often have standardized processes in place, this may also impact the organization of architectural decision-making processes. For example, study participants stated that *decision-making depends on the company. In the startup everybody makes decisions, in the software vendor the project teams make decisions, and in big companies architects and managers make decisions*.

In general, 29% of the companies mentioned were small-sized companies (up to 50 employees), 19% were medium-sized companies (up to 250 employees), and 54% were large-sized companies (up to several thousand employees). In cases where study participants had worked for several companies of different sizes during their career, we related each of their statements to the respective size of company.

2) Business factors: In this category we collected all factors related to economic considerations. All in all, 11 study participants (44%) made statements assigned to this category, which we organized into the four subcategories *Business Domain*, *Business Model*, *Cost/Risk/Time to Market*, and *Strategy*.

The participants in our study have operated in many different business domains, such as medical systems, automotive systems, industrial and process automation, and enterprise systems (cf. Section IV). In some domains, constraints such as available resources (e.g., CPU power, network connectivity) have to be considered during the decision-making process.

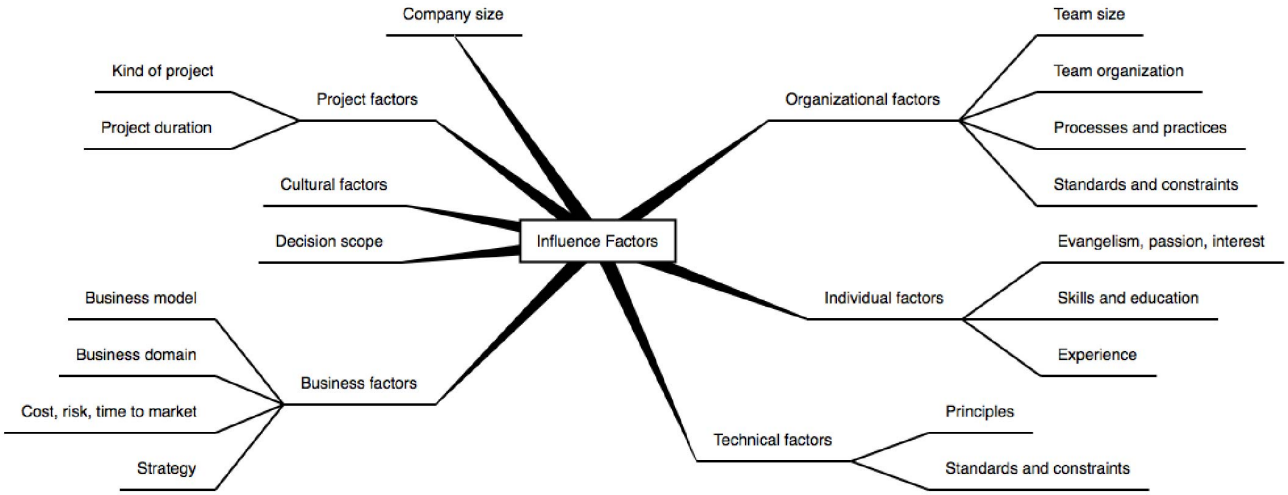

Fig. 2. Identified Influence Factors

Regulatory requirements were also mentioned by experts working in the medical and in the banking domains. One expert stated that *regulatory requirements are aggressively pushing them*. Compliance rules were also mentioned in this context. The business domain may also have an influence on the number of people involved in the decision-making process. One expert stated that *when developing enterprise systems typically more people are involved, which requires more communication, explanation, and education*.

Some statements related to companies' business models. For example, one expert working for a company selling customer-specific solutions reported that *his company competes with companies selling out-of-the-box solutions*. The company is doing green-field developments over and over again and thus *has to be more cost effective than other companies*. This specific situation and the relation to other competitors in the same domain leads to cost analysis being an inherent part of the decision-making process. Another expert mentioned that business value in their case is defined *by products and parts of products that can be sold individually*. Therefore, only specific parts of the product portfolio are allowed to depend on each other. Teams are responsible for different products; interfaces between products are *managed by the platform team*, which influences decision-making.

Several experts mentioned cost, risk, and time to market as important influence factors. For example, one expert working for a large company stated that, in their company, *everything is driven by risk and cost*. Therefore, risk analysis is performed as an inherent part of the decision-making process. Risk analysis was also mentioned several times by experts working in the medical domain. Sometimes risk assessments are performed to rate the risks of *new technologies or dependencies to external systems*. Different types of costs were also discussed during the interviews. Implementation cost in terms of developer days, whether specialists have to be consulted, and capital costs (in make-versus-buy decisions) have all been rated as important drivers of the decision-making process. Consulting external specialists influences the team organization and thus how decisions are made. Time was mentioned several times as a driver of decision-making. One expert stated that *they are constantly driven by time to market*. Time constraints may lead a team to follow an agile development process, which in turn influences the decision-making process.

Finally, one expert mentioned *IT strategies and guidelines such as focusing on processes* as important. Establishing defined processes in an organization often also includes guidance regarding how, when, and by whom decisions are made. In this way, the strategies followed with respect to introducing processes can influence decision-making.

3) Organizational factors: In this category, we collected all factors related to team organization. It is quite obvious that organizational structures and processes influence how decision-making is organized. We collected statements from 24 study participants (96%) in this category, organizing them into the four subcategories *Team Size*, *Team Organization*, *Processes and Practices*, and *Standards and Constraints*.

Several study participants mentioned team size as an important factor influencing how and by whom decisions are made. In small teams, decision-making is often a group effort. One expert mentioned that *important decisions are typically discussed in the whole team. Ten people is not that many so everybody in our team takes part in architectural decision making*. It has also been reported several times that in small teams ad-hoc meetings are arranged whenever important design problems arise. Larger teams often require dedicated roles that are responsible for guiding the decision-making process. For example, one expert stated that *depending on the size of the project, different roles responsible for architectural decisions are included*. Another expert mentioned that *the bigger the team, the more important communication and documentation becomes*. Knowledge transfer and documentation is an issue especially in large teams, which might lead large teams to implement a more formally defined decision-making process.

Global distribution of teams seems to negatively affect decision-making because this makes it harder to communicate

and thus reach a consensus. One expert stated that *how distributed and global the team is influences decision-making. If you can do things at one site, this will lead to better designs*. Also, accessing decision documentation seems to be an issue for globally distributed teams. One expert reported that *people from the other end of the world have to explicitly ask for permission to access decision documentation*. Such restrictions also negatively affect decision-making. Also, the inclusion of external people influences the decision-making process, because communication is harder and availability is often an issue. Formal structures, strict hierarchies, and distinct roles within an organization influence how and by whom decisions are made. One expert stated that in his organization *people have roles and job titles and are assigned to projects, which comes from management*. One expert reported that in his organization *the chief product owner is responsible for taking all architectural decisions*.

It is no surprise that the development process followed by a team largely influences how decision-making is organized. Many experts (80%) reported that they follow an agile process, with daily stand-up meetings and retrospectives. One expert stated that his team *is living in the world of sprints*. Many decisions are made during the daily meetings whenever design problems arise. Some experts reported that they follow a waterfall-like process, in which design decisions are made during a design phase before the actual implementation. Agile decision-making is much more flexible than designing the system up-front. One expert reported that in his organization, *quality gates are established where the architecture is verified*. Another expert mentioned *councils, which look at the architecture for quality reasons*. Such reviews influence the decision-making process, because they typically require decisions and their rationale to be thoroughly documented.

Finally, decision-making is sometimes influenced by company standards. One expert stated that his company *is very document-driven. Before starting to make any change to the software, the impact of the change has to be documented*. Such standards require an in-depth analysis of the consequences of each decision.

4) Technical factors: In this category, we collected all factors related to the technical realization of the system under development. In total, we collected statements from 7 participants (28%) in this category, which we organized into the two subcategories *Principles and Standards* and *Constraints*.

Working with frameworks could influence decision-making. One expert reported that *since we were working with Eclipse, the Eclipse spirit was present in our daily work*. Another expert mentioned that *working with the newest technologies was important to stay future-proof*.

Some organizations have principles in place that also influence decision-making. One expert said that *our principle is to always stay compatible; there is no breaking of interfaces*. Another expert stated that *our key principle is separation of concerns*. Another principle mentioned was that *the code is self-documented and the use of elaborated comments is discouraged*.

Company standards also guide the decision-making process. One expert stated that *it is obvious that within the company if a certain platform is used or a certain way of deploying applications is done, you cannot do it differently*. Another expert mentioned that product standards at his company contain different "dos" and "don't dos." In some domains, industrial standards are important. The IEEE standard and ISO certification have also been mentioned in this context.

5) Cultural factors: This category groups influence factors related to the culture established in the team or organization. We assigned statements from 10 experts (40%) to this category.

Several experts talked about the level of freedom that is given to the people in their team or about how democratic their organizations are. One expert stated that his organization *was always very liberal about making decisions because we knew that at least some of these decisions could be easily reverted if they don't work. We can always experiment, try things, tune things, and improve things later*. This was in line with the statement from another expert that *they are a learning organization and not a dogmatic one*. Another expert reported that *their philosophy is to constrain people as little as possible and to push the decision-making as far down in the hierarchy as possible*. A high degree of freedom impacts the decision-making process because people are allowed to make as many decisions as possible themselves; only a few, high-impact decisions are escalated in the hierarchy.

One expert called his organization a *consensus-driven organization*. This means that decisions are mostly discussed as a team until everybody agrees upon a solution. One expert reported that *if the decision is good for the team, the customer, and money-wise then you just do it*. This simple constraint also fosters a non-bureaucratic decision-making process.

Regarding the level of documentation, one expert reported that *they do not want to over-document things*. This is in contrast to what was reported by another expert. His organization seems to be very *document-driven. Before making a change, the impact of the change has to be documented*. Documenting decisions beforehand requires an impact analysis as part of the decision-making process. Less documentation, by contrast, fosters more ad-hoc decision-making.

Other interesting statements were made regarding the distribution of work. One expert said that *if required we just hire consultants; the actual development is performed by a large number of developers in India*. The inclusion of external people and globally distributed teams was already discussed as an influence in the *Organizational Factors* category.

Finally, internal political factors sometimes drive the decision-making process. One expert reported that in his organization, *teams are responsible for components and the more often a component is included in a product, the more important the team is*.

6) Individual factors: This category groups influence factors related to the individual preferences or biases of certain individuals in the team. We assigned statements made by 11 experts (44%) to this category. We divided this category into the three subcategories *Evangelism, Passion, Interest*; *Skills and Education*; and *Experience*. Sometimes people influence the decision-making process because their opinion is respected by the others. One expert said that *one does not have to deal with designs from scratch all over again because if you have experience you use what you have and people will accept that*.

The *Evangelism, Passion, Interest* subcategory refers to development practices that someone favors. One expert stated that he *spreads his passion for domain-driven design and related practices*. *Passion for building DSLs* was also mentioned. One of the experts stated that *his role in the organization was to bring ideas from research into design*. One example mentioned in this regard was aspect-oriented software development. In one organization, a codex has been developed containing a list of guidelines defined by the architects. The goal is to explain to developers how architects think in order to support the decision-making of the developers. The passion of a whole group of people can also drive the decision-making process. One expert reported that *it was a hobby of the team to apply as many patterns and industry standards as possible*.

Some experts mentioned that the decision-making process is greatly driven by the *skills and capabilities of the team members*. Qualifications gained through regular training also influence the way decisions are made.

Experts mentioned that experience with different platforms led individuals to drive the decision-making process in certain directions. Interestingly, one expert stated that the fact that *he was the oldest team member made him a respected person in the team*. Some team members seem to know best what the customer expects, whether because of direct contact to the customer or a gut feeling. These people greatly influence the decision-making process. Knowing alternatives is a prerequisite for any decision-making. Experienced people often know more alternatives and thus drive the way decisions are made.

7) Project factors: In this category, we collected all factors related to characteristics of a project. In total, we collected statements from 12 participants (48%) in this category, which we organized into the two subcategories *Kind of Project* and *Project Duration*.

Our interview partners discussed the different kinds of projects on which they worked. One expert was part of a platform development team, which made decisions together with lead architects and teams using the platform. Two experts were involved in open-source projects in which architectural decision-making is a group effort together with the lead developers of the project. Other project characteristics that were mentioned related to external people involved. In this context, one expert reported that *usually we are working very closely with the customer*. In this case, the customer was involved in the decision-making process, which required additional communication and documentation. Another expert worked in a project where *many subcontractors were involved who did not invest in updating the wiki in which decisions were documented*. Here, external organizations were involved in the decision-making, which seemed to complicate the process. Several experts mentioned green-field or brown-field developments when reporting about their experience in decision-making. One expert working in green-field projects mentioned that *the system was brand new and the team had control over their decisions*. Another expert involved in brown-field projects reported that *when changing existing systems you need to work in alignment with the existing design decisions*. It was also mentioned that *when developing similar projects again and again, many important decisions can be reused and people know what to do*.

Experts also reported on the duration of their projects. They worked in projects lasting from several months up to ten years. One expert reported that he likes *one-year projects because they allow us to start something fresh and to give new experiments a chance*. This relates to the other statements made about green-field projects. Other experts worked in projects lasting several years that have a long lifespan. In such cases, alignment with existing decisions is part of the decision-making process.

8) Decision scope: In this category, we collected statements related to decisions' impact. We assigned statements made by 16 experts (64%) to this category.

The scope and impact of a decision influences how, when, and by whom the decision is made. In our previous study [4] we reported on the differences between design and architectural decisions. Out of the 25 experts we interviewed, 20 said that there is a difference between design decisions and architectural decisions. The main difference mentioned by the participants was the impact of a decision. In this study, our analysis found that the difference between design and architectural decisions also influences the decision-making process. One of the experts who had the role of a lead architect reported that *everybody in the team can take design decisions but with architectural decisions, I keep a hand on them because they spread further*. This accorded with the statement of another expert who said that *the development team itself is not involved in deciding architectural questions*. In some organizations, dedicated roles are responsible for high-impact decisions. One expert reported that, in his organization, *they have dedicated architects if it really goes on the system level; if the decision is limited to a collection of subsystems, that falls under the responsibility of the lead designer*. Decisions that impact multiple teams are sometimes also made by a group of people. One expert mentioned that *if the decision has an impact on multiple teams, the platform team deals with those kinds of decisions*. In organizations with small teams and flat hierarchies, the impact of a decision typically influences the number of people involved in the decision-making process. One expert working in such a context reported that *architectural decisions deserve a broader audience, not just a few people, and maybe the whole team*. In general, many participants mentioned the fact that *in case of high-impact decisions you have to communicate better and you have to communicate with more people, including also non-technical people*. This may require a more formalized, controlled, and documented decision-making process.

B. RQ2: Decision-making process

1) Who makes decisions?: Analyzing the statements related to who makes decisions reveals that decision-making is to a large extent a group effort. It is very common for potential solutions and their alternatives to be discussed among team members. A suitable solution is selected by either a team, which discusses and evaluates alternatives in the team until a consensus is reached or one dedicated person has the final saying.

Who makes decisions mostly depends on the scope of the decision. One expert reported that *the impact is the distinguishing thing*. In case of high-impact decisions either

more people are involved or a person with a dedicated role (e.g. architect, technical lead) is consulted. One expert reported that *the decisions that have a big impact are typically discussed in the whole group, everybody takes part in architecture decisions in our team*. On the contrary, another expert reported that *it is the architect that is responsible for architectural decisions, the development team is not involved in such decisions*. It is also possible to combine both approaches. One expert mentioned that *it is the architect that proposes a solution but the team decides at the end*. Low-level decisions are typically taken by a single developer or a small group of developers. One expert reported that *everybody in the team can take design decisions but typically one needs somebody else to discuss the decision with. Usually two or three team members discuss those kinds of decisions*.

Two experts reported that who can make architectural decisions depends on the capabilities of the team. Both experts were working in organizations with a small team of highly qualified people. One of the two experts reported that *they have a very sophisticated hiring process*. In such an environment probably everybody is capable of taking architectural decisions.

In total, 17 out of 25 experts (68%) reported that the team decides together on architectural decisions. The other experts (32%) reported that in their organizations they have dedicated roles in place that are responsible for architectural decisions. All experts reported that low-level decisions can be taken by the developers. In this context, one of the experts reported that *as long as they have documented their rationale, the way they go is their decision*.

2) When are decisions made?: Analyzing the statements assigned to when are decisions made revealed that decisions are either made ad-hoc as reaction to a design problem or at defined points in the development process. One expert reported that *at the beginning of each sprint we usually think about architectural decisions or we retake architectural decisions*. In such cases, architectural decisions are mainly taken during dedicated meetings or workshops. On the contrary, another expert reported that *there are no specific points in the process when we make architectural decisions, they are made all along the way*. In such cases, architectural decisions arise during discussions and are also taken during those discussions. Another expert reported that *there are mostly ad-hoc meetings whenever developers feel the need to discuss something. If we know there is a huge problem we just schedule a meeting, which is also pretty ad-hoc*. Making decisions in dedicated phases of the development process is of course largely influenced by the kind of development process followed.

The survey participants either follow an agile approach or a more waterfall-like process. In total, 5 out of 25 experts (20%) reported that their organization follows a traditional plan-driven development process. The other experts (80%) reported that they follow an agile approach in their organization.

3) How are decisions made?: How decisions are made is of course related to who makes decisions and when decisions are made. Analyzing the statements of the experts related to how decisions are made revealed that decisions are sometimes made according to a plan. One expert reported that *every year a high-level plan is made about which applications use which technologies and platforms*. It has also been mentioned during the interviews that architecture boards are installed in some organizations. Different department heads are part of such a board and make important strategic architectural decisions during their meetings. For critical architectural decisions technology evaluations are sometimes performed. The result of such an evaluation is a document that compares the features of a certain technology or platform to support the decision-making process. Architectural reviews performed with methods such as ATAM for scenario-based architecture evaluation are also applied during the decision-making process. Such methods are applied to evaluate different candidate architectures or different scenarios for system changes. One expert reported that *this is performed for bigger architectural decisions*.

Discussions as a way to evaluate different options have been mentioned often by the experts. One expert reported that *we discuss all the ideas that come around, the one that wins is the one we will go with. We discuss until everybody understands or believes that the chosen solution is the best one*. This is a very consensus-driven way of making architectural decisions and often performed in small teams.

Experiments and prototyping has also been mentioned several times by the experts. One expert reported that *sometimes we are not quite sure where to go architecture-wise so we have to try something out. Unfortunately this is something a customer does not want to pay for*. Whether prototyping is used heavily is also a question of the culture of the organization. One expert mentioned that in his organization *we could always experiment and try thing and improve things later*. Prototyping has been mentioned as important if a consensus cannot be reached. In these cases the alternatives are prototyped and evaluated later on. In general, the experts reported very positively about the possibility of doing prototypes if people cannot agree on a solution upfront. In this context one expert mentioned that *prototyping is more powerful than just reviewing things upfront*. Another expert said that *design is strongly influenced by how much time you spend to make an informed decision*. It has also been reported that for critical decisions that have an impact on system performance up to a week is spent for developing a prototype.

V. Discussion

In this section, we present some lessons we learned from our study regarding architectural decision-making in practice. In particular, we look at how the influence factors we identified (cf. Section IV) relate to each other and how the context in which the architect works influences architecting.

Analyzing the development processes used by the study participants at work, shows that 80% of the participants work in an agile environment instead of a traditional plan-driven (e.g., waterfall-based) environment. Thirty percent of the companies were small (partly start-up) companies, while more than 50% of the companies were large companies. This shows that both plan-driven (partly waterfall-like) and agile processes were used at companies of all sizes. Larger companies typically had additional structures and roles in place to coordinate different agile teams and to escalate architectural decisions that cross team boundaries.

Ad-hoc meetings for architectural decision-making seem to be the predominant form of decision-making in agile teams. Meetings are arranged as needed and can be initiated by any team member. Often, such meetings evolve through the issues that "pop up" repeatedly in the daily stand-ups of agile teams. Typically, the whole team then discusses the design problem (group decision-making) until a consensus is reached. This approach seems to work quite well with educated and experienced people.

It is also interesting that education and experience in general greatly influences the decision-making process. On the one hand, several participants mentioned trusting people with experience. This may lead to some design alternatives not being discussed at all. During the interviews, it was mentioned that *you have to know that there are alternatives; otherwise, you do not even realize that you are making a decision*. Considering this statement, the more educated and experienced people become, the more complex decision-making can get because more alternatives might have to be considered. This matches a study conducted by Tofan et al. [10] which showed that the actual time junior architects spend on making a decision is only one quarter of the time spent by senior architects. Tofan et al. speculated by way of a possible explanation that senior architects deal with higher-impact decisions than do junior architects. In our study, the participants mentioned that senior architects typically consider more alternatives, which could be another reason why senior architects spend more time on decision-making.

Decision ownership is a concept that is often used in both agile and process-oriented environments. This means that one person ultimately makes a decision and thus owns it. In agile teams, this is typically the person who also raised the issue and took it to the group for discussion. The decision owner is the person who can be consulted later for the rationale of the decision. However, this typically requires equally high education and experience throughout the team, and it also requires that the team be somewhat stable over time. In larger organizations, decisions are owned by different people throughout the organizational structure of the company. The larger the scope of a decision, the higher the ownership of a decision is escalated through the organizational structure.

About 20% of participants worked in organizations with installed plan-driven development processes and organizational structures. This choice seemed to be mainly influenced by company culture, tradition, and education of people rather than company size, project size, or domain. For example, clearly defined processes and roles were mentioned in the enterprise systems domain, though there were also people working in an agile context in this domain. While such organizations are often process-oriented and document-driven, the reasons for this have been more argued through education of people and turnover of staff than through company size and/or domain. But even if defined processes for decision-making and documentation are in place, this alone may strongly influence the decision-making process, as illustrated by a statement of one of the study participants, who stated that *revealing too much about a decision can make trouble because you have to spend a lot of time justifying your decision. A solution is often to simply present a plausible design and discourage the discussion of alternatives*. This shows that the idea of having a defined decision-making process in place, which requires the explicit documentation of decisions, their rationale, and alternatives, may actually be a hindrance for the consideration of different alternatives and thus may discourage an open reasoning process.

If we look at the influence factors distilled from the statements provided by the participants (shown in Figure 2) it is interesting to note that there is an equal distribution over most of the main categories in terms of the number of participants that provided statements in a specific category. For example, cultural and individual factors were mentioned by an equal number of participants as were business factors and project factors (about 40-50%). Technical factors were mentioned by about 30% of the participants. This means that individual factors and cultural factors seem to have about the same influence as business factors (cost, business model, business domain, etc.) and project factors (green-field, brown-field, open source, customer involvement, subcontractors, etc.).

The influence of technical, cultural, and individual factors also became apparent when analyzing the interviews and interpreting the rationale provided by participants (in addition to counting the number of participants mentioning a particular influence factor). This means that education and experience, and also biases like passion, evangelism, personal preferences of the people in charge, and company values, influence how architectural decision-making is performed within an organization. In our previous study [4] we showed that individual factors influence the decisions themselves, and we argued that mechanisms for reducing bias in decision-making are required, as proposed by other authors (e.g., [11] [12]). In this case, we argue that these factors need to be taken into consideration when establishing the decision-making process itself. In the simplest form, this can be achieved by making decisions and their influence factors explicit.

Business and project factors (and some organizational factors), on the other hand, could be used to establish a list of best practices for organizing the decision-making process under different conditions. Examples include decision-making in the context of green-field or brown-field projects, in a distributed project setting, and decision-making with external stakeholders. Some of the identified practices described as part of our study could be a starting point for such a best-practice catalog.

We should note that, so far, we have largely ignored the category of organizational factors shown in Figure 2. About 96% of participants mentioned existing organizational structures and processes as an influence factor, but we think it is rather obvious that established organizational structures and processes influence the decision-making process. Thus, we discussed some of the aspects of this category in the context of agile and plan-driven development processes. Other aspects, like turnover of staff, number of people, and people's education were also discussed in other contexts.

Finally, factors related to the decision itself, especially the decision scope, are a major influence factor. Statements related to this category were mentioned by about 65% of the study participants. This is not surprising, since the decision scope is directly related to organizational units and responsibilities/roles. Thus, scope has to be considered when planning

decision-making processes, regardless of the other influence factors discussed above.

VI. Study Validity

Gasson [13] proposes criteria such as confirmability, dependability/auditability, internal consistency, and transferability to evaluate research rigor and quality in involving qualitative research methods. Various techniques for ensuring these criteria have been proposed [13], [14]. For example, confirmability can be addressed by using reflexivity to reduce subjectivity, making assumptions and frameworks explicit, documenting the rationale underlying the constructs used, and getting feedback on research results. Dependability/auditability can be addressed by establishing clear and repeatable procedures for the research process and by making the process explicit (through documentation). Internal consistency can be achieved by comparing different views on the same data and by explaining from which data the constructs discussed are derived. Finally, transferability requires an explicit description of the context of a study, including such detail as the education and background of participants, in order to judge the applicability of the results to other contexts.

We addressed confirmability by repeatedly discussing and restructuring the identified categories. In terms of dependability/auditability, we followed a standardized research process (cf. Section III) and used approved methods for data analysis, such as the qualitative content analysis method as described by Mayring [9]. Internal consistency was addressed by having two senior researchers cross-check and discuss the assigned statements. Finally, transferability was addressed by capturing and describing the background of the study participants.

Our study has the following shortcomings. The interviews we conducted were originally targeted towards design-decision documentation and classification. As we used open questions during the interviews and also asked questions about how, when, and by whom decisions were made, we were able to analyze the interviews to examine the decision-making process and how this process is influenced by the context in which the architect is works. Similar to many qualitative studies, we have a limited sample. This is acceptable from our point of view, since our main aim was to identify potential factors that influence the decision-making process, not to evaluate existing knowledge. To ensure transferability, we interviewed 25 experts from 10 different countries, with at least a master's degree from more than 20 different universities. The experts have worked at 22 different companies and had on average over 13 years of professional experience in software engineering.

VII. Related Work

This study is related to others in the field of architectural decision-making. We specifically consider here studies on decision-making in practice.

Van Heesch and Avgeriou [15] performed a survey with 53 software architects to find out how architects reason in their projects. They asked how architects propose architectural solutions and how they select those different solutions. The first important difference with our study is that we used open questions during our interviews, as opposed to the use of a web-based questionnaire in [15]. The questionnaire provided predefined answers for each question, while in our interviews the experts talked freely about their experiences with architectural decision-making. The study participants in [15] reported that during design they usually search for different design options and also think about the pros and cons of each option. This is confirmed by our study. What was not looked at in [15] is how the actual decision-making is influenced by different context-related factors. This is an important contribution of our study.

Tang et al. [16] conducted a controlled experiment with software designers to gain insight into how decisions are made during design. In particular, they looked at how the application of different reasoning and decision-making approaches influences software design effectiveness. Design effectiveness in this case is defined as requirements coverage and design-time utilization. The study found that proper planning of design discussions improves the identification of design issues and facilitates the search for solutions. The participants in our study rated ad-hoc meetings as very effective. In small teams working in an agile environment, planning design discussion in advance does not seem to be an established practice. However, the rating in our study was purely subjective; participants reported their own practice in contrast to the measures of effectiveness as performed in [16].

Falessi et al. [17] conducted a study to assess the characteristics of existing decision-making techniques. The techniques were ranked according to the degree of difficulty that architects may encounter when employing a specific technique. The goals of the survey was to support software architects in choosing among existing decision-making techniques based on the difficulties they want to avoid. Our study analyzes the context in which architects operate and also the potential difficulties with which they are faced. We describe how, when, and by whom decisions are made, but we do not analyze existing decision-making techniques from the literature.

Group decision-making has been studied by Rekha and Muccini [18]. They performed a questionnaire-based survey with 30 participants to gain insight into how practitioners make group decisions and to understand the challenges they face in this context. The study revealed that group decision-making is typically a process of discussion involving all stakeholders with intervention from management if required. Structured approaches to group decision-making are not commonly used in practice. This is also confirmed by our study. Interestingly, Rekha and Muccini reported that most groups arrive at a win-win situation with consensus through collaboration. In our study, two participants explicitly mentioned their dissatisfaction with the compromises that are often the result of group decision-making.

A survey with 43 architects from industry conducted by Tofan et al. [10] analyzed the difficulty of making architectural decisions. According to Tofan et al., dependencies between decisions as well as the effort required to analyze decisions contribute to their difficulty. The study also revealed that 86% of architectural decisions are group decisions. The importance of group decision-making was also confirmed by our study.

Finally, Boehm and Turner [19] identified and discussed different factors influencing the selection of a specific development methodology (in the context of agile vs. plan-

driven development processes). They list personnel, criticality, dynamism, culture, and size as primary factors. While they did not look specifically at architectural decision-making, some of their findings, like the influence of personnel and culture, are also reflected in our study.

VIII. Conclusions and Future Work

To gain better insight into the practice of architectural decision-making, we reanalyzed the interview transcripts of a previously conducted expert survey in practice. The survey was performed with 25 software architects, software team leads, and senior developers from 22 different companies in 10 different countries. As a result, we gained important insights into how decisions are currently made in practice in different organizational contexts and which factors influence architectural decision-making.

We identified eight categories of factors influencing the architectural decision-making process. Apart from organizational factors, which obviously influence the decision-making process, we found that individual and cultural factors seem to have about the same influence as business and project factors. Company size and domain are not as influential as one might expect, especially regarding the development process in use. Agile processes are applied in companies of various sizes. In certain domains (e.g., medical systems) there are often dedicated activities in place (e.g., risk analysis), but decision-making itself does not seem to be strongly influenced by the domain.

We also identified different scenarios of how, when, and by whom decisions are made in different organizational contexts. Our study revealed that most participants (80%) work in an agile environment. Within their responsibilities, developers are mostly free to make decisions. For high-impact decisions, either more people are involved in the decision-making process or people with dedicated roles and responsibilities are consulted.

The insight we gained regarding how, when, and by whom architectural decisions are made in practice provides valuable input for our own work concerning decision capturing and decision-making support. Group decision-making and the concept of decision ownership are widely used in practice. Our study showed that the context in which an architect works influences decision-making. It might thus be beneficial to provide context-specific decision-making support.

Finally, additional research is necessary to understand how to better support architects during decision-making processes. Also, the documentation of the design decisions made during these processes requires support. In our previous study [4] many participants mentioned various problems related to a failure to document architectural decisions. Best practices regarding decision-making under different circumstances could support practitioners in systematically identifying and evaluating architectural alternatives. This study provides a first step in this direction by identifying important factors and practices for decision-making in different contexts.

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