

Strategy-focused architecture investment decisions

Citation for published version (APA):

Ivanovic, A. (2011). *Strategy-focused architecture investment decisions*. [Phd Thesis 2 (Research NOT TU/e / Graduation TU/e), Industrial Engineering and Innovation Sciences]. Technische Universiteit Eindhoven.
<https://doi.org/10.6100/IR708956>

DOI:

[10.6100/IR708956](https://doi.org/10.6100/IR708956)

Document status and date:

Published: 01/01/2011

Document Version:

Publisher's PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

- A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
- The final author version and the galley proof are versions of the publication after peer review.
- The final published version features the final layout of the paper including the volume, issue and page numbers.

[Link to publication](#)

General rights

Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the "Taverne" license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy

If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Strategy-focused architecture investment decisions

Ph.D. thesis

by

Ana Ivanović

Part of this research has been carried out under the DARWIN project at Philips Healthcare, which runs under the responsibilities of the Embedded Systems Institute (ESI). The DARWIN project is partially supported by the Dutch Ministry of Economic Affairs under the BSIK program.

Copyright © 2011 by Ana Ivanović
All rights reserved. Reproduction in whole or in part is prohibited without the written consent of the copyright owner.

A catalogue record is available from the Eindhoven University of Technology
Library

ISBN: 978-90-386-2452-5

Printer: Eindhoven University Press

Cover design: Henny Herps

Strategy-focused architecture investment decisions

PROEFSCHRIFT

ter verkrijging van de graad van doctor aan de
Technische Universiteit Eindhoven, op gezag van de
rector magnificus, prof.dr.ir. C.J. van Duijn, voor een
commissie aangewezen door het College voor
Promoties in het openbaar te verdedigen
op donderdag 24 maart 2011 om 16.00 uur

door

Ana Ivanović

geboren te Kragujevac, Servië

Dit proefschrift is goedgekeurd door de promotor:

prof.dr. C.C.P. Snijders

Copromotor:
dr. P. America

A catalogue record is available from the Eindhoven University of Technology
Library
ISBN: 978-90-386-2452-5

Table of Contents

Part I: Challenges	1
1 Introduction	3
1.1 Motivation.....	3
1.2 Research challenges	5
1.3 Goal of the thesis.....	7
1.4 Thesis overview.....	9
2 Literature	11
2.1 Introduction.....	11
2.2 Methods for decision making on architecture investments	12
2.3 Information use of experts in decision making.....	17
2.4 Strategic vs. architecture decision-making.....	18
2.5 Conclusions and research questions.....	22
3 Practical challenges in architecture investment decision making: a business case at Philips Healthcare	25
3.1 Study design.....	26
3.2 Case: Phase out legacy at Philips Healthcare	28
3.3 Study 1: The legacy phase-out decision by the expert team	30
3.4 Study 2: The legacy phase-out decision by applying the real options way of thinking	37
3.5 Practical challenges to support architecture investment decisions	46
3.6 Conclusions	47
Part II: Information	49
4 Information needs of architects and managers for architecture investment decisions	51
4.1 Study design.....	52
4.2 Step 1: A preliminary set of information	54
4.3 Step 2: Frequencies of information needs by architects and managers.....	56
4.4 Step 3: A comparative analysis on information needs by architects and managers.....	58
4.5 Step 4: Discussion.....	62
4.6 Conclusions	64
5 Drivers of architecture investment decisions: business and individual perspectives.....	65
5.1 Study Design	66
5.2 Measurements	71
5.3 Results.....	72
5.4 Discussion and Conclusions.....	78
Part III: Best practices	81
6 Modeling customer-centric value to support architecture investment decisions.....	83
6.1 Study design.....	85

6.2	Study 1: Customer value-in-use	87
6.3	Study 2: Customer segments	94
6.4	Discussion and conclusion	100
7	Strategy-focused architecture investment decisions: A real-world example	105
7.1	Introduction	105
7.2	Strategy-focused architecture (StArch) method to support investment decisions	107
7.3	StArch: A real-world example	112
7.4	StArch evaluation	122
7.5	Discussion and Conclusions	124
Part IV: Conclusion and appendices		127
8	Conclusion.....	129
8.1	Focus and approach	129
8.2	Summary of main findings.....	131
8.3	Discussion	134
8.4	Future lines of research.....	137
Appendix A: Interview format		139
Appendix B: Case descriptions: automotive and consumer electronics.....		141
Appendix C: Data and analyses		145
Reference list		149
Summary		157
Acknowledgements		161
Curriculum vitae		163

PART I: Challenges

1 Introduction

Organizations have been investing in the development of software-intensive systems, such as medical devices, airplanes, or satellite systems, for decades. Over time, these systems become complex and unique, making them hard to imitate by competitors. They develop into crucial assets of an organization. Continuous quality improvements of these systems are critically important for a company's competitive advantage on the market and for business success. Investments in these system-quality improvements are called architecture investments. Architecture investments have a strategic importance because they are large, risky, and lengthy with long-term benefits spread across an organization and different products. To make a successful investment decision, the organization asks an expert team to evaluate architecture. In this process, the expert team challenges the architecture solution to maximize utilization and to create the most value over its lifetime.

Nowadays, a decision on architecture investment is treated like any other development investment in the organization. An expert team, which consists of architects and business managers, evaluates architecture to support architecture investment decisions. The system architect, who creates architecture, provides a proof-of-concept on how quality improvements meet the business goals, while business managers attempt to assess business consequences of these quality improvements. This implies a cost benefit analysis that is not straightforward in industrial practice. While costs of architecture investments are routinely calculated using established cost models, benefits of quality improvements are difficult to identify and quantify. A common approach to estimate benefits of architecture changes is by using quality scores. Quality scores are sufficient to compare architecture alternatives, but not to decide on architecture investments based on the business value creation. Therefore, there is an urgent need for a systematic evaluation with business indicators in mind, such as sales, customer satisfaction, cash flow, or revenue. Without a systematic method to guide decisions based on business value, a decision is driven by the anecdotes and personal preferences of deciders. Such decisions, driven by personal rather than business incentives, are sub-optimal for an organization's success.

In this chapter we explain in more detail this need for developing a systematic approach to evaluate system architecture to support an investment decision, which is driven by business goals rather than personal preferences. Then, we elaborate on research challenges in the literature to support architecture investment decisions. Based on the research challenges, we define the goal of the thesis and highlight the main research contributions. Finally, we present an overview of the thesis to help a reader to more easily navigate the book.

1.1 Motivation

In software-intensive systems, software architecture is a dominating part of system architecture. Therefore, in this thesis, we often refer to the software-architecture literature to address important aspects of system architecture. System architecture represents a set of the most significant system design decisions (Jansen and Bosch 2005; Tyree and Aker-

man 2005). These design decisions are made by a system architect, a creator of the system architecture, to meet business goals (Bass, Kazman et al. 2003). The literature suggests a large number of business goals are accommodated by system architecture, such as to improve market position, reduce total cost of ownership, improve capability/quality of system, support improved business processes, and improve confidence in and the perception of the system (Kazman and Bass 2005). This business perspective implies high expectations from system architects to select design decisions and assess their benefits and costs aligned with the business goals.

The type of design decisions, business goals, and therefore the scope of architecture evaluation, evolved dramatically over time. In the early beginnings of system architecture as a discipline, architecture decisions referred mainly to deciding upon a system structure (Parans, Clements et al. 1984). For example, structuring a system in independent modules enabled multiple teams to work in parallel to increase productivity. In that period, the main objective of architecture evaluation referred to checking proof-of-concepts completed by the system architect. Under these circumstances, business managers would allocate resources required by architects to implement architecture changes without any economic assessments. Thus, architecture investment decisions were rather driven by a sound proof-of-concept and resource availability rather than by the benefits created by architecture changes.

Over time, system architecture shifted its focus from structuring system designs towards designing systems to fulfill quality-attribute requirements (e.g., performance, reliability, or upgradability) to meet business goals (Bass, Kazman et al. 2003). Explicit business objectives of system architecture implied changes in architecture evaluation, involving cost-benefit analysis. Multiple stakeholders scored how architecture alternatives could realize quality requirements to meet business goals (Kazman, Asundi et al. 2002). The quality/cost ratio of architecture alternatives are compared to decide on the best investment. Although a cost-benefit analysis was the first economic evaluation, it was mainly used by architects to support tactical decisions on “best” architecture design given limited resources (Moore, Kazman et al. 2003).

According to Clement and Shaw (2009), we left a golden age of innovation and concept formulation in system architecture. System architecture is beginning to enter a more mature stage of reliable use and maximum utilization. Design decisions relevant to architecting are the ones with a significant impact on business strategy (Malan and Bredemeyer 2002). These design decisions should maximize the value creation of architecture over its lifetime and be aligned with the business strategy. The evaluation process of architecture becomes closely related to the evaluation of any other strategic investment in an organization (Smit and Trigeorgis 2004). Consequently, the scope of architecture evaluation has changed again.

First, strategy-focused architecture investments need to deploy many management and financial tools to make a meaningful business case analysis to support architecture investment decisions. Management tools help identify information considering business, processes and organizational aspects that is used as an input for economic valuation (van der Linden, Schmid et al. 2007). Financial tools help break down an architecture investment into a set of investments over time to anticipate the maximum value created by the architecture over its lifetime. In this respect architecture evaluation is consistent with

the valuation of any strategic investment (Trigeorgis 1996). Strategic investment valuations, in particular Net Present Value (Wesselius 2005; Kreuter, Lescher et al. 2008) and real options (Erdogmus 2000; Bahsoon and Emmerich 2003; Ozkaya, Kazman et al. 2007) have been adapted to the architecture context to help tackle methodological issues in supporting decisions on architecture investments. Little evidence on using such tools exists in practice, which calls for a better understanding of practical challenges to accelerate these tools' adoption in industry.

Second, the roles of architects and managers in the evaluation process become interwoven, each with diverse needs in the decision-making process. Originally, architects would create the architecture and evaluate whether it met business goals within a budget. Business managers would decide on architecture investments based on gut feelings. In the new process, business managers are asked to actively participate in the evaluation process. Their aim is to understand the impact of design decisions on business goals (Nord, Clements et al. 2009). In such a constellation, system architects no longer just create architecture, but also communicate the impact of design decisions to business managers (Tyree and Akerman 2005; Farenhorst, Hoorn et al. 2009) and help business managers to build the business case (Bass and Berenbach 2008). Thus, managers and architects depart from their original roles in the evaluation process by bringing their own particular expertise in architecting and management, which might affect how the evaluation process is conducted. For example, given that architects are driven by quality and cost while managers are driven by business indicators such as EBITA (earnings before tax and amortization) or profit, the new evaluation process must adequately accommodate the information needs of architects and managers.

This implies that architects need to learn more about business and tools to orchestrate successfully their new role in the evaluation process on architecture investment (Clements, Kazman et al. 2007; Bass and Berenbach 2008). However, it has been shown that architects underuse knowledge about business assessment, for example, trade-offs and risk analysis, in their practice (Clerc, Lago et al. 2008). Furthermore, the literature suggests that little attention is given to the training and education of system architects in analyzing business implications of design decisions (Clements, Kazman et al. 2007). One explanation might be a lack of systematic methods, which link architecture practice explicitly to business. This is consistent with the survey findings recently conducted among architects in the Netherlands, which demonstrated a strong need for supporting methods in decision management (Farenhorst, Hoorn et al. 2009).

1.2 Research challenges

Architecture investment decisions should be considered complex phenomena where business and individual aspects interact. This implies accounting for a broad research agenda. In order to build a consistent and comparable corpus of literature, some guidance and boundaries are required. To narrow down our investigation, we identify three topics for the literature review: (1) an overview of the existing methods to support architecture investments, (2) the information needs of experts in decision-making, and (3) an overview of tools used to support strategic decision-making analyzed in the architecture context.

The literature suggests no single method to support a decision on architecture investments in serving diverse business goals. The existing methods support specific business goals measured through, for example, cost-benefit analysis, business-case analysis, and real options analysis. Cost-benefit analysis supports practitioners to optimize an architecture design by maximizing scored benefits of quality improvements in a comparison to costs of implementation (investments) (Kazman, Asundi et al. 2002; Ionita, America et al. 2005). Despite the benefits of explicitly linking quality to benefits, a lack of monetary benefits and an effort-thirsty process (Moore, Kazman et al. 2003) make cost-benefit analysis inadequate for supporting a decision on architecture investments. A business-case analysis supports a decision on architecture investments by comparing the economic value from architecture with investments based on economic criteria, such as a return on investments. A business-case analysis improves on cost-benefit analysis, mainly by quantifying the cost-saving value of the new architecture in so-called cost models. Evidence on using cost models in practice, especially in the product-line context (Schmid 2003; Böckle, Clements et al. 2004; Clements, McGregor et al. 2005), shows high adoption rates of such models by industry (Kreuter, Lescher et al. 2008). However, business case analysis in the form of cost models focus on estimating cost-saving value and neglect the architecture customer-centric value in facilitating customer business objectives, such as market positioning or customer satisfaction. Real options approaches support practitioners in evaluating the additional value of flexibility facilitated by architecture investments under uncertainty (Erdogmus 2002; Bahsoon and Emmerich 2004; Baldwin 2006). Although promising, in their current form, real options in an architecture context provide little guidance in complex practical settings—e.g. which data to collect that resulted in little evidence on its use in industry. Drawing upon the pros and cons of the existing methods to support architecture investment decisions in practice, the main research challenge is to *provide a means to identify and quantify the economic value of architecture, in particular customer value, to make existing methods more appealing to industry.*

Regardless of the tools used, collecting relevant information is necessary to avoid information overload when supporting architecture-investment decisions. Furthermore, with an actively involved manager, we expect changes in the information landscape used in architecture evaluation. These challenges call for a better understanding of information needs to support architecture investment decisions, not only from a business perspective, but also an individual perspective. The literature about expertise suggests that experts' performance is domain-specific and experience-dependent (Chi 2006). Experts in decision-making across different domains use fewer information cues than expected. The experts also differ by selecting the relevant information sets (Shanteau 1992). This implies that architects and managers, with their expertise in architecting and management, might differ in information needs. A need to support architecture investment decisions with relevant information sets up a challenge to *identify information needs of architects and managers in the architecture-evaluation process.*

Architecture investment decision-making analyzed in the context of strategic decision making unfolds high-level similarities but also potential for improvements, which is elaborated in more detail in section 2.4. First, strategic decisions are about the most important managerial decisions (Smit and Trigeorgis 2004); architecture is about the most important system design decisions (Jansen and Bosch 2005; Tyree and Akerman 2005). Second, strategy development coincides with system architecture creation. Third, finan-

cial evaluation of any strategic and architecture investments are almost the same, e.g. using real options. However, we realized that a translation phase in strategic decision-making, which follows the strategy development and precedes the financial evaluation phase, is not apparent in the existing architecture evaluation. In the translation phase, the strategy is mapped to operational goals and measures as targets (Kaplan and Norton 1992; Kaplan and Norton 2004) that would be further used in the next steps, financial investment evaluation. Incorporating this phase in the existing process of the architecture evaluation might bring the right measures to support architecture investments based on the business-strategy goals. This phase might also support the research challenge on identifying customer-centric values to support customer-centric business goals. Thus, the last research challenge is *how to exploit “best practices” on strategic decision-making and architecture evaluation to improve a decision on architecture investments.*

These research challenges will be fine-tuned into research questions in section 2.5 after a more elaborate literature review.

1.3 Goal of the thesis

The main goal of this thesis is to improve decisions for architecture investments by providing ways to identify and quantify relevant information in assessing the impact of design decisions on the business strategy. To reach this goal, we use a hybrid research strategy (Yin 2003) that combines the strong points of case studies (Dul and Hak 2008), interview data, and experimenting.

Case studies are used to investigate different aspects of decision-making in naturalistic settings in the business context (Schmitt 1997). The case studies investigate the practical challenges in architecture evaluation (chapter 3), how to quantify customer-centric value (chapter 6) and how to support architecture investment decisions in practice (chapter 7). Furthermore, we conducted structured interviews to elicit quantitatively the information needs of architects and managers (chapter 4). The case studies were conducted in Philips Healthcare and with one of their customers (a hospital). Depending on the research questions, different sources of evidence were used, such as review meetings, documentation, time archives, tools for resource management, etc. Next to the case studies and interviews, we used a conjoint study to empirically analyze the information used in architecture investment decisions by managers and architects (chapter 5).

The first contribution this thesis makes is to identify practical challenges in architecture decision-making based on “best practices” and by exploring a use of the real options way of thinking in practice to support architecture-investment decisions. The investigation is completed through two case studies. In the first study, we analyzed a decision on architecture investment, which had been already made, with respect to business goals, information, and decision rules. The findings were used as a reference to “best practices” in decision-making. Then, in the second study, we adapted the real options way of thinking to the architecture context and applied it to the same case to support a decision on architecture investments. Practical challenges mostly reflect theoretical ones on making architecture investment decisions. A hurdle of collecting data and a need for a structured approach with a focus on the customer value are some of the common challenges. However, we identified an additional practical challenge that was not addressed earlier. Any

improvements to “best practices” should be close to the practitioner’s way of working in order to be adopted (Rogers 2003).

The second contribution of the thesis is the in-depth analyses of the information needs of architects and managers. Using interviews as our source of evidence, we identified a large information set required to make decisions on architecture investments, which was distinct for managers and architects. A comparative analysis on information needs unfolds architects’ needs for system-specific information and managers’ needs for business-specific information. Because the identified information is reported as used, we were interested in whether and how the information is actually being used in making architecture investment decisions. In an experimental setting using a conjoint analysis design, we investigated the impact of identified information on architecture-investment decisions considering the roles and experience of experts. Furthermore, we compared these findings to the information needs reported by architects and managers. In the experiment, the participant was asked to select between two architecture scenarios based on the architecture description and on business information inputs. The results showed that the identified information needs were much richer than the information set used to decide on architecture investments. Beside the small amount of information used, under time pressure and with larger development experience, the information predicted “unexpected business decisions”. This implies that without a structured decision-making process, the decision might be based on the right information but the interpretation might be driven by personal characteristics, i.e. development experience and resilience to time pressure, rather than by business incentives. Thus, to support an informed decision, identifying relevant information and determining how this information should be combined (e.g. predefining decision rules) is necessary to make sound business decisions.

The third contribution of the thesis is in providing guidance to identify and quantify the economic value of architecture, in particular the customer-centric value, based on “best practices”. We propose to exploit best practices in management and marketing to model customer-centric value and evaluate its possible acceptance in two real-world case studies. Management tools, strategy maps (Kaplan and Norton 2004) and balanced scorecards (Kaplan and Norton 1992) are used to translate customer-centric business goals into architecture decisions and related measures to identify the sources of architecture customer-centric value. Furthermore, we adopt two marketing concepts, customer value-in-use and customer segments (Kotler and Keller 2008) for quantifying the architecture value for a single customer and multiple customers. Modeling the customer-centric value appeared advantageous compared to existing value indicators in the organization. Furthermore, it was confirmed that practitioners more easily accepted the concept, which had already been used in the organization. In particular, customer segments were preferred over the customer value-in-use because of its existing use in business-case modeling. Although, we linked the architecture and customer-centric value, further improvements require explicitly translating customer-centric value to financial value to enable comparing architecture value with investments.

The fourth contribution of the thesis builds upon previous contributions to propose a systematic approach to support strategy-focused architecture investments; we have named this the Strategy-focused Architecture (StArch) approach. First, to acknowledge the practitioners’ need for approaches close to their way of working, we decided to use

scenario analysis and business cases as identified “best practices” in architecture decision-making. Second, we decided to keep the strategy map concept used to map architecture decisions to business goals, as it resonated well with practitioners. Third, given the controversial findings on individual information needs and their use in architecture investment decisions, we propose to guide information selection based on business goals rather than on individual preferences by using a balanced scorecard tool. Summing up, StArch integrates established management techniques, strategy maps and balanced scorecards with architecting best practices, scenario and business case analysis to support decisions on architecture investments in a step-by-step process. Following StArch, practitioners were highly satisfied (scoring 4.3 out of 5) in evaluating architecture-design decisions based on sound business objectives and measures in real-world cases.

1.4 Thesis overview

Part I (chapters 2 and 3) introduces the reader to some theoretical and practical challenges on making decisions on architecture investments. In particular, chapter 2 presents an overview of related literature, providing the underlying issues, which touch upon architecture-investment decisions. These, already hinted in the previous section, are: the existing approaches in supporting architecture investments, information needs of experts in decision-making, and an overview of business tools for strategic decision-making analyzed in the architecture context. Finally, chapter 2 ends with the explicit statement of the research questions tackled in this thesis. Chapter 3 presents the practical challenges with respect to information and criteria used in making a decision in a real-world project using “best practices” and the real options way of thinking. A lack of systematic guidance and non-economic criteria in making decisions were the main practical issues. The findings on practical challenges confirm the theoretical challenges in proposing solutions to (1) guide quantification of the customer-centric architecture value and (2) to identify information needs for architecture investment decisions.

Part II (chapters 4 and 5) represents a piece of quantitative research that focuses on individual aspects in determining information needs, in particular experience and roles for decision-makers (architects and managers). In chapter 4 we present the quantitative analysis of 19 interviews on the information needs of architects and managers in making a decision. From this chapter, it emerges that architects and managers need different information types to support a decision on architecture investments. This account was a fundamental base for setting up an experiment in chapter 4. The aim of the experiment was to investigate whether and how the information needs reported in the interviews relate to information used cognitively in decision-making.

Part III (chapters 6 and 7) centers the investigation on supporting the evaluation process of architecture investments based upon the findings of the previous chapters. In particular, chapter 6 builds on the theoretical and practical challenges to develop guidance on quantifying the customer-centric value of architecture. We propose how to adopt management and marketing concepts to the architecture context to model the customer-centric value. The concepts have been applied and evaluated in two real-world cases. The evaluation indicates that the modeling of customer-centric value is adequate only if the cost of conducting the evaluation is low and the company has a strong customer-centric

strategy. Chapter 7 presents the final result of the cumulative knowledge built up through the thesis, namely, a systematic approach to support architecture investment decisions termed Strategy-focused architecture (StArch). StArch integrates established management techniques, strategy maps and balanced scorecards, with architecting practice, scenario and business case analysis, to support a decision on architecture investments in a step-by-step process. We present each step of StArch in detail in an example of making real-world architecture investment decisions. The StArch evaluation unveils high satisfaction of practitioners, in particular with the first step of mapping design decisions to the business goals (scoring 4.3 out of 5). Furthermore, the time spent in applying StArch appeared to be time efficient when compared to the existing decision-making process in the organization.

Finally, in Part IV, chapter 8 provides a summary of the main findings of this thesis, discusses their implications, and suggests future line of research.

2 Literature

2.1 Introduction

In chapter 1 we defined the scope of this thesis, namely the support for strategy-focused architecture investment decisions required to accommodate the information needs of architects and managers. Understanding a complex phenomenon on investment decisions requires a broad research program to investigate the interaction of both business (finance and management) and individuals. To build a consistent and comparable corpus of literature, some guidance and boundaries are required. We narrow down our search to explore three topics: (1) methods for architecture evaluation, (2) the information needs of experts in decision-making, and (3) strategic decision-making (see Figure 1). The literature reveals theoretical challenges for decision-making in architecture investments, which helped to define the research questions for this thesis. Because of the broad scope and multidisciplinary nature of the field, we do not provide a comprehensive literature review. This literature review should be read as a guideline to related literature, while a more elaborate literature review will be provided throughout the remaining chapters.

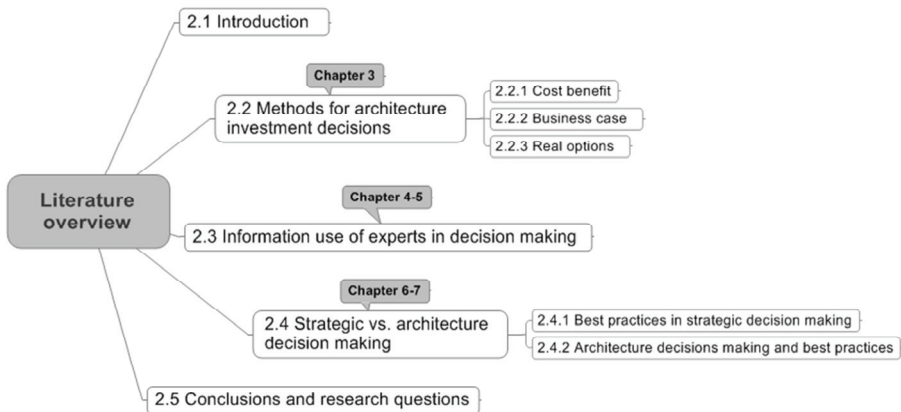


Figure 1. Literature topics and their relevance to particular chapters

In section 2.2, we review literature on existing methods for architecture evaluation to analyze their pros and cons and identify areas for improvement. Given the business scope of architecture evaluation, we focus exclusively on methods for applying economic decision rules. In this respect, we disregard methods that demonstrate proof-of-concept for architecture design with respect to business goals (requirements). Methods are classified in three groups with respect to the objective of evaluation: cost benefit, business case, and real options analysis. For each group, we selected representative examples to examine the process, information and decision rules, and evidence of their use in practice. These insights are used throughout the thesis to create proposals that will build on existing advantages and avoid pitfalls. In particular, in chapter 3, we exploit some elements of existing methods in real decision-making to identify practical challenges.

In section 2.3, we review the literature on the information needs of experts in decision-making, showing that experts are indeed different from lay-people in the way they make decisions. This topic emerges from a trend, presented in chapter 1, in which managers and architects must together be actively involved in architecture evaluation. We investigated determinants of an expert's performance, in particular for decision-making. Special attention was spent on the information needs of experts as a crucial element in decision-making. The findings helped us define two studies to investigate (1) the information needs of architects and managers in architecture evaluation (chapter 4) and (2) information predictors of their architecture investment decisions (chapter 5).

Given the strategic nature of architecture investments, in section 2.4, we review best practices on strategic decision-making from management and financial perspectives to learn how to potentially improve existing methods. For each perspective, we discussed elements of the process and compared them by making analogues with existing methods. "Best practices" are identified to propose improvements in the existing methods, for instance, to identify and quantify customer-centric value (chapter 6) and to guide strategy-focused architecture investments (chapter 7).

Finally, in section 2.5 we discuss the literature findings and define the main research questions of the thesis.

2.2 Methods for decision making on architecture investments

An architecture investment decision stems from an architecture evaluation process. Nowadays, evaluation means making a proof-of-concept for an architecture design with respect to meeting business goals (Bass, Kazman et al. 2003). In this respect, evaluation is an important duty of architects (Clements, Kazman et al. 2007) and is an unavoidable part of architecture design (Hofmeister, Kruchten et al. 2007). Although there are numerous methods for supporting architecture evaluation from different perspectives (Clements, Kazman et al. 2001), we focus on methods that apply an economic criterion in an investment decision.

The process starts when an architect proposes architecture alternatives for evaluation. Each alternative is a set of design decisions (Jansen and Bosch 2005) selected to have the highest impact on the business strategy (Malan and Bredemeyer 2002). In a review meeting, architects and managers evaluate alternatives by assessing the consequences of design decisions on business objectives and customer needs (Nord, Clements et al. 2009). To compare alternatives, each decision offers potential benefits and costs to implement, i.e. investments. With the economic methods, a decision to invest is driven by maximizing benefits with respect to costs. While cost is routinely calculated following established cost models (Boehm, Horowitz et al. 2000; Rommes, Postma et al. 2005), identifying benefits and estimating related value is not straightforward. Therefore, methods mostly elaborate on how to assess the benefits of architecture investments when costs are known.

We identified three categories of methods that evaluate architecture: cost benefit, business case, and real options analysis.

2.2.1 Cost benefit analysis

Cost benefit analysis is meant to ensure good design decisions by maximizing benefits and minimizing cost.

The Software Engineering Institute proposed the first Cost Benefit Analysis Method (CBAM) for the economic evaluation of architecture (Kazman, Asundi et al. 2002). CBAM analyzes architecture decisions from the perspective of two main elements—cost and benefits—by using a scenario-based approach. The structured process guides multiple stakeholders to assess the consequences of architecture decisions on the quality attributes of a system. A key point is to propose scenarios that describe quality attributes in the context of system use. For example, a reliability scenario of an imaging system in a hospital is described as: “The system shuts down five times per month on average”. Then, stakeholders challenge each scenario with architecture alternatives, scoring how well each quality scenario meets business goals. In multiple steps, including weighting and prioritization, a total quality score presents the estimated benefit for each alternative. Ultimately, a decision is driven by the maximum quality/cost ratio of the architecture alternatives. It is important to notice that the last step of CBAM calls to corroborate the decision with the practitioners’ own intuition. This means that the chosen architectural strategy by CBAM should be challenged with the organization’s broader business goals. If the selected strategy strongly opposes the practitioner’s intuition, the practitioners are asked to perform further iterations and consider issues that may have been overlooked.

Despite the seemingly clear link of architecture design to quality benefit scores, CBAM’s use in practice has met with only partial success. CBAM in a real-world project demonstrates that practitioners appreciate the systematic guidance that it offered to quantify quality benefits, but disliked the long time spent in the process (Moore, Kazman et al. 2003). Furthermore, facilitators observed that stakeholders tried to tune quality benefits as soon as they understood how the method worked. The same phenomenon on expertise-biased decision-making is recognized with other experts (Chi 2006). Nevertheless, we acknowledge the advantage of involving multiple stakeholders in the process to drive less-biased scoring than by the architect alone.

The Software Engineering Institute proposed a series of CBAM improvements (Kazman, Asundi et al. 2001; Ozkaya, Kazman et al. 2007). For example, a management tool—a project-portfolio analysis—is used to investigate the set of quality scenarios that maximize benefits under predefined costs (Kazman, Asundi et al. 2001). We think that these improvements bring additional complexity to an evaluation that is already time-consuming and explains why no evidence of its use could be found. In general, we think that a lack of “dollar value” in quality benefits is the main reason that CBAM is rarely accepted. In this respect, CBAM is better suited to prove that an architecture design meets business goals on an economic basis, rather than to support architecture evaluation with respect to business-value creation.

Philips-related research on cost benefit analysis takes a different tack. Recognizing the importance of monetary value, the Systematic Quantitative Analysis of Scenario Heuristics (SQUASH) guides the assessment of profit and the cost of quality improvements to support a decision on architecture alternatives (Ionita, America et al. 2004). Compared to

CBAM, SQUASH uses architecture and strategic scenarios in a different context. Strategic scenarios scout for different futures (for instance, by considering customer segments or competition) to understand their possible consequences on architecture. The businesses strategies help determine implementable architecture scenarios by optimizing quality attributes, including system (for instance, reliability or performance) and process quality (time-to-market and effort). Finally, quality attributes of architecture scenarios are challenged within different strategic scenarios. This means that the quality attributes of architecture alternatives are scored as a percentage of market-share increase for each strategic scenario. Ultimately, a decision is based on maximizing profitability graphs across architecture scenarios. An example of SQUASH, however, shows the complexity of using the method in practice (Ionita, America et al. 2005). Similarly to CBAM, the process requires intense involvement from stakeholders. Furthermore, assessing a contribution of quality improvements to market share was not straightforward. Unlike in CBAM, where quality benefits are assessed easily in the context of system use, in SQUASH, a market-share assessment of quality improvements was not a common practice. Although SQUASH improves on CBAM by using an explicit monetary value for assessments, long and ambiguous data collection is the main inhibitor of its adoption in practice.

The previous examples, from institutes with extensive experience in conducting cost-benefit analysis, demonstrate the main advantage to making benefits of architecture decisions on quality improvements explicit. However, a lack of monetary value (CBAM), large effort (CBAM and SQUASH), and data collection outside of common practices (SQUASH) leave cost-benefit analysis as a proof-of-concept rather than a method to support architecture investments by maximizing business value.

2.2.2 Business case analysis

Business case analysis is a key element of value-based software engineering (Boehm 2006) used to decide on investments, which uses established economic techniques such as return on investments (ROI) or net present value (NPV).

Most evidence in using business case analysis is in software-product-line practice (Khourum, Gorschek et al. 2008). Product line facilitates the development of multiple products on the same architecture, meaning software can be reused, hence decreasing development effort (Pohl, Böckle et al. 2005). Business case analysis is mostly used to support large investments when migrating from single products to product line development. In this perspective, business case analysis is actually a cost model used to compare cost functions in the organization before and after a product line (Böckle, Clements et al. 2003; Schmid 2003). Cost functions are migration-specific (e.g. organizational and learning effort) or product and time related (e.g. software reuse effort). Given that costs mostly refer to development effort, Earnings Before Interest Tax and Amortization (EBITA) becomes a criteria to communicate the financial impact of a product line on the organization (Kreuter, Lescher et al. 2008). Despite particularities in product lines, the literature suggests that cost models apply to single product development as well (Clements 2007; van der Linden, Schmid et al. 2007). The high acceptance of cost models by practitioners can be explained by the fact that the software industry has long adopted a family of cost estimation models (Boehm, Horowitz et al. 2000).

It is important to notice that cost models explicitly focus on process-quality improvements, e.g. cost and time-to-market, while overlooking system quality improvements such as performance or reliability, which are addressed by cost benefit analysis.

Furthermore, costs models help determine architecture investments that support two business objectives: business process improvements or total costs of ownership in the organization. Both refer to the internal business of the organization. According to Kazman and Bass (2005), beside these objectives, architecture investment is also driven by customer-centric business goals, such as improving market position, improving the capability/quality of a system, and improving the confidence in and perception of a system. Thus, cost models overlook customer-centric benefits; therefore, they are inadequate for supporting customer-centric business goals.

The literature shows a few attempts to address this problem, but presents little evidence of practical use. For example, existing cost models (Böckle, Clements et al. 2003) have been extended by adding benefit functions (Clements, McGregor et al. 2005). However, we can say that benefit functions were mostly recognized as a substitute for the helpful guidance of assessments. Furthermore, market scoping (van der Linden, Schmid et al. 2007) was recognized as helpful in segmenting markets to estimate the size of the customer base that would be affected by architecture changes. Despite a shift from internal-development goals towards maximizing benefits for the customer base, market scoping was mainly used to fine tune input for cost models. One explanation for the little evidence on business case analysis to support customer-centric objectives might be a lack of guidance to collect data in a complex organizational context.

In a nutshell, business case analysis is widely used as a cost model to support architecture investments driven by internal business goals. Cost models support investments on quality-process improvements by comparing costs before and after the architecture implementation. Unlike cost benefit analysis, cost models overlook the benefits of system-quality improvements that are important to customers, such as performance or reliability. To extend the cost-centric scope of business case analysis to customer-centric, it is important to provide guidance on how to assess customer-centric value. In this way, business case analysis would support architecture investments for different business goals, including internal- and customer-oriented ones, by considering related measures that are expected in any decision-making (Berry and Aurum 2006).

2.2.3 Real options analysis

Real options analysis evaluates a decision to invest in system flexibility as a particular business goal of the architecture. Based on financial options theory, real options analysis supports decisions on project investments under uncertainty (Black and Scholes 1973) (Noble Prize winning).

We recognize two benefits of real options in architecture evaluation. Real options help identify options in a system design that might create value (Wang and Neufville 2005), and they estimate the additional value from future outcomes under uncertainty. We provide a few examples to explain how options bring additional value in the future that would otherwise be missed. In the 1990's, computer design was modularized (splitting

system design into independent modules), which created an option. The option allowed companies to distribute development to multiple teams so they could work in parallel. A large number of companies in the American computer industry exercised this option, which resulted in a huge increase in market share (Smit and Trigeorgis 2004). In web servers, an architecture improvement that enhances availability also creates an option. This option prepares a company to better offers services to a larger number of customers (Ozkaya, Kazman et al. 2007). Without this option, the company would lose potential customers that need services. In these examples, architecture investments (in modularity and availability) created an option to prepare the system to take advantage of upside opportunities, for instance an increased number of web users. In contrast to other methods (cost benefit and business case), this is the only method that explicitly accounts for strategic value, considering architecture value not only at the point of the product's release with the new architecture, but also over the entire architecture's lifetime (Schulz, Fricke et al. 2000).

Real options have been adapted to suit different business goals for an architecture investment. Taudes (1998) uses real options to support a decision to invest in IT infrastructure under uncertain IT application demands. Erdogmus (2000) demonstrates how to decide on the architecture investments when faced with uncertain market value. Bahsoon and Emmerich (2003) adapt real options to support investments in software re-factoring under uncertain requirements changes. The power of the real options approach created high expectations, particularly in the academic world, but there is little evidence on applying real options in practice.

One explanation for the lack of real-world application of the method could be that the complex mathematical formulism for calculating the option value (Black and Scholes 1973; Cox, Ross et al. 1979) is too far from architecture evaluation (section 2.2.3).

Despite the advantages of identifying options as a source of architecture value, assessing this impact is not within the stakeholder's reach and understanding. The large disparity between the real options method and common practice slows the adoption rate (Rogers 2003), which is recognized in the corporate world (Copeland and Antikarov 2003). Even if an expert is hired to generate the complex formulism, he or she still needs assistance with data collection, which is still not straightforward (Ozkaya, Kazman et al. 2007). This issue is similar to the once faced in a business case analysis, where customer value is difficult to quantify (section 2.2.2). Ultimately, even if guidance is provided, applying real options requires historical data. This implies having infrastructure in the organization to collect historical data on architecture projects, e.g. requirements changes or market value, and then to build tacit knowledge over time.

According to Amram and Kulatilaka (1999), one way to overcome challenges in practice, such as complex mathematical formulism and a lack of historical data, is to use the real options way of thinking heuristically rather than literally. This means exploiting the power of real options to identify a source of value for investments and to find simplified techniques to quantify that value. We explore this recommendation in a real-world project in chapter 3.

2.3 Information use of experts in decision making

Business objectives determine the methods that practitioners use to collect predefined data (e.g. cost benefit analysis requires quality scores and investments) to support architecture-investment decisions. Ultimately, individuals make a decision, and their information needs might differ from the ones required by the methods. As seen, customer-centric value was neglected in business case analysis, although such information is needed in an evaluation (section 2.2). Furthermore, we recognized a trend of business managers taking active part in architecture evaluation, which could bring forward additional information. Given that, understanding the information needs of architects and managers is crucial to providing relevant information for an architecture evaluation. A literature review on the information use of experts helped us design the study on the information needs and decision predictors for architects and managers (chapters 4 and 5).

According to Nord et al. (2009), business managers and architects are responsible for ensuring that the information for an architecture evaluation is complete. In this process, architects and business managers are selected as experts by their peers (Shanteau 1992).

It is recognized that experts differ from non-experts through their domain knowledge and experience. According to Chi (2006), expertise is domain-specific. A more skilled person becomes expert-like after acquiring knowledge about a domain through learning, studying, and deliberate practice. In architecture evaluation, a domain can be informal (i.e. architecting and management) or formal (i.e. healthcare and automotives) The literature suggests that architects need formal domain knowledge to successfully perform architecting duties, including architecture evaluation (Clements, Kazman et al. 2007; Bass and Berenbach 2008). Next to domain knowledge, the time required to gather domain knowledge is also important, namely experience. Experience distinguishes the proficiency level of experts, non-experts (one who is totally ignorant of a domain) or novices (someone who is new to the field). This means that to investigate the information needs of architecture evaluation, we need to explicitly address the domain knowledge and experience of architects and managers.

According to Carroll and Johnson (1990), information is a crucial element in decision-making. Understanding the information use of experts can help in the design of expert systems or improve guidance on decision-making, which is our aim.

It is expected that all cues in effective decisions that diagnose or predict an outcome should be included in a decision. In complex real-world environments, there will be numerous sources of diagnostic information. It follows that experts should base judgments on many cues. In contrast, most decision-makers use simplifying heuristics when making judgments (Tversky and Kahneman 1974). This leads to a reliance on less-than-optimal amounts and inappropriate sources of information. This means decision-makers may generally base their judgments on a suboptimal number of cues. Regardless of the expectation that expertise should reflect the amount of information use, the literature shows that the judgment of experts can be described by fewer significant cues than expected. For example, medical radiologists use two to six cues (Hoffman, Slovic et al. 1968) and medical pathologists one to four cues to make their diagnoses (Einhorn 1974). Stockbrokers rely on six to seven cues in their judgments on stock prices (Slovic 1969). In these

studies, analyses of experts produced a small number of significant cues. Yet in each case, (often much) more information was available. This suggests that experts may make important decisions without adequate attention to a complete set of cues. One possible explanation for the limited use of relevant information by experts is that they are often influenced by irrelevant cues. Clearly, experts should be selective and use only information which is the most relevant or diagnostic. However, the literature suggests irrelevant cues inappropriately influence the judgments of both naïve and expert subjects (Gaeth and Shanteau 1981). Subjects often use and even choose irrelevant information over relevant when both are available (Doherty, Mynatt et al. 1979).

Apparently, decision-makers have difficulty ignoring information that is irrelevant for the task at hand. A literature review of five studies by Shanteau (1992) confirms the previous findings and brings additional insights. The analysis across studies shows that a number of significant cues did not differentiate experts and novices, but the selection of information did. Consistently, it appeared that experts and novices differed in their ability to discriminate between relevant and irrelevant information. This implies that where experts differ from novices is in what information is used, not how much.

This review brings forward a need to investigate the information use of architects and managers. The goal is to determine a relevant set of information to support architecture evaluation.

2.4 Strategic vs. architecture decision-making

Strategic and architecture decision-making are similar. Strategic decisions are the most important managerial decisions in terms of both the size of expenditure and their impact on the future of an organization (Smit and Trigeorgis 2004). Architecture is a set of the most important design decisions (Jansen and Bosch 2005; Tyree and Akerman 2005) with the highest impact on business strategy (Malan and Bredemeyer 2002). Similarly, in a complex landscape of decisions, numerous tools are used to support different objectives (section 2.2). In this section, we aim to understand best practices on strategic decision-making to learn and identify possible improvements in architecture evaluation, which will then be explored in chapters 6 and 7.

2.4.1 Best practices in strategic decision-making

Literature on strategic decision-making is broad, encompassing management, financial, organizational, or cultural perspectives. We investigate best practices from a management and financial perspectives, given the scope of this thesis. According to Kaplan et al. (2008), successful strategic decision-making has two basic rules: understand the management cycle and know what tools to apply at each stage of the cycle. From a financial perspective, strategic investments are formally evaluated to maximize value creation (Trigeorgis 1996).

The management cycle is a closed-loop system to determine and execute a strategy. With our aim to investigate evaluation as part of architecture design, we narrow down our investigation to best practices in management to support strategy determination. The

strategy is determined by a complex landscape of decisions to (1) develop the strategy, (2) translate the strategy into operational objectives and targets, and (3) conduct strategic planning to execute these objectives. Numerous management or financial tools support an organization in making strategic decisions.

An organization develops a strategy by proposing how to generate a competitive advantage with maximum value creation (Trigeorgis 1996). Competitive advantage is created by distinguishing an organization's offering from their competitors (management perspective). Next, it is important to consider how to maximize value creation (e.g. shareholder's value), which will be elaborated in more detail later (financial perspective).

Best practices in strategic management suggest creating competitive advantage by considering the external and/or internal factors of the organization. For example, Michael Porter (1980) proposes to analyze external factors such as rival companies, potential entrants, suppliers, customers, and substitutes. This helps the organization to select between two broad strategies: (i) cost advantage and (ii) differentiation advantage. The cost-advantage strategy of producing at a lower cost than competitors should be used in low-cost product markets when the price elasticity of demand is high. In contrast, the differentiation advantage should be used in markets where the organization can set a premium price for a product that may be perceived as highly valuable by customers. Furthermore, competitive advantage can be developed by considering internal factors, such as resources and capabilities (Wernerfelt 1984). In this respect, a strategy is created by identifying growth opportunities in the market and capitalizing on them using a specific bundle of resources and capabilities that are difficult to imitate by competition (Barney 1986). It is important to notice that the architecture of complex, software-intensive systems is an internal factor, i.e. a crucial asset of the organization with tacit knowledge on the system's design, created by thousands of people working on its development over several decades. Thus, in such a development organization, system architecture must be considered in addition to external factors in strategy development. Recently, new tools have emerged on developing the strategy by (1) offering initially less capable products at a much lower price—disruptive innovation (Christensen and Raynor 2003), (2) considering a new value proposition for a large customer base—blue ocean (Kim and Mauborgne 2005), or by anticipating unpredictable events—black swans (Taleb 2007).

The strategy is then translated into a set of executable objectives to be monitored and controlled (Kaplan and Norton 2008). The strategy maps tool (Kaplan and Norton 2004) supports translating the strategy into the organization's long-term financial objectives and then links them to objectives from three operational perspectives: customer, internal business, and innovation and learning. The map's objectives refer to short-term (e.g. cost-reduction or quality improvements) or long-term (e.g. innovation and customer relationship) objectives. Next to strategy maps, a balanced scorecard tool (Kaplan and Norton 1992) can be used to identify related metrics and measurable targets for each objective in the strategy map. The main breakthrough that these tools have brought is in the introduction of non-financial objectives and measures, such as market share, time-to-market, satisfaction, etc. Thus, strategy maps and balanced scorecards help stakeholders to identify sources of value creation. The strategy (e.g. cost or differentiation advantage) determines related objectives and therefore requires a selection of scorecards. For example, if the company pursues a customer-centric (differentiation advantage) strategy,

customer scorecards become crucial in driving profit (Kotler and Keller 2008). Perceptual customer metrics (e.g. customer satisfaction) or observed / behavioral metrics (e.g. customer retention and lifetime value) (Anderson, Jain et al. 1993) are some examples. Empirical evidence of a direct correlation between customer metrics and financial performance (Gupta and Zeithaml 2006; Keiningham, Cooil et al. 2007) makes customer scorecards popular measures in organizations. An explicit link between financial and non-financial objectives/measures to describe the value creation process make these tools widely accepted in practice (Kaplan and Norton 2001).

Planning on how to achieve the strategy map's objectives involves making decisions on a portfolio of short-term projects with a finite duration and then authorizing resources for these projects. This stage involves setting priorities for process improvement, making detailed sales plans, devising a resource capacity plan, and setting budgets (Kaplan and Norton 2008). From a management perspective, by completing this stage, the organization is ready to execute the strategy.

Until now, we have presented best practices in strategic management to create a competitive advantage. Beside the competitive advantage, a strategy is developed to create the maximum value in an organization (Trigeorgis 1996). Thus, the financial perspective is crucial to create maximum value. Smit and Trigeorgis (2004) identify three levels of strategic planning and valuation that impact on value creation: project appraisal, strategic planning of growth options, and competitive strategy.

Project appraisal is a traditional approach to measure value creation and is commonly used in organizations. A project is evaluated by determining the expected cash flows once the company has made all discretionary investments, such as projects planned. This valuation technique is known as Net Present Value (NPV). NPV is suitable when valuing bonds, deciding on maintenance or replacement, or determining other passive investments in a stable environment when a stream of cash flows can be well specified. This approach, however, cannot revise future decisions to account for additional cash flows. To account for additional value and give managers the flexibility to revise future decisions, it is important to break down a strategic investment into a set of investments (options) over time. Strategic planning of growth options accounts for possible future opportunities that may be exploited depending on future uncertainties. From this perspective, the NPV is increased by a flexibility value based on the organization's ability to react to uncertain future opportunities, quantified by real options (Dixit and Pindyck 1995; Amram and Kulatilaka 1999; Copeland and Antikarov 2003). Finally, competitive strategy captures additional strategic value by improving the company's position compared to competitors through game theory and industrial organization economics (Schelling 1980; Shapiro 1989; Brandenburger and Nalebuff 1995). We can say that real options and game theory bridge the gap between strategic planning and traditional NPV by reflecting the analytical information of budgets and objectives and by using formal valuation.

It is recognized that formalizing complex strategy making and planning from a financial perspective is not straightforward. Mintzberg (1994) claims that strategic planning does not provide management with the soft information needed for successful decision-making. However, strategic-investment planning and valuation supports decision-making

in strategy development in a more formalized way, preventing project evaluations from becoming highly politicized (Luehrman 1997).

2.4.2 Architecture decision making and best practices

We compare strategic and architecture decision-making by taking a broad view on architecture decision-making, from architecture creation to evaluation. In this respect, we analyze methods for architecture design, in particular evaluation (see section 2.2) with respect to strategic tools to draw potential improvements.

The first step, developing the strategy, is fundamentally analogous to the process of creating the architecture. The strategy is developed to bring a competitive advantage while maximizing value creation (Trigeorgis 1996), and architecture is created to meet business goals by maximizing its utilization (Clements and Shaw 2009). Similarly, architecture creation is supported by methods that consider external factors such as business, process, and organization (van der Linden, Schmid et al. 2007), and internal factors, such as system quality improvements aligned with business goals (Bass, Kazman et al. 2003). A large research community provides support on how to design architecture that meets business goals. An elaborated view on how the five methods are used in practice is presented by Hofmeister et al. (2007).

The idea of the second step, translating the strategy into operational goals and measures, is somewhat apparent in a cost benefit analysis (see section 2.2.1). Although not so explicit, quality scenarios can be seen as objectives in strategy maps that take different perspectives, such as the customer (e.g. improve reliability), internal (e.g. improve maintainability), or growth and innovation (e.g. share knowledge with reusability). Furthermore, scores on quality scenarios in meeting business goals are analogous to balanced scorecards measuring objectives. Despite some similarities, making relations more explicit might be helpful. Method improvements should (1) establish explicit cause-effect relationships between the objectives of design decisions and financial objectives and (2) identify measures for these objectives that are not subjective quality scores but rather business scorecards. In this respect, the main disadvantage of cost benefit analysis, a lack of monetary value, will also be overcome.

The third step of planning operations can be related to splitting architecture implementation tasks into executable deliverables, setting priorities and estimating costs of architecture changes (Rommers, Postma et al. 2005; Boehm 2006). We find this step comparable to cost models (section 2.2.2). For example, cost models in product line development involve market scoping, splitting architecture improvements into manageable operational plans, or estimating cost before and after. However, as we said, this is only applicable for explicitly addressing internal business objectives and ends up neglecting customer objectives, which remains the main drawback of cost models.

Finally, when we refer to the financial techniques used in the architecture method for supporting investment decisions formally, we found large similarities with financial approaches for strategic-investment valuation. We started a discussion with a traditional approach, which suggests using net present value. As expected, cost benefits analysis without monetary value are not applicable for formal valuation. On the other side, busi-

ness case analysis can apply NPV. Finally, we observe that real options analysis for architecture investments (Erdogmus 2000; Bahsoon and Emmerich 2003; Ozkaya, Kazman et al. 2007) are established in the academic world but we have found little evidence to suggest they are used in practice (section 2.2.3). However, the challenge lies not in methodology, but in complicated data collection. We could not find any method addressing the effect of competition on decision-making. This is explained by the fact that architecture needs must align with the business strategy, which is already concerned by competition.

2.5 Conclusions and research questions

Above, we provided a broad overview of the relevant literature given the scope of this thesis. The literature corpus touched on representative methods for architecture evaluation, the information needs of experts in decision-making, and strategic decision-making. Here, we conclude with our main findings and bring forward our research questions.

To identify areas of improvement in supporting architecture evaluation, it is important to understand the pros and cons of existing methods. We reviewed economic methods classified in three groups: cost benefit, business case, and real options analysis. Cost benefit analysis supports a decision on “best quality” architecture design with respect to investments. Stakeholders score a degree of quality improvements (benefits) for each architecture alternative to decide on one with the maximum quality/investment ratio. The main advantage is a direct relationship between architecture design (quality improvements) and benefits. However, a lack of monetary value, large effort, and data collection outside of common practices mean that cost benefit analysis remains a proof-of-concept rather than a method to maximize business value in supporting architecture investments. The business case analysis improves on cost benefit analysis by explicitly addressing monetary value. Business case analysis is widely used as cost models to support development improvements by comparing costs before and after architecture implementation. Unlike cost benefit analysis, cost models overlook the benefits of customer-observable quality improvements, such as performance or reliability. To expand the cost-centric scope of a business case analysis to be customer-centric, it is important to provide guidance on how to assess customer-centric value. In this way, business case analysis should support architecture investments for different business goals, including internal and customer ones. Finally, real options analysis brings forward an additional value of investing in system flexibility to shorten time-to-market, enable growth and/or reduce development effort under uncertain changes. Although promising in the research community, there is little evidence of its use in practice. The reason is complex mathematical formalism that requires data that is often difficult to collect. To overcome these pitfalls and exploit the power of real options, it is recommended to apply the method to facilitate discussion in identifying options, i.e. design decisions, which create business value.

As seen above, these methods call for collecting information that might differ from what decision-makers need. The literature on the information use of experts suggests that they use fewer information cues than expected. It is recognized that experts differ from non-experts not by the amount of information they consider, but by their ability to discriminate irrelevant information. Thus, to support the “new” architecture evaluation with

relevant information, it is necessary to understand the information needs of both architects and managers.

Finally, the literature review on strategic decision-making from a management and financial perspective revealed large similarities with architecture decision-making. Strategic management tools are used as a preparation to apply soft financial techniques, which support formal procedures on architecture evaluation. When compared to existing methods, the main improvements would be in using strategy maps and balanced scorecards to link the business objectives of design decisions and related measures. In this respect, the main advantage of cost benefit analysis—mapping quality improvements to benefits—would be formalized via business objectives and related measures. The next suggestion would be to enable continuity of architecture evaluation, like in strategic decision-making, by planning architecture implementation and deployments. This would mean estimating budgets and value over the architecture’s lifetime. After the preparation process, formal financial techniques should be used, in particular, NPV rules, to support decisions. The main reason for selecting NPV over real options is due to expected difficulties for data collection.

Based on our motivation and better understanding of the research challenges, we define research questions to improve architecture evaluation in practice:

To be able to propose meaningful improvements, we need to better understand architecture investment decision-making in practice. In Chapter 1, we identified a trend towards a “new” evaluation process with active involvement of managers and a need for strategy-focused architecture investments. In this chapter, we recognized theoretical challenges that might emerge in the “new” evaluation when using the existing methods. For example (1) quantifying customer value, (2) addressing the information needs of both architects and managers, and (3) guiding the evaluation process in a systematic way to prepare for applying formalized procedures. The identified trends and theoretical challenges need to be verified in practice. Hence, the first step is a better understanding on architecture evaluation in practice by addressing *what are the practical challenges and how do they relate to trends and theoretical challenges* (chapter 3). These findings help complete a landscape on challenges in architecture evaluation and provide boundaries for conducting the subsequent studies.

Furthermore, the new evaluation calls for a better understanding of the information needs of managers, next to architects. The literature suggests that experts are biased by their domain of expertise, which might affect the information landscape. This implies that expertise in architecting and management might impose different needs in architecture evaluation. To provide relevant information in architecture evaluation, it is necessary to understand the information needs of both architects and managers. The understanding will help us to examine the applicability of the existing methods with respect to information and define possible improvements. Given that, we aimed to interview managers and architects to answer a research question, *what are information needs of architects and managers for architecture evaluation?* (chapter 4).

We cannot guarantee that information reported as needed in interviewees is actually information used in making a decision. These findings call for an investigation on *whether*

professionals use the information they ask for and on how individual characteristics (experience and roles) determine information use (chapter 5).

As seen in the literature, the main challenge with the existing methods is their lack of adequate guidance to assess architecture value efficiently, in particular monetary value. The business case analyses have been identified as the most promising and frequently used method for architecture evaluation. Despite clear guidance on estimating cost-saving value (i.e. by cost models), there is a lack of information on identifying and quantifying customer value. An increasing number of development companies rely on a customer-centric strategy and call for using customer value explicitly in architecture evaluation. Given that we define a research question, *how to identify and quantify the customer-centric value?* (chapter 6).

Finally, best practices on strategic decision-making (from management and financial perspectives) bring forward possibilities for architecture-evaluation improvements. First, there is little evidence on translating business goals into design decisions, e.g. on quality improvements (Ozkaya, Bass et al. 2008), and this link should be made more explicit, for instance by using strategy maps and balanced scorecards. Furthermore, planning the project within a business case analysis might maximize architecture utilization. Finally, NPV is recognized as a promising formal decision rule that can be extended to real options if data are available. Given this fact, we raise the last question, *how to propose a systematic method for supporting a decision on architecture investments based on best practices in architecting and strategic decision-making and by considering information needs of architects and managers?* (chapter 7).

3 Practical challenges in architecture investment decision making: a business case at Philips Healthcare

In chapter 1, we recognized a trend towards “new” architecture evaluation to support the joint activities of architects and business managers to make strategy-focused architecture investments decisions. Next, chapter 2 brought forward the theoretical challenges in support decisions. To propose meaningful improvements in practice, we needed to understand how trends and theoretical challenges actually correspond to practical challenges. In this chapter, we examine the theoretical challenges and trends in investment decisions for an architecture project at Philips Healthcare.

According to Nord et al. (2009), business managers and architects are responsible for ensuring that information is complete for an architecture evaluation. The business manager is the spokesperson for the business goals facilitated by the system. These goals include meeting the needs of the customer and the objectives of the organization building the system. At the same time, the architect creates architecture by making a set of the most important design decisions. To communicate the implications of those design decisions to business managers, the architect collects information related to technical feasibility, difficulties for implementation, and potential risks. In a review meeting, architects provide information to business managers to facilitate a discussion whose ultimate aim is to support a business case analysis.

The strategic nature of architecture investments (Malan and Bredemeyer 2002) suggests exploiting economic techniques used when making strategic investment decisions (Smit and Trigeorgis 2004). A large research community has examined how to use real options, an established method for strategic investment evaluations, in diverse software investment initiatives (Sullivan, Chalasani et al. 1998; Erdogmus and Favaro 2002; Baldwin 2006; Erdogmus 2006). Real options show two benefits when applied to architecture investments. First, real options help identify options in system design that might create additional system value depending on how the future unfolds (Wang and Neufville 2005). Second, real options help quantify additional architecture value under uncertainty, when net present value is just below zero. Despite its high potential, challenges such as a lack of data and a complex mathematical formulism hinder its use in practice, resulting in little evidence that real options are used (section 2.2.3). Thus, the examples mostly refer to methodological challenges and theoretical studies (Borison 2003). This perspective might explain slow adoption of real options in the corporate world (Copeland and Antikarov 2003), in particular in software development (Erdogmus 2006). According to Amram and Kulatilaka (1999), one way to overcome practical challenges is to use the real option way of thinking heuristically rather than literally. This means exploiting the power of real options to identify a source of value in investments and to find simplified techniques to quantify that value.

We conducted two studies at Philips Healthcare. In the first study, we aimed to better understand an official process to support decisions for architecture investments in a project at Philips Healthcare. First, we describe the official process in general, addressing

stakeholders and their responsibilities. Then, following the completion of the official process, we reconstructed the architecture-project evaluation used by the expert team to support the final investment decision. Based on the findings, we discuss how trends in the new evaluation (chapter 1) are mirrored in practice. In the second study, we aim to identify practical challenges in decision-making on architecture investments. As seen in the literature (sections 2.2 and 2.4), business case is the most frequently used method. Real options are the most adequate method to address strategic value, but little evidence suggested it was used in practice. Therefore, we proposed to combine the best of the two methods by using the power of the real options way of thinking with the business case analysis. This new combined method should then be applicable in practice. Next, we collected data, together with practitioners, that would be necessary to support a decision. In a subsequent review meeting with practitioners, we discussed the pros and cons of the expert team's decision-making and applied the real options way of thinking.

Ultimately, based on the findings from the two studies, we identified key practical challenges in making decisions for architecture investments.

This chapter is organized as follows. Section 3.2 presents the study design and elaborates on the steps for each study. Then, section 3.3 introduces the organizational context in which the case study was conducted (Philips Healthcare) and describes the real-world case, a decision on phasing out legacy software. Next, section 3.4 analyzes the decision-making process in a legacy phase-out project by the expert team at Philips Healthcare. Section 3.5 elaborates on the decision-making by applying the real options way of thinking to this same project and identifies improvements. Based on the findings of the two studies, section 3.6 highlights key practical challenges to support decisions on architecture investments. Finally, section 3.7 concludes on how practical challenges correspond to trends and theoretical challenges of “new” architecture evaluation.

3.1 Study design

The objectives of this investigation are to:

- 1) investigate how the new architecture evaluation corresponds to the decision-making process in practice;
- 2) investigate possible improvements by applying the real options way of thinking; and,
- 3) generalize findings to highlight practical challenges in making architecture investment decisions.

Understanding the practical challenges to support architecture investment decisions calls for case study research (Yin 2003; Dul and Hak 2008) in a natural environment (Schmitt 1997). We selected a case from the Magnetic Resonance Imaging (MRI) business at Philips Healthcare, the Netherlands. The system and organizational complexity of MRI was expected to highlight a broad span of practical challenges that could be applicable in similar or less complex environments. Philips suggested a representative case for this study, a decision on a legacy phase-out project, which had been made just before the study. In this way, we were able to reconstruct the decision-making process on a project

without influencing it (as the decision had already been taken). The case selection was driven by the fact that such decisions were frequent in the organization.

The study design is shown in Figure 2.

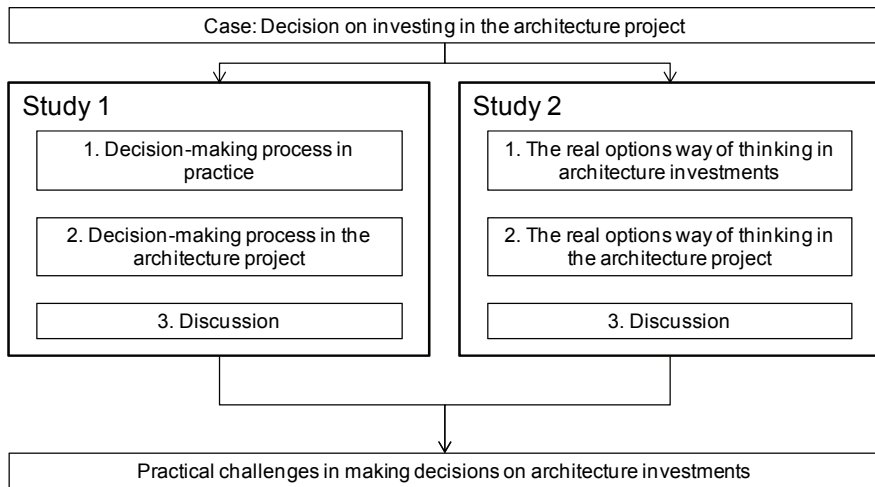


Figure 2. Study design

Study 1 contributes to the first objective. The study follows three steps. The first step, *Decision-making process in practice*, aims to understand the decision-making process on architecture investments in practice in general. To describe the process, we use an established framework for the software development process, namely the Rational Unified Process (RUP) (Kruchten 1999). RUP describes the process as *who* is doing *what*, *how*, and *when*. *Who* refers to stakeholders (for instance, architects and business managers) that are using information (*what*) to support activities of architecture evaluation (*how*) at a particular moment in the process (*when*). In the second step, *Decision-making process in the architecture project*, we map decision-making in the given architecture project on to the process defined in the first step. The findings are discussed in the third step, *Discussion*.

Study 2 contributes to the second objective. Study 2 follows three steps. The first step, *The real options way of thinking in architecture investments*, roughly proposes how to support a decision on architecture investments in practice. The second step, *The real options way of thinking in the architecture project*, uses guidance from the first step to collect data to support a decision in the case. Next, in the third step, *Discussion*, the findings from the two studies are presented to relevant practitioners at Philips Healthcare to discuss possible improvements.

Finally, based on the findings of the two studies, we highlight the practical challenges to support architecture investment decisions.

The main sources of evidence for both studies were weekly meetings with the lead architect of the project (in total 50 hours) and internal project documentation. This helped us learn about the domain, the organization, and the particularities of the project. Next,

following suggestions of the lead architects, we interviewed more than 20 related stakeholders who might have been affected by the given architecture projects. The stakeholders had different roles, such as business managers, marketers, third party translation services, clinical scientists, system designers, etc. The findings were used in both studies. However, in the second study, when we applied the real option way of thinking, we needed additional sources of evidence: five hour-long interviews with marketing and clinical experts, two two-hour workshops with architects, and using the *Clarity resource management tool* (2010).

3.2 Case: Phase out legacy at Philips Healthcare

In this section, we introduce Philips Healthcare and our cooperation in conducting the case studies described in this thesis. Then, we describe the real-world case, a decision to invest in phasing-out legacy software.

3.2.1 Philips Healthcare

Philips Healthcare is the main pillar in driving the “Vision 2010” strategy of Philips as a people-focused, market-driven company. Philips Healthcare offers imaging systems, home healthcare solutions, clinical care solutions, healthcare informatics, and customer services. With 35,000 employees, more than 450 products, and services in over 100 countries, Philips Healthcare has created sales in 2008 of more than EUR 7.6 billion (2009).

Case studies conducted for this thesis were hosted by the Magnetic Resonance Imaging (MRI) business at Philips Healthcare, the Netherlands. The MRI business is one of the top-five businesses focusing on developing software-intensive imaging systems for diagnostics and treatment, such as MRI scanners, workstations, or clinical applications for the professional market. There is a large amount of complexity—both system and organizational—involved when developing MRI systems, as seen in Table 1. For example, the MRI systems are organized in families of product lines to reuse software (ten million lines of code) and to enable parallel development (van der Linden, Schmid et al. 2007). The organizational complexity brings forward a challenge to use adequate processes in guiding more than 400 developers on multi-development sites to bring a product to market in a timely fashion. Furthermore, more than 20 years of development and knowledge embedded in MRI architecture makes it a crucial asset in driving their business.

We acknowledge that the MRI system is not unique with respect to its complexity. Many systems of comparable complexity exist, such as wafer steppers used in the semiconductor industry, airplanes, automobiles, cellular phones, and copiers. We think, however, that the system and organizational complexity related to the MRI system will highlight a broad span of practical challenges to tackle when supporting architecture investment decisions.

Table 1. System and organizational complexity at MRI, Philips Healthcare by Laar et al. (2010)

Item	Quantification (approximately)
Total MRI FTE's (sales, service, ...)	1,000
Multi-site development (worldwide)	Three main sites and a few satellites
Subsystems	Ten
Different technologies used	50
Development FTE's	Hundreds (multidisciplinary)
Software engineers	150
Programming languages	Ten
Lines of code	Ten million
Installed base (worldwide)	7,000

The main incentive for Philips Healthcare to participate in our case studies was to improve their decision-making process on architecture investments. Thus, reciprocal learning was expected, with investigator(s) learning about practical challenges and the organization learning about possible improvements.

Case studies were selected from an ongoing development project in MRI. For each case study, the architect of a particular project was assigned to the author of this thesis (an investigator) to supervise the investigator, half a day per week. This meant teaching about the domain, identifying practical problems, and serving as a peer contact to diverse stakeholders such as managers, marketers, and developers. The encounters likewise included the architect learning from the investigator on how to possibly improve decision-making in practice. An inevitable part of each case study was a review meeting with practitioners to evaluate our findings.

3.2.2 The legacy phase-out project

Philips Healthcare asked us to analyze an expert team's decision-making in the legacy phase-out project (a decision had already made) and to propose improvements for similar projects.

A reason for selecting this case was three-fold. Methodologically, an investigation of a past decision does not influence experts. Organizationally, the decision was not driven by economic value, and we were expected to propose improvements to address this challenge. Next, such decisions on phasing out legacy software were frequent. As explained earlier, the existence of legacy software is result of a common practice in the professional healthcare market to introduce new software in parallel with existing software, which is expected to become redundant. Such development strategies reduce development risk and better manage market acceptance of newly introduced software.

Therefore, a decision on phasing-out legacy software was an important case for investigation.

An MRI scanner is a complex, software-intensive system used for acquiring and post-processing medical images. At the moment of this study (2007), image acquisition was controlled by one of two software environments. The operator could use old software, so-called Scan Control/Scan Define (SC/SD), to tune numerous parameters (more than 400 available) for optimizing image quality and acquisition time. Alternatively, the operator could use new technology, the so-called ExamCard (EC) environment, to select a predefined clinical procedure for body parts (head, body, or cardiac), which automatically sets all parameters related to the selected body part. As expected, the simplified workflow of ExamCard was readily accepted by customers quickly after its introduction (2004). Since then SC/SD continued to be used only by a few customers, such as clinical research sites or internal development groups for research purposes.

The co-existence of SC/SD and ExamCard control software caused several complaints in the development unit immediately after ExamCard's introduction in 2004. First, introduction of new features in the control software increased development effort. ExamCard software had been tightly coupled with SC/SD, implying that any market release required changes in both environments, meaning at least double the effort. Second, maintenance of the SC/SD also increased. We learned that during the last few years, many SC/SD developers left and little documentation was available. This implied that more than 10 years of development knowledge on SC/SD evaporated. For the new developers, the main source of knowledge about SC/SD was highly embedded in the source code, and it required a long time to learn the system before any change could be made.

The increased development and maintenance effort due to the legacy software led to cascading negative effects in the organization. With scarce resources, the MRI business unit was unable to allocate more people to develop new features and SC/SD maintenance, which resulted in a prolonged and generally unpredictable time-to-market. To solve the problem, the architects proposed to phase-out the SC/SD software to reduce development effort required for new features, hence, shortening time-to-market. The main requirement was to keep all clinical functionality operational in both software environments during and after the phase-out period.

It was decided to propose multi-site architecture projects in India and the Netherlands. Outsourcing software development to India was driven by the high software competence and processes quality combined with the lower wages. This project was the first cooperation project of its kind, and it was expected to become common practice at the MRI business.

The decision to invest in the SC/SD phase-out was made at the beginning of 2006 after six months of architecture evaluation.

3.3 Study 1: The legacy phase-out decision by the expert team

Study 1 aims to better understand how new architecture evaluation, which requires active management involvement and strategic focus, corresponds to evaluation in practice. We describe a decision-making process at Philips Healthcare, analyzing how this process maps to the architecture (phase-out legacy) project, and discuss the findings.

3.3.1 Decision making at Philips Healthcare

At Philips Healthcare, there is a dedicated business initiation team (BIT) responsible for making decisions on investments on a portfolio of development projects with limited resources. Development projects cover any initiative that requires changing a system design and involves more than several developers, such as releasing a new product, large software releases, or architecture changes. Given the diversity of projects and knowledge needed to assess the project's impact on business, BIT assigns an expert team to evaluate the project and provide recommendations on the project investment. The expert team follows a formally defined and documented process, so-called *project preparation*, to evaluate the individual development project.

The project preparation process consists of two phases, *project proposal* and *project definition and planning*, as shown in Figure 3.

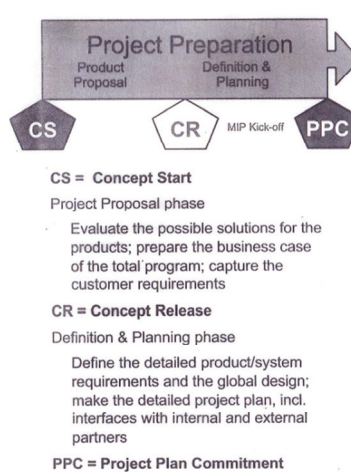


Figure 3. Project preparation at Philips Healthcare (2007)

When BIT recognizes a need for a project that requires significant resources, it initiates the project concept start. This is the beginning of the project proposal phase. In this phase, possible solutions for product development are evaluated with respect to meeting customer needs and promising business case. Based on the evaluation, the expert peer reviewers make a decision on a concept release—that is whether to continue to the next phase—and then continue to project definition and planning. This is an informal decision on the potential of a project, which is then evaluated again after collecting more evidence in the following phase. The following phase is executed only if the project proposal is approved. In the definition and planning phase, the project is defined in more detail with respect to system design and project planning. Ultimately, the expert team presents the consolidated findings from the project preparation to BIT, which then decides whether to invest in the project. The BIT decision on project investment results in a project-plan commitment with allocated resources. It is important to notice that the project investment decision is considered final only when resources are allocated.

The expert team assigned to conduct the project preparation involves diverse stakeholders, as shown in Table 2.

Table 2. Stakeholders and their responsibilities in the project preparation phase at Philips Healthcare (2007)

Roles	Project preparation	
	Project proposal	Project definition and planning
Development	<ul style="list-style-type: none"> • Proof of concept <ul style="list-style-type: none"> - Possible solutions and feasibility results - Patent issues identified - Technical Proposals - Platform solution 	<ul style="list-style-type: none"> • Global (high level) design • System requirements specification <ul style="list-style-type: none"> - Final industrial design concept • Test strategy & plan (part of project plan)
Marketing	<ul style="list-style-type: none"> • Commercial Requirements Specification • Business case • Industrial design direction and requirements (part of commercial requirements) 	<ul style="list-style-type: none"> • Market introduction plan (part of Project Plan) • Releases for Talk
Sales & Services	<ul style="list-style-type: none"> • Unit forecast (part of business case) 	
Project management	<ul style="list-style-type: none"> • Project plan for definition and planning phase (staffing, planning and budget, charter) • Cost target setting & monitoring (part of business case) 	<ul style="list-style-type: none"> • Project plan • Project risk assessment and mitigation • Product security & risk assessment • Configuration management (part of project plan)

The selection of stakeholders depends on the project scope. The success of any development project cannot be guaranteed without development. The main representative of development stakeholders is a system or software architect who is recognized as an expert for a particular development project by his or her peers (Chi 2006), who is then named by BIT. The architect proposes possible technical solutions and provides a proof-of-concept to demonstrate that solutions are implementable. The proof-of-concept includes several activities, including a platform (architecture) solution. These responsibilities reflect the mind-set of the architect who will create the architecture and provide a proof-of-concept that will then communicate the architecture's consequences (Clerc, Lago et al. 2008). Next to development, we observe numerous roles, such as marketing, sales and services, and project management; we group them into a business manager role. The main responsibility of business managers comprise the business case analysis (marketing), which is supported by unit forecasting (sales) or cost-target setting and monitoring (project management). We also noticed that project planning is the second-most prominent responsibility of business managers. It is important to observe that little overlap exists between the business case and project planning phases. This contrasts the literature, which suggests that a successful evaluation of strategic investment

requires incorporating planning into the economic evaluation (Mintzberg 1994; Smit and Trigeorgis 2004).

The project preparation process aims to evaluate any development project, largely supporting projects with predicted outcomes (new product development) and neglects projects with large strategic impacts, such as architecture investments. In strategy-focused projects, we would expect that project planning is directly incorporated into the business case analysis. These insights provide a basis on which to analyze decision-making in the SC/SD phase-out architecture project.

3.3.2 Decision making in the legacy phase-out project by the expert team

We analyze decision-making in the legacy phase-out project by investigating *who* is doing *what*, *how*, and *when* (Kruchten 1999). We elaborate on stakeholders (*who*) and their responsibilities (*how*) in a particular phase (*when*) of project preparation at Philips Healthcare (Figure 3 on page 31 and Table 2). Then, we analyze *what* stakeholders do in the process by investigating the main elements of decision-making: objectives, information needs, and decision rules (Carroll and Johnson 1990).

3.3.2.1 Stakeholders and their responsibilities

The evaluation process to decide on investing in the SC/SD legacy phase-out lasted six months. The interviewees involved in the SC/SD project evaluation confirmed that a decision was made by following the same project preparation process as described in section 3.4.1.

In total, an expert team of four stakeholders conducted the evaluation; we group them into architects and business managers, as shown in Table 3.

Table 3. Stakeholders and their responsibilities in the SC/SD phase-out project

Roles	Project preparation		
	Project proposal		Project definition and planning
Architects	Lead architect (NL)	Make proof of concept with feasibility study of SC/SD phase-out; align it with the MRI product roadmap	Make testing strategy and plan
	SC/SD architect (IN)	Propose control software changes in the MRI architecture (part of the proof-of-concept)	Plan SC/SD phase-out integration
Business managers	Software department manager (NL)		Plan the SC/SD project with other development projects in the product roadmap
	Project manager (IN)	Plan project (coarse estimations of staff, budget, and cost targets)	Make a detailed project plan Assess risk and mitigation strategy

Given that the project was a multi-site development (in India and the Netherlands), each site was represented by one architect and business manager, each with different roles and responsibilities. The lead architect of the MRI system from the Netherlands was responsible for a proof-of-concept and how the new SC/SD architecture would be integrated into the overall MRI system architecture. The SC/SD software architect from India was responsible for proposing the SC/SD phase-out design (as a part of the proof-of-concept) and planning implementation for the SC/SD. Two business managers had also different responsibilities in the architecture evaluation. The software department manager from the Netherlands was responsible for “fitting” the SC/SD software into the MRI product roadmap. The SC/SD project manager from India was responsible for planning and executing the SC/SD phase-out project. It is important to notice that in this project, the software department manager was a member of the business intuition team (BIT), and he had the power to steer and make a decision, which was not always the case (see Chapter 7). BIT’s involvement in the project preparation was explained by the fact that this multi-site architecture project was the first of its kind at Philips Healthcare, and the software department manager wanted to learn more about the process.

Focusing on the responsibilities of architects and managers across the two phases highlighted the lack of a business case and a strong focus on proof-of-concept and project planning.

To understand the decision-making process better, we reconstructed the two-hour review meeting using internal documentation and observations of the SC/SD architect. According to the architect, two points were discussed at the meeting: a proof-of-concept of the architecture solution and project planning.

The proof-of-concept highlighted the technological advantages of deploying the service-oriented architecture when decoupling the two control software environments. We noticed that these were general advantages to service-oriented development that had been assigned to the SC/SD project, such as:

- Separating design concerns: this would imply a more predictable development effort and improved change management; and,
- Loosely coupled services allowing each service to have an owner; this implies easy implementation of new features and supports independent development of multi-site teams.

It appeared that the proof-of-concept touched upon implantation details of the project, which were linked to the project objectives: elimination of SC/SD maintenance effort and improvements in system evolvability to introduce new features with a shorter time-to-market. It was expected that benefits would be apparent after the SC/SD was phased-out. We did not observe any use of qualitative data to demonstrate the proof-of-concept.

At the meeting, in addition to a proof-of-concept, project planning was presented, which elaborated on time and effort. The effort to accomplish the project was estimated to be 24 man years (using the COCOMO II cost estimation model (Boehm, Horowitz et al. 2000)). The large investment and no previous knowledge with such multi-site architecture meant that the project was a high risk. To mitigate this risk, it was suggested to stage development over four years. Hence, the project plan proposed annual deliverables, and for

each year, this deliverable was integrated into other development projects. According to the lead architect, this staged proposal triggered a discussion on resource planning on a departmental level, which became a focus for the meeting.

A final decision on investing in the SC/SD phase-out legacy was made in consultation with the expert team. The project plan commitment was expected within a week of the review meeting.

3.3.2.2 *Objectives, information, and decision rules*

To elaborate on *what* stakeholders did in the decision-making process for the SC/SD project, we elaborate on information and decision rules applied in supporting the decision for meeting businesses objectives.

As seen earlier, the business objective of the legacy phase-out project was *to reduce maintenance effort and to improve system evolvability for easy introduction of new functionality*, which was confirmed by all interviewees. Nevertheless, we elicited other latent objectives of the project, mostly from stakeholders not directly involved in the evaluation process. For example, a clinical scientist expected *improved usability*, and accordingly, an increased number of users after the legacy phase-out. In addition, *shorter time-to-market* was implied in the documentation, though not explicitly discussed by stakeholders at the review meeting.

To demonstrate how the proposed architecture solution met the business objectives, the stakeholders used dozens of information types in the evaluation process. We distinguish between explicit (documented in internal documents) and implicit information types (residing in the people's heads). Explicit information types were used to support a proof-of-concept and a project plan. For example, to support a proof-of-concept, the architect used quality improvements, such as evolvability, development and maintenance effort, and time-to-market to substantiate a decision on a service-oriented architecture. Given information types were not quantified. At the same time, the project managers used investments and a roadmap of the related projects to evaluate the project plan in stages. In this case, the implementation time and investments were quantified.

Interviews with stakeholders not directly involved in the legacy phase-out evaluation brought forward additional information that might have affected a decision implicitly. These were mainly benefits and pitfalls of the project outside the internal development business. For example, the third-party, translation-service team indicated enormous translation-effort savings because the new features would not be translated to the legacy environment (in 25 different languages). Furthermore, clinical scientists expected more customers, that is, research hospitals using legacy functionalities who would migrate to the new, user-friendly environment. In addition to these benefits, the stakeholders also envisioned negative impact of the project on other businesses. It was expected that the legacy phase-out project would jeopardize the upgrade sales for more than 50 research sites. Thus, evaluation of the legacy phase-out project primarily focused on managing internal development business, while consequences of the legacy phase-out project on customers and other businesses was not directly discussed.

The business case in the phase-out project focused on cost benefit analysis and the economic value of architecture was omitted. However, we found evidence that a business case analysis based on economic value was used in other architecture projects (section 6.4). One explanation for this discrepancy was management's commitment to explore a new way of working, which is the multi-site architecture project, regardless of the business-case outcome. Another explanation, consistent with the motivation of this study, is the expert team's lack of knowledge on how to quantify value, which would be necessary for the business case analysis. Despite a missing formal decision rule in this project, i.e. the business case, informal rules were apparent. Informal-decision rules were, literally speaking, rationales for system design and resource management. These rationales linked information about system design (quality and maintenance and development effort) and the project plan (investments) to the business objective (reduce maintenance and improve system evolvability for easy introduction of new functionality).

3.3.3 Discussion

In this study, we aimed to better understand how new architecture evaluation, which requires active management involvement and strategic focus corresponds to evaluation in practice. In two steps, we first described the formal process to evaluate any development (including architecture) projects at Philips Healthcare. Then, we investigated the particularities of the architecture evaluation of the legacy phase-out example. We analyzed stakeholders and their responsibilities, and how they combined information to support a decision.

In general, the official project evaluation at Philips Healthcare (Table 2 on page 32) required management involvement, which confirms a trend recognized in chapter 1. Business managers' primary responsibilities lie in making the business case and defining the project plan. As expected, architects are part of the project evaluation but their responsibilities (making a proof-of-concept) are clearly separated from responsibilities of business managers (making a business case). Thus, despite active management involvement in the project evaluation, this process calls for improvements to guide joint activities of architects and managers in architecture evaluation (Nord, Clements et al. 2009).

The development project evaluation does not entirely support strategy-focused architecture project evaluation. We observed that making the business case and project planning were subsequent activities in the process. Such a project evaluation can be beneficial for development projects with predictable value creation. In contrast, strategic investments, in particular architecture separating valuation, (building business case) and project planning might disregard potential long-term value creation (Smit and Trigeorgis 2004). It is important to notice that this strategic perspective of linking two phases is not easy in practice because the business managers who are responsible for making the business case and defining the project plan are often different individuals. As seen in section 2.4, successful strategy-focused investment decisions imply that strategic planning must be a part of the economic evaluation (Mintzberg 1994; Smit and Trigeorgis 2004). Thus, improvements should propose activities that link business case analysis and project planning to accommodate strategy-focused architecture investments.

The findings on this particular legacy phase-out project confirm the general insights; business managers were involved and inadequately guided when making architecture investment decisions. Unlike the official process, the business case analysis was neglected. Instead, architecture evaluation focused on the proof-of-concept and project planning. In the proof-of-concept, architects reported on benefits by explaining how design decisions that improved quality would meet the business goals. At the same time, business managers proposed related project plans based on development effort and implementation time. Given that fact, the main discussion in supporting an investment decision was on resource management. We explain this perspective by the fact that development effort of architecture implementation (investment) was the only quantifiable information on which to base a decision. Thus, decision-making in the architecture project was more tactical in trying to manage resources rather than strategic in looking to maximize value. We conclude that the new evaluation was not entirely in place.

It is important to notice that different stakeholders used different information sets to support their architecture evaluation. For example, architects used quality attributes, maintenance and development effort, while business managers focused on investments and projects in the roadmap. Unlike architects and managers, the stakeholders not directly involved in the architecture evaluation brought additional insight to the business and customer value supported by new information types. Although we cannot be sure about the importance of the information, this strengthens our observation that information used in architecture evaluation might be people-biased. If this was true, decisions would be driven by information biased by individual preferences rather than by business-relevant information. In such circumstances, there is a need for guidance to identify relevant information to support architecture investments.

As seen earlier, although all elements for strategic evaluation are present, separated activities of architects and managers make it difficult to determine a “strategic” value for architecture investments. To shift the “old” evaluation to the “new” one, improvements should facilitate joint activities of architects and business managers in making a proof-of-concept, a business case analysis, and project planning to drive strategy-focused architecture investments.

3.4 Study 2: The legacy phase-out decision by applying the real options way of thinking¹

Study 2 aims to explore the real options way of thinking to support architecture investment decisions in practice, in particular in phasing out legacy software and to identify possible improvements. The study follows steps defined in section 3.2.

3.4.1 The real options way of thinking in architecture investments

In this section we explore how to use real options to identify sources and underline information to quantify the architecture value for a business case analysis. While exploiting the power of the real options way of thinking to identify sources of architecture value, we

¹ An earlier version of this study was published as a paper at the 2nd International Workshop on Measurement and Economics of Software Product Lines (MESPUL2008), Limerick, Ireland.

still use an established NPV decision rule to avoid practical challenges when applying real options.

It is important to notice that this exercise was mainly used to gather hands-on-experience of practical challenges in architecture evaluation. Thus, we do not claim that the proposed guidance would be sufficient to guide practitioners to support decision-making in practice.

Source of architecture value. According to Amram and Kulatilaka (1999), any strategic investment is a contingent of investments and associated decisions for those investments. Adapted to the context of architecture investments, two kinds of decisions are associated with architecture investments:

- *A decision to invest in architecture implementation (buying the option).* This decision enables architecture implementation (writing or modifying software following the guidelines of the architecture). It is important to note that during architecture implementation, we do not expect that additional value is generated.
- *Decisions to invest in architecture deployment (exercising the option).* These decisions put forward new feature developments, software upgrades, new services, or systems sold with the new architecture. A decision rule is simple: invest in an architecture deployment when the value created by this investment is larger than the investment itself at the moment of architecture deployment. Identifying design decisions, which create explicit business value, so-called options, is not straightforward (Wang and Neufville 2005).

For demonstration purposes, we visualize architecture investment decisions (Invest in architecture and Implement feature) and associated costs and values in a simplified decision tree, as shown in Figure 4.

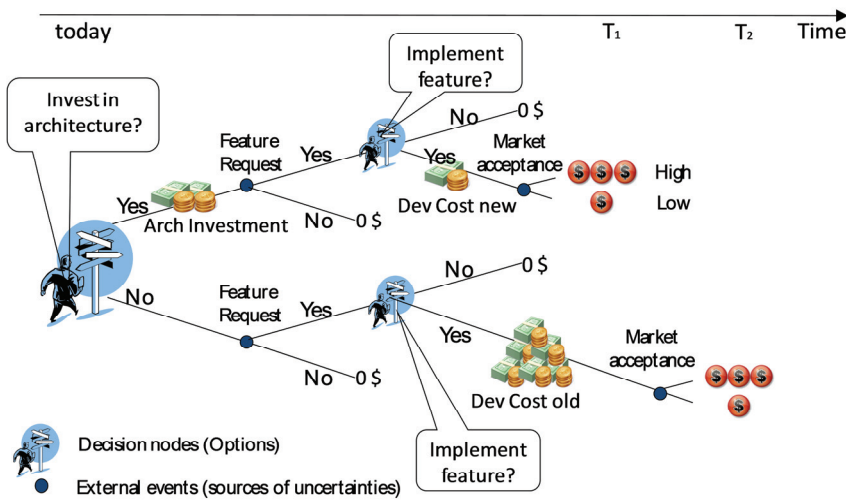


Figure 4. A decision tree of architectural investments

The first decision point, *Invest in architecture*, determines two scenarios: Invest and Don't Invest. In the invest scenario, the organization decides to implement architecture with a certain amount of effort, i.e. *architecture investment*. Time needed for architecture implementation (*implementation time*) determines the moment when the architecture can be deployed. Given that architecture erodes over time because of continued deployment and maintenance, architecture deployment has a limited timeframe. We define the time of the maximum architecture utilization as *architecture lifetime*. Although the architecture might still be deployed after the architecture lifetime, such deployments are far in the future. This means that the value created in the future is largely depreciated and contributes little to the architecture value used to support the architecture investment decisions. In the “don't invest” scenario, the organization keeps business as usual.

Regardless of the organization's decision to invest in architecture, there might be a request from customers to implement a new feature in the future. This brings forward a second decision point, *Implement feature*, to either abandon or approve feature implementation. A decision to abandon a feature would affect the associated cash flow of possible sold features. More importantly, customer needs are not met, which could reduce customer satisfaction and might result in decreased customer retention. In the professional markets (MRI business), keeping existing customers satisfied (for instance, with upgrades and new features) is a source of customer value creation (chapter 6). Thus, the organization will more likely implement a new feature. A decision to implement a feature has different consequences in the two scenarios. It is expected that the *development and maintenance effort* of a new feature is lower and time-to-market is shorter in the “invest” than in the “don't invest” scenario. Furthermore, a shorter time-to-market implies multiple benefits in the invest scenario. For example, earlier cash flow or higher market value because of higher market acceptance was offered quickly after the customer request.

Information needed to assess architecture value. A rough analysis of alternative scenarios determines the basic information needs, as shown in Table 4.

Table 4. Information needed to support architecture investment decisions

Information	Definition
Architecture investments	Costs of architecture implementation
Architecture implementation time	Time needed for architecture implementation
Architecture life-time	Time of architecture utilization
Development costs	Costs of deploying architecture to facilitate cash flow, for instance, developing the requested feature
Maintenance costs	Costs of maintaining architecture after deployment, for instance maintaining the requested feature
Market value	Value created by the architecture deployment (cash flow), for instance the value of the feature paid by customers
Deployment time	Time needed for deploying the architecture, for instance the elapsed time from the moment of the feature request until the feature implementation

Information	Definition
Time-to-market	Time when the market value (cash flow) of architecture deployment is generated, for instance time when the feature is sold
Uncertainty of feature request	Probability of a feature request
Uncertainty of market	Probability of market acceptance of a new feature

The top three information types are architecture investments, architecture implementation time and architecture lifetime, which are specific to the invest scenario. The last two information types refer to the uncertainties of the feature request and market acceptance of the feature. This information is needed for the real options analysis. Given a practical challenge to identify how the architecture creates value, rather than estimating the value of real options by applying the complex mathematic formulism, we do not make use of uncertainty. The remaining information types, including cost, value, and time, refer to both scenarios and should be used for each scenario independently. Not only are the amount of cost and value (cash flow) different across the scenarios, but cash flow also depends on the time when it is generated.

The identified information types are the base sources of architecture value, in particular the flexibility to deploy decisions with different timelines. We expect that the information landscape would be more elaborate in practice and needs to be tailored to each particular case. Thus, with this example, we succeed in making it explicit how architecture value is created when architecture investments are analyzed as a set of investment decisions.

Decision rules. The value of architecture investments lies in architecture deployments with lower costs, quicker time-to-market, and higher market value that generates larger cash flows. A decision on architecture investment depends on whether the architecture value pays off the architecture investments within the architecture lifetime. Thus, the first decision, invest in architecture, is based on one of the following decision rules:

- The Net Present Value (NPV) rule supports a decision to invest in architecture when the present value of cash flow facilitated in the invest scenario is greater than cash flow facilitated in a “don’t invest” scenario. If NPV is just below zero and uncertainty is high, the organization should consider the added value of architecture flexibility to NPV and apply the real options rule.
- Real options rule supports a decision to invest in architecture when the option value calculated using Net Present Value and Market Assessment Assumption (Copeland and Antikarov 2003) is greater than zero. How to perform this calculation can be found in the literature (Cox, Ross et al. 1979; Copeland and Antikarov 2003). Since the source of architecture value was identified as the main practical challenge of this chapter, calculating the option value is outside of the scope of this thesis.

3.4.2 *The real options way of thinking in the legacy phase-out project*

We apply the real options way of thinking to support a decision on phasing-out a legacy product. The finding of this and the previous study were presented to the marketing expert and the software department manager. They evaluated decision-making by the expert team and by applying the real options way of thinking.

In this study, we reuse numerous sources of evidence from the previous study, such as internal documentation and interviews, complemented by the main study findings. Nevertheless, to apply the real option way of thinking to identify the value, we needed additional sources of evidence: five interviews with marketing and clinical experts to elicit possible market value, two workshops with architects to identify cost-savings, and using the *Clarity resource management tool* (2010) to analyze maintenance effort.

3.4.2.1 *The legacy phase-out decision*

Source of architecture value. To identify the source of architecture value, we investigated the legacy phase-out project as a set of investments.

First, we recognized that the phase-out investment is divided into four stages, totaling 24 man-years over four years. At each stage, an investment of six FTE was expected to deliver value to other projects on the roadmap in the organization (section 3.4.2). It is important to note that the staged investments are not options because they do not represent decision points. The staged investments might create value if the projects on the roadmap used the legacy phase-out benefits. The project on the roadmap could also be delayed and then the benefits of the phase-out project deliverables would not be exercised. Regardless of the value created by the staged investment, the subsequent investment is guaranteed by a project plan commitment. On the other side, applying the real options would mean that a decision on subsequent investment for the phase-out project is made only if the value created by the annual investment is larger than the total investment.

Second, we expected a set of deployment investments would occur after the legacy phase-out, which would then create market value and cost savings, analogous to the decision three examples. For example, the legacy maintenance effort would be zero after phasing out the legacy software. We also think that the legacy-phase project would bring development-effort savings and market value via quicker releases of new functions in the control software.

Thus, we expect that the legacy-phase out project would create value by (1) delivering benefits to the projects on the roadmap during the legacy phase-out (2) eliminating maintenance on the legacy software, and (3) reducing development effort and shortening time-to-market for new function developments.

Information needed to quantify architecture value. The findings in section 3.4 provided insights on *architecture investment*, which would be 24 man years, representing an *architecture implementation time* of four years. Furthermore, the lead architect estimated that the *architecture lifetime* would be five years, which is consistent with other architecture pro-

jects at Philips Healthcare. In a five-year roadmap possible benefits of architecture changes are explicitly documented.

We continued to investigate the value of the legacy phase-out delivered to the projects on the five-year roadmaps. The interviewees disclosed that the legacy phase-out project enabled the existing projects on the roadmap to continue new development without making it compatible with the legacy environment. Thus, the projects on the roadmap would save development effort; we name this compatibility effort savings. It is important to notice that in resource management, tool compatibility effort would be recorded as development effort for the running projects; therefore, it would not be directly connected to lost effort due to SC/SD compatibility changes. This means that in the architecture evaluation, the value of compatibility effort savings across the roadmap projects would not be accounted for at all.

With this insight, we organized a two-hour workshop to estimate compatibility effort savings with existing projects in the organization, touching upon legacy software. The workshop involved all software architects in the organization leading projects that could be affected by the elimination of the legacy software. We began the workshop by presenting the objective of this study and the real option framework for assessing the architecture value. Then, we asked architects to identify past (2006), existing (2007), and planned projects (2008-2011) affected by the phasing out of the legacy product. In total, six projects were identified, as shown in Table 5. Finally, we asked the architects to estimate additional effort (maximum and minimum), which would be spent in a particular development project per year, if the legacy remained.

Table 5. Compatibility effort savings per project per year (FTE)

Project name	Year	2006	2007	2008	2009	2010	2011
Asterix		2	6±2	6±2	-		
Abraracourcix					6±2	6±2	...
Idefix		5±2	-				
Assurancetourix		3±1	3±1	-			
Panoramix				3±1	3±1	...	
Obelix				3±1	-		

The estimations are presented in Table 5. Although the architecture lifetime is five years after the implementation, the architects were able to provide estimates only for the first five years from the moment of architecture implementation. The reason is that the product roadmaps and development project planning is based on the five-year time window in the organization. Looking at the data in Table 5, we noticed a pattern emerging in a project planning chronology. For example, Abraracourcix is a project planned in 2009 as a successor of the Asterix project, which would be finished the year before, in 2008. Similarly, Panoramix would be a successor for Assurancetourix. We could conclude that although a project changes its name, the compatibility effort savings of the project in the context of legacy would stay the same over the next years. This suggests continuous savings of 9-10 man-years each year, even after year 2010. It is important to notice that the

projects in professional healthcare have a relatively long time-to-market, and it allows releasing features without backwards compatibility, which might not be the case in the consumer market.

When considering the maintenance effort in the phase-out legacy project, we realized that after phasing out legacy, maintenance of legacy effort would be zero. Thus, the maintenance effort is apparent only in the “don’t invest” scenario. This is consistent with the expert team’s observation in section 3.4, who claimed large maintenance effort savings; however, there was no quantified evidence to support this claim.

The lead architect helped to gather historical data to estimate the amount of effort spent maintaining legacy before the legacy phase-out project started. Together with the lead architects, we used the resource management tools to assess tasks associated with the software-legacy maintenance and related time spent. In total, one FTE in 2004 and 0.1 FTE in 2005 were spent on maintaining legacy. It was interesting to notice that this tool was implemented in 2004 and the maintenance effort of legacy before 2004 was not accessible. Furthermore, we observed that identifying maintenance-relevant tasks was an issue. The reason was that time archiving was mainly used for project management purposes and task naming was mostly determined by the project deliverables. This meant that without architects previously involved in past legacy activities, data collection would be impossible.

The low maintenance effort required to maintain the legacy was a surprise. Even if we extrapolate the historical data to reach a ten-time increase of legacy maintenance effort in five years for the “don’t invest” scenario (Table 6), the maintenance effort savings can be ignored when compared to the 24 man years required to phase out the legacy.

Table 6. SC/SD Legacy maintenance effort (fte): historical (2004-2005) and predicted data (2006-2010) in the “don’t invest” scenario

	Year	2004	2005	2006	2007	2008	2009	2010
Maintenance effort								
Historical data		1	0.1					
Predicted data				0.2	0.4	0.6	0.8	1

Our next challenge was to identify functions that would create value by development effort savings or increased market value after the legacy would be phased out. To identify such features, we interviewed several stakeholders that were mainly customer representatives. The stakeholders had difficulties envisioning new features, applications, or businesses in the future with significant differences in development effort and market value. Nevertheless, they agreed that such benefits might be recognized once the software is in use. One explanation is similar to what we observed with the architects: practitioners might have difficulties to think beyond the roadmap horizon. Given that, we simplified our estimation model, neglecting the value of the new features.

Decision rules. Based on the compatibility effort savings (minor maintenance effort savings were neglected), we applied the NPV decision rule (section 3.5.1) to support a decision on architecture investments.

Figure 5 visualizes compatibility effort savings and architecture investments in SC/SD during implementation and shows that the effort savings outweighs the investments. This finding justifies a decision to invest in the SC/SD phase-out.

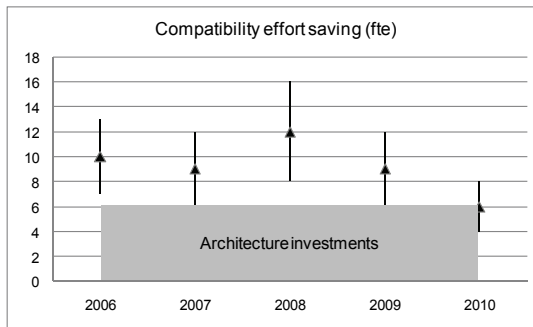


Figure 5. Compatibility effort savings and architecture investments in the SC/SD phase out project over architecture implementation

It is interesting to notice that even if the organization decided to reevaluate the staged investments every year (creating the option), the decisions on the 24 man years would still be positive.

3.4.3 Discussion

In the two-hour review meeting, we presented our findings on the legacy phase-out decisions that had been guided by the experts, and applied the real options way of thinking. The reviewers included two members of the expert team (the lead architect and the software department manager) and the head of marketing. The aim of the meeting was to discuss how decision-making by the expert team compares to the real options way of thinking with possible improvements. The findings were analyzed by the author of this thesis and another investigator, who was also present at the meeting.

The real options way of thinking vs. expert team evaluation had several advantages.

The decision was based on a business case analysis. In this respect, we followed the official process for project evaluation (see Study 1, section 3.4.1), which was neglected by the expert team. As seen in Study 1, the expert team made their decision based on the rationales of reducing maintenance and development effort and estimating investments. The informed decisions also challenged the “gut feeling” of architects on high maintenance costs, which appeared to be a wrong decision driver. The reviewers expected the business case would shift the focus of architecture investments from “gut feelings” and resource management to value creation, allowing decision-makers to assess architecture projects side-by-side with other development projects.

The real options way of thinking quantified the architecture value in ways that the expert team could not. Our approach for identifying the source of value and data collection brings forward a few points of discussion.

First, we identified new sources of value not anticipated by the expert team (compatibility-effort savings). By applying a concept of architecture as a set of investments, we demonstrated that architecture value could be created not only after, but also during implementation. Furthermore, architecture value should be assessed in a broader context by including related development projects. This was unexpected and triggered discussion on potentially extending the boundaries of the business case analysis (compared to the official process in section 2.3.1) to include cross-benefits to other projects or businesses.

Second, practitioners acknowledged the value of architecture flexibility assessed by the real options. However, they were concerned about how the proposed method would address the value of architecture projects that improve customer-observable quality attributes of the system, such as usability, reliability, or performance. Similarly, the head of marketing asked for a support tool on architecture-investment decisions that would be aligned with the Philips strategy: a customer-centric and market-driven organization (section 3.4.1). This means that next to cost-savings value, we would need to demonstrate the impact of architecture changes on established measures in the organization, whether customer satisfaction or revenue.

Third, the reviewers were concerned about the quality of data for value quantification. This was especially apparent when discussing the low legacy maintenance effort, which challenged the expert's expectations. The main concern was the completeness of maintenance-relevant tasks that the lead architect retroactively identified using the resource management tool. This perspective highlighted a need for creating infrastructure, in particular tools for data collection to support informed decisions. Therefore, the reviewers suggested tagging maintenance-related tasks in the resource management tool. It is important to notice that practitioners did not question the subjective estimation of compatibility-effort savings. Apparently, subjective effort estimation within the roadmap planning was established practice. This means that architecture valuation is only feasible when practitioners' estimates are reasonable, i.e. within the project roadmap timeframe.

After a discussion of the advantages and implications of using a business case analysis and quantified value, practitioners posed their expectations on further improvements in supporting architecture-investment decisions.

All reviewers agreed that the architecture evaluation should be a part of the existing project evaluation process. This means, we should propose a structured approach for architecture evaluation built upon architecture proof-of-concept, business case analysis, and project planning. The envisioned improvement gives detailed guidance to identify the source and quantity of the architecture value, which might be particular to the architecture project compared to other development projects. It is expected that "small incremental improvements" would more likely be accepted (Rogers 2003).

The new evaluation should support a broad spectrum of business goals facilitated by architecture, and not just business objectives, to support flexibility like in the real options. Given the Philips customer-centric strategy, assessing the impact of architecture changes on customer-centric value was necessary. The head of marketing proposed to exploit existing best practices in the organization for further improvements.

3.5 Practical challenges to support architecture investment decisions

Based on the findings of the two studies, we highlighted the main practical challenges to support a decision on architecture investments.

The new architecture evaluation process is not entirely supported. As we have seen in Study 1, development project evaluation might not be suitable for architecture-project evaluation (section 3.4). Development projects are often different from architecture because they have shorter implementation times, predictable benefits, and straightforward value assessments. Unlike development, architecture projects might have a source of value spread across different projects that is difficult to identify and quantify (Study 2). This means that architects and managers should work together to identify design decisions and their impact on business architecture evaluation. In contrast, as seen in Study 1, business managers and architects have disjointed activities with no clear overlap in architecture evaluation. Furthermore, the main strategic value driver linking project planning with economic evaluation was not explicit. Regardless of the particularities of architecture projects, according to practitioners, architecture evaluation has to follow the established process in the organization (section 3.5.3). The reason is that any process change in a complex organization requires cultural changes which would then necessitate large management effort that would go far beyond the scope of our research project. One can argue that we would never improve “obsolete practices” in organizations if we followed this reasoning. However, we believe that innovative thinking can only be accepted if it is based on small incremental changes (Rogers 2003). Thus, to increase adoption of research results in practice, we accept identified challenges as requirements for improvements to architecture evaluation.

Improvements will only be accepted if based on best practices. As we have seen in Study 2, the business case analysis was highly appreciated, as it was established practice for project evaluation in the organization. This is consistent with our literature finding on the business case analysis as the most promising method for architecture evaluation (section 2.2). Similarly, it was evident that proposing improvements by exploiting best practices in the organization (as suggested by the head of marketing in Study 2) or exploring approaches benchmarked in industry (for instance, the real options way of thinking in Study 2) would accelerate adoption. To tackle this challenge, it is necessary to have a good understanding of best practices in architecting and strategic decision-making (section 2.4).

Decisions are driven by incomplete information and “gut feelings”. As we have seen in Study 1, architects and business managers used a disjointed set of information, particularly for “proof-of-concept” and project planning. Besides that, the stakeholders not directly involved in architecture evaluation brought additional information on business and customer value that was not considered in the process. In Study 2, we also highlighted new information that was neglected. Furthermore, in section 2.5.2, we observed that practitioners made false assumptions based on their “gut feelings” (unexpectedly, legacy maintenance effort was low); therefore, they made uninformed decisions. In such circumstances, without a structured process on eliciting relevant information for evaluation, people can be strong catalyzers or inhibitors of particular information use. This observation is consistent with our literature findings on information use biased by expertise.

Infrastructure for data collection is missing. This challenge is not specific to architecture evaluation. As seen earlier, the existing tools in practice (for instance, the resource management tool in section 2.5.2) are currently not used to collect data to support architecture investments. Although tool improvements can be suggested (for instance, tag-maintenance effort in the resource management tool), it will take time for these tools to become an archive of meaningful historical data. In the meantime, an organization without an established infrastructure has to rely on the experience of architects and business managers to subjectively estimate data. It is important to note that subjective estimates beyond the five-year roadmap planning are difficult to make (section 2.5.3). For practitioners without a roadmap, estimation becomes uncertain and increasingly vague. We acknowledge this practical challenge, and given the scope of this thesis, we decided to deploy subjective estimates as a common practice in subsequent studies in this thesis. This can explain the challenges in using real options analysis, as seen in section 2.2.3.

3.6 Conclusions

Meaningful improvements on architecture evaluation require a good understanding of the practical challenges in supporting architecture-investment decisions. To identify practical challenges, we examined new evaluation trends (chapter 1) and the theoretical challenges of applying the existing methods (section 2.2) in practice. We conducted two studies on the example of a legacy phase-out decision at Philips Healthcare. In the first study, we investigated how decision-making by experts matched the new evaluation with management involvement and strategic focus. In the second study, we discussed the expert team's decision-making and applied the real options way of thinking to the same project to identify possible improvements. The findings of the two studies highlighted practical challenges to support architecture-investment decisions.

We learned that the new architecture evaluation process was partially supported in practice. This means that despite manager's involvement, managers and architects had clearly separated responsibilities, which is not desired (Nord, Clements et al. 2009). Few overlaps between responsibilities made it difficult to identify and quantify the "strategic" architecture value to support a business case analysis. Despite that, the practitioners explicitly asked for improvements that fit within the existing processes to avoid process changes in the organization. This means improvements should be built upon architects' and managers' responsibilities, such as proof-of-concept, business case analysis, and project planning in a more cooperative way.

Challenges are mostly the same in practice and theory. However, when implementing the decision-making process in practice, there are additional challenges not examined explicitly in theory.

Quantifying architecture value was crucial to support informed decisions. Furthermore, business case analysis was an established method for developing project evaluation. Without quantified values, decisions by experts were based on the size of investments and false "gut feeling" assumptions. Consistently within the literature, practitioners asked to measure both the cost-savings for customer value and to improve business case analysis (section 2.2.2). Improvements should be based on best practices to increase adoption rates.

It was also apparent that without guidance on relevant sets, information selection is driven mostly by the responsibilities of practitioners. We know that this phenomenon is also apparent for other experts (Chi 2006). Although, this is not a challenge to the “old” evaluation with separated responsibilities, information overload might occur in the new evaluation. Knowing that irrelevant information is misleading in making decisions, improvements should address relevant information for architects and managers, who are driven by business goals.

Finally, the challenge is to provide systematic guidance that helps architecture evaluation explore “best practices” within the officially-defined process. Organizational infrastructure might also be a barrier in data collection. However, it is acceptable to use subjective estimates in the time span when practitioners are able to assess changes reasonably well.

We take these insights as boundaries of our research proposals. With trends (chapter 1), theoretical (chapter 2), and practical challenges in this chapter, we completed an overview on the challenges in making architecture investment decisions (part I of this thesis).

PART II: Information

4 Information needs of architects and managers for architecture investment decisions²

In chapter 3, we observed that a decision to invest in a real-world architecture project was based both on explicit information provided by architects (quality improvements, investments, and implementation time), and on implicit information from managers (time-to-market or customer satisfaction). To support decisions based on business rather than individually biased information, it is necessary to improve our understanding of relevant information for decision-making. In this chapter, we aim to identify information needs built on interview findings with architects and managers. Furthermore, the findings are used to analyze whether the existing methods (see section 2.2) provide sufficient information for architects and managers and identify possible improvements.

According to Carroll and Johnson (1990), information—next to objectives and decision rules—is a crucial element of decision-making. In section 2.2, we analyzed how these crucial elements fit in existing methods for supporting architecture-investment decisions. As discussed, economic decision rules were apparent in all methods. However, each method supports a particular objective of architecture evaluation, which consequently determines information selection. For example, cost-benefit analyses support an objective to optimize architecture design by trading off quality attributes; they require knowing the benefits of quality-attribute improvements and investments (Kazman, Asundi et al. 2002). Next, business-case analysis, in particular cost models, support a decision on development-process improvements, which requires knowing development-effort savings, product-portfolio size, and investments (Böckle, Clements et al. 2003; Clements, McGregor et al. 2005). Finally, real-options analyses (Bahsoon and Emmerich 2003; Baldwin 2006) support investments in flexibility to allow quicker reactions to market changes; they use investments, cash flows, and uncertainty information. Each method exploits only a few, quite different information types, with the exception of investments. The open question is whether the identified information sets used in the existing approaches is sufficient for deciding on architecture investments in practice. One way to answer this question is to interview practitioners about their information needs during decision-making and then to compare the information deployed in the existing methods (see section 2.2). We are aware that the information needs reported by practitioners may not actually be used in the decision-making that is investigated in the following chapter.

Architects and managers are experts for architecture evaluation because they have been selected as experts by their peers (Chi 2006). The literature also suggests that expertise is domain-specific (Chi 2006). This implies that experts' actions should be investigated in informal domains, particularly in architecting and management, and in formal domains, such as healthcare, automotives or telecommunication. In this chapter, we focus on the information aspects of decision making by architects and managers. Regardless of the domain in which a decision is made, experts only use a few information cues in their decision-making (Shanteau 1992). For example, medical radiologists used two to six cues (Hoffman, Slovic et al. 1968) and medical pathologists one to four cues to make their di-

² A shorter version of this chapter was presented at the 1st International Workshop in Product LinE Approaches in Software Engineering (PLEASE2010), Cape Town, South Africa.

agnoses (Einhorn 1974), while stockbrokers relied on six to seven cues in their judgments on stock prices (Slovic 1969). In these studies, analyses of experts revealed a small number of significant cues. Yet in each case, more (often much more) information was available. This suggests that experts may make important decisions without adequate attention to a complete set of cues. In addition, what differentiates a more and less experienced expert was not the amount of information, but their selection of relevant information (Shanteau 1992).

To improve our understanding on the information needs of architects and managers, we interviewed them. In total, we conducted interviews with ten architects and nine managers at Philips Healthcare, each with experience in the healthcare domain. The quantitative analysis of 19 interviews unveiled that, on average, 7 to 11 information types were reported as needed; a larger number than actually used by other experts in decision-making. Furthermore, information needs were different for architects and managers; architects focused on system-specific data while managers on financial information. Based on the findings, it appears that existing methods partially fulfill the information needs of practitioners, meaning further improvements could be made. However, before we draw such conclusions, we investigate how the information reported as needed was actually used in making a decision in the following chapter.

The rest of this chapter is organized as follows. Section 4.1 presents the study design and the questions used for the comparative analysis. Section 4.2 describes the preliminary information set needed for decision-making. Section 4.3 quantitatively verifies the information needs of architects and managers. Section 4.4 presents results of a comparative analysis between the information needs of architects and managers. Section 4.5 discusses the consistency of these results with the findings of the previous chapters and then indicates implications for existing methods in architecture investment decisions. Finally, section 4.6 presents conclusions on how these implications are addressed in the next chapters.

4.1 Study design

The main aim of this study is to identify the information needs of architects and managers to support a decision on architecture investments.

Since there is little evidence on the information used by architects and managers, we decided to conduct a descriptive case study (Dul and Hak 2008). At first, we wanted to observe how practitioners make decisions and which information they use in real-time architecture evaluation processes, e.g. by using contextual inquiry. However, based on our findings in chapter 3, we realized that a decision on architecture investments could last up to six months in a complex organization. This implies that even if we could observe in real-time architecture investment activities, data collection might last for years. Even if we neglect the time issue, we realized that our domain knowledge on architecting, management, and healthcare might be insufficient to follow the decision-making process without interfering in the practitioner's way of working. Therefore, we rejected the observation approach for data collection. Another approach would be to gather reports on architecture-investment decisions in practice and try to extract information used to support the process. Because only a few reports referring to different domains are available,

and because some of these have already been elaborated (section 2.2), this approach was also discarded. Therefore, we decided to use interviews as the main source of evidence, to collect the data, to cover a diverse and large set of real-world, architecture, and decision-making projects as well as to learn about the domain.

We interviewed architects and managers at Philips Healthcare directly involved in architecture investment decision-making. A selection of interviewees is examined in more detail.

The study design is presented step-by-step in Figure 6. The first two steps refer to data collection, step 3 explains the analytical strategy, and step 4 discusses findings.

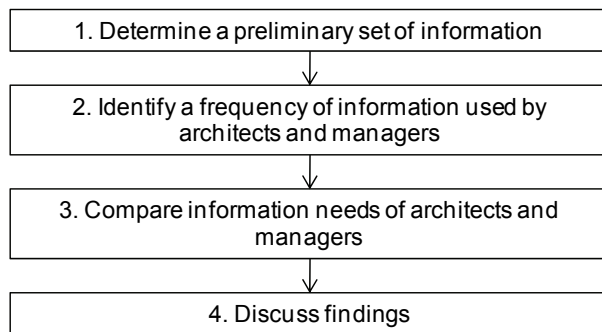


Figure 6. Study design

In the first step, *Determine a preliminary set of information*, pilot interviews with two architects and one manager were conducted to identify and describe information needed for architecture-investment decisions. The interview consisted of two parts (see Appendix A): first, we gathered general information about the interviewees, such as their domain knowledge and their role in the organization. Second, we asked practitioners to select a typical architecture case from their experience and then to describe the rationales and information used for architecture decision-making. We consolidated the results into a preliminary set of information and descriptions.

In the second step, *Identify frequencies of information needs*, an additional 19 interviews with architects and managers were conducted to quantitatively verify a preliminary set of information. In a semi-structured interview (more details on the interview form are presented in Appendix A), each interviewee was asked the same question as in their pilot interview (step 1). In addition, the interviewee selected types of information used in decision-making from a preliminary set. We organized the data from interviews into a structured matrix to quantify the frequency of information used per architect's and manager's group.

In the third step, *Compare information needs of architects and managers*, data collected in step 2 was analyzed to answer the following questions:

- 1) What are the relevant sets of information needs of managers and architects?
- 2) Which information do both managers and architects say they need?

- 3) Where is the strongest disagreement in information used by architects but not by managers?
- 4) Where is the strongest disagreement in information used by managers but not by architects?
- 5) How many information types do managers and architects typically use?

Finally, in the fourth step, *Discuss findings*, we discuss how architects and managers benchmark against other decision-makers and how information needs are supported by existing approaches.

Subsequent sections describe and elaborate each step in more detail.

4.2 Step 1: A preliminary set of information

In the first step of this study, we aim to identify a preliminary set of information for supporting architecture investment decisions.

We conducted interviews with two system architects and a manager. They had academic knowledge about architecting and considerable industrial experience in healthcare architecting. They were principal architects at Philips Research with 10 and 15 years of experience in the architecture consultancy role at Philips Healthcare. The manager was a program manager at Philips Healthcare, responsible for developing roadmaps for multiple product lines across the organization. Before this role, the program manager had been a department manager and a project manager. He also had a technical background.

The interviewees were aware of our investigation prior to the interviews. In an hour-long interview, we followed the interview structure as a shown in Appendix A. Each interviewee was led through a two-step procedure: *Introduction* and *Case description*. In the first step, we presented the study's objectives, the interview structure and general questions about identity, domain knowledge, experience, and their role in the organization. In the second step, we asked practitioners to select a typical architecture case from their experience and to describe the rationales and information used for architecture decision-making. Based on their inputs, we constructed a list of information used and provided information descriptions. To ensure correct information was collected in the interviews, all interviewees reviewed this material. In case of disagreement, refinements were made until consensus was reached. To avoid that interviewees influenced each other, individual information was not shared between the interviewees.

After reaching a consensus with all interviewees, merging information sets from the three interviews resulted in a set of 14 information types and respective information descriptions, shown in Table 7. Qualitative analysis on how elicited information was used in practice revealed three main groups of information—financial, customer-specific, and system-specific—to support architecture-investment decisions.

Financial-specific information, the top five items in Table 7, is typically used to make a business case: *investments, cash flow, sales, market uncertainty, and customer segments*. For the purpose of illustration, we reconstruct a business case using business-specific information according to the interviewees. A manager is assigned to make a business case for

architecture investments, which is consistent with the findings in chapter 3. Then, the manager defines customer segments that would benefit from the architecture changes so as to scope the architecture evaluation. This is also known as market scoping (van der Linden, Schmid et al. 2007). Once the scope is clear, sales data are used as proxies for customer segments to forecast cash flow created by architecture changes for the next five years. Finally, the total cash flow is compared to the investments required for architecture implementation by applying different economic techniques, such as Return on Investments or Net Present Value. If the manager uses a business tool for a sensitivity analysis, uncertainty is used to check how possible market changes affect the business-case analysis. Despite a very logical reconstruction on using financial information in business case modeling, the real-world example in chapter 3 failed to reveal financial information being used in the business case.

Table 7. A preliminary set of information needs for architecture investment decisions

Group	Information	Description
Financial	Investment	The money needed to implement architecture changes
	Cash flow	Cash generated because of architecture changes
	Sales	Volume of product shipments
	Market uncertainty	Probability of changes in the market that may influence cash flow
	Customer segments	Group of customers with homogenous needs for architecture changes
Customer	Time-to-market	Time required to release the product to market using the new architecture
	Upside potential	Potential for business growth enabled by the architecture changes
	Customer satisfaction	Extent to which the product is perceived as successful by customers
System	Quality attribute trade-offs	Exchange of benefits of one quality attribute for another in the architecture design process
	Future proof	Ability to accommodate technological changes in the future
	Downside effect	Negative business consequences of the existing architecture or of the newly proposed architecture
	Resources	Development effort needed for architecture implementation
	Technology risk	Probability of deviation from the intended results to implement the architecture
	Cost savings	Savings in bill of material and development effort because of architecture improvements

The middle of the table refers to customer-specific information, such as *time-to-market*, *upside potential*, and *customer satisfaction*. Time-to-market is important for the organization from all perspectives. Based on qualitative data from the interviews, time-to-market

mainly refers to delivering the system on time as promised to establish a good customer relationship. Furthermore, the upside potential of architecture investments was mentioned in the context of enabling new projects that would otherwise be impossible without architecture changes. For example, improving the performance of imaging scanners with architecture investments enables development of applications for real-time, image-guided surgery. Although upside potential is not explicitly considered in the business case, this aspect can significantly increase the value of architecture investments for the evaluation. Finally, customer satisfaction was a hot topic. Established measures for customer satisfaction, such as net promoter score (Keiningham, Coil et al. 2007), were often cited in architecture-evaluation meetings and used as targets for quality improvements to boost the organization's brand image. However, except for time-to-market data, customer-specific information has only been implicitly used in decision-making because of difficulties giving the data a monetary value.

The rest of the table refers to system-specific information commonly used in designing and evaluating architecture design, such as *quality attribute trade-offs*, *future proofness*, *downside effects*, *resources*, *technology risks*, and *cost savings*. To illustrate system-specific information used in architecture evaluation and increase confidence in findings, we refer to the real-world example in chapter 3. As seen in this example, trading-off on quality attributes refers to designing a system to fulfill quality attributes such as maintenance, evolvability, or usability. Future proofness of a system is associated with the advantages of a service-oriented architecture, i.e. the architecture's ability to incorporate future technological changes and prevent quick architecture erosion. Downside effects are the consequences of keeping old (legacy) architectures that are not addressed in the new architecture design. Finally, the resources needed to implement changes were also used for the architecture evaluation. As opposed to the information explicitly used in the real-world case, technology risk assessments on the feasibility of architecture solutions and cost savings were also implicitly used. We can conclude that the real-world example in chapter 3 confirms that system-specific information was used.

In the process of refining definitions of information types, we realized that some information types are related, such as resources and investment. In this example, the architect may consider resources but never accounts for money allocated to those resources, which is typically considered by managers. Although the similarity might imply that some information types are redundant, we decided to keep the whole list for subsequent interviews as these information types were used by practitioners; therefore, they were closer to their way of thinking.

We also realized that the two architects explicitly mentioned *gut feeling* when making a decision. The closest definition of gut feeling gathered from the interviewees would be an intuition that is difficult to substantiate with a logical rationale. Although gut feeling is difficult to classify as tangible information, we deliberately decided to include gut feelings as "additional information" used to support a decision.

4.3 Step 2: Frequencies of information needs by architects and managers

The second step in this study refers to data collection to quantitatively verify the information needs identified in Step 1. In the interviews, we illustrated the information types

used by architects and managers (Table 7 on page 55). Based on multiple interviews, we quantified a percentage of information types used by the architects and manager.

The lead architect of MRI business, Philips Healthcare, responsible for the overall system architecture, suggested interviewees. The interviewees were managers and architects with extensive experience in architecture-related projects, in particular for supporting architecture evaluation to decide on architecture investments. The interviewees included software and system architects as well as department, product, program, and project managers. The number of interviews for each group was determined by one criterion: a subsequent interview should not impact significantly on quantitative results. Thus, we do not expect that interviewing more architects or managers would lead to different conclusions.

In total, we conducted interviews with ten architects and nine managers at Philips Healthcare. Each interviewee was invited to an hour-long semi-structured interview (see Appendix A), which followed a three-step procedure: *Introduction*, *Case description*, and *Information selection*. The first two steps of the interview were the same as the steps described in section 4.3. The third step involved asking interviewees to select types of information from a preliminary set (Table 7 on page 55) that they used in decision-making. We collected the data from the interviews into a structured matrix (see Appendix A). We closed the interview with a question on whether Table 7 on page 55 provided enough categories, so we could verify the completeness of the preliminary information list.

The results of the 19 interviews are presented in Table 8 as a percentage of individuals in each group that use a particular information type to support decisions on architecture investments.

Table 8. Frequencies of information needs by architects and managers

Information types	Architects (%)	Managers(%)
Gut feeling	100	44
Investment	30	100
Cash flow	50	78
Sales	50	78
Market uncertainty	40	67
Customer segments	40	56
Time-to-market	100	100
Upside potential	80	78
Customer satisfaction	50	67
Quality attribute trade-offs	100	22
Future proof	70	44
Downside effect	40	78
Resources	60	56

Information types	Architects (%)	Managers(%)
Technology risk	100	78
Cost savings	80	56

When asking interviewees whether they could envision an information type not on the list, only one thought the list was incomplete. This interviewee, an architect, wanted to know about the intellectual property (IP) of technology used for “green” architecture development. Trying to better understand this need in an open discussion, we realized that the architect needed IP in the lab-venture healthcare business, in which he had been engaged before joining Philips Healthcare. We think that the IP landscape might be relevant information in that context, but since no one else within Philips Healthcare suggested this information type, we are satisfied with the completeness of information types provided in Table 7 on page 55.

During data collection, we observed that the interviewees could immediately select approximately five to seven relevant information types commonly used in their practice. The selected information was usually derived from the typical architecture investment case, which interviewees described in the second step of the interview. For other information types, they had to think carefully about a selection process. Typically, interviewees wanted to select a few additional information types, which had not been mentioned when describing their particular real-world example. One explanation might be that people have short-term memory and recalling past actions in decision-making is difficult (Carroll and Johnson 1990). Another explanation might be that the list was suggestive and the interviewees were tempted to show that they make informed decisions based on a larger set of information than they actually do. To ensure that we collected the right data, we asked the interviewee to provide another example in which the doubtful information type was used. An elaborate explanation of the interviewee on a potential need for such information type resulted in abandoning it in approximately 50% of cases. Our suggestion is that weighting factors to prioritize information types, rather than to select by yes/no, might have been helpful in fine-tuning the relevance of the delicate information types.

4.4 Step 3: A comparative analysis on information needs by architects and managers

The third step aimed to analyze the information needs of architects and managers (Table 8) to understand whether they differ, and if they do, the size of this difference. The findings are used as inputs to discuss implications on future research to support architecture investment decisions.

This analytical strategy is based on comparing the information sets of architects and managers (Table 8) by addressing the following questions:

- What are the relevant sets of information needs by managers and architects?
- Which information is agreed to be used for both managers and architects?

- Where is the strongest disagreement in information used by architects but not by managers?
- Where is the strongest disagreement in information used by managers but not by architects?
- How many information types do managers and architects typically use?

To answer the first four questions, we visualize the results of the analysis in Table 9, elaborated in more detail for each questions below. Next, to answer the last question about the amount of information needs, we use a graph that shows the distribution of the amount of information needs across the architect’s and manager’s group in Figure 7 on page 61.

Each cell in Table 9 is a bar, whose length represents the cell value. The first two columns (**A** and **M**) in Table 9 are visual representations of quantified results in Table 8 on page 57, such as the frequency of information used by the architects and managers, respectively. The third column, **Max(A,M)**, shows the maximum number of information types used either by architects or managers to support an analysis on information relevance.

Table 9. Qualitative analysis on information types by managers and architects

	A	M	Max(A,M)	Min(A,M)	A-M	M-A
Gut feeling						
Investment						
Cash flow, NPV, IRR						
Sales						
Market uncertainty						
Customer segment benefits						
Time-to-market						
Upside potential						
Customer satisfaction						
Quality attribute trade-off						
Future proof						
Downside effect						
Resources						
Technology risk						
Cost savings						

Legend	
A	Information used by architects (%)
M	Information used by managers (%)
Max(A,M)	Information used by architects and/or managers (%)
Min(A,M)	Agreement between architects and managers about the information used (%)
A-M	Architects use the information that managers do not (%)
M-A	Managers use the information that architects do not (%)

The fourth column, **Min(A,M)**, demonstrates when information needs of architects and managers are the same by visualizing the minimum information needed by one of these two groups. The last two columns, **A-M** and **M-A**, show information needs by architects not by managers, and vice versa, respectively. These findings are used to discover relevance, commonalties and differences on information needs of architects and managers and to discuss an impact on the architecture evaluation process.

Given the low number of respondents, the results of the analysis are indicative at best. We made use of qualitative data from the interviews to support findings of these quantitative results and to draw a more comprehensive conclusion.

First, each type of information identified in the preliminary set was used by more than half of the managers or architects (Table 9, Max(A,M) column). Based on this finding, we can conclude that the list of information types identified in the pilot interviews (Table 8 on page 57) does not contain superfluous elements. One can argue that the list might not be comprehensive, but strong agreement across interviewees increases our confidence in the completeness of the list. Given that expertise, in particular in selecting information to support architecture investments, is domain-specific (Chi 2006), the generalization of results in this chapter is applicable to the healthcare domain. Thus, we conclude that Table 8 presents a relevant list of information to support architects and managers in making architecture investment decisions in the healthcare domain.

Second, managers and architects strongly agree on using time-to-market, upside potential, and technological risk (Table 9, Min(A,M) column) in more than 78% of cases. A closer look unveils that two information types, time-to-market and upside potential, are customer-specific information. Even agreement between architects and managers on using these information types can be explained by the customer-centric strategy of Philips Healthcare (section 3.2.1). Thus, customer-centric strategy encouraged interviewees to select information types with a strategic focus. Next to customer-specific information, technological risk as system-specific information (Table 7 on page 55) appeared to be necessary to assess potential hurdles in project implementation. As the interviewees explained, architecture solutions with high risk are not necessarily considered when making a decision to invest. Risk is needed to thoughtfully plan resources and to identify mitigation strategies for the implementation stage. As such, risk is more a traffic light for project implementation than for an architecture investment decision.

Third, the architects are strongly concerned with product and process quality (quality attribute trade-offs, future proofness, technological risk, and cost savings), which is less typical for managers (Table 9, A-M column). These findings are consistent with the system-specific information types used by the architects in the real-world project described in chapter 3. In that example, maintainability and evolvability refer to quality attribute trade-offs, service-oriented architecture is an argument for future proofness, while risk and cost savings were implicitly considered. Furthermore, next to this system-specific information types, all architects reported using gut feeling for decision-making, in contrast to the managers. The interviewees explained that they used gut feelings because of the complexity of the architecture decision-making process. Therefore, gut feeling is used to transfer their experience from similar projects, although they were unable to explain rationally how they made a decision. This is consistent with the literature findings on decision-making in a naturalistic environment, in which deciders cannot explain

their course of action, especially in a complex environment, such as business, where more than one actor plays an important role in decision-making (Schmitt 1997).

Fourth, managers are strongly concerned with financial-specific information types (investment, cash flows, downside effects, market uncertainty, and customer segments), which is not typical for architects (Table 9, M-A column). These findings do not reflect our observations in chapter 3 in which financial information types were not used, although the business case was required in the decision-making process. The qualitative data from the interviews disclosed that managers select information types closely related to the input requested by the business tools (investments, cash flows, and market uncertainty) used in the organization. This and finance-related responsibility can explain the high need for financial information types.

Finally, after answering the first four questions, Figure 7 is used to improve our knowledge on the amount of information types required by architects and managers to make decisions on architecture investments. We observed that while describing the case, interviewees mentioned on average five to seven information types used in one particular project to support a decision (see the interview design). Interestingly, after probing the interviewee about doubtful information types to support decisions in other projects in the organization (see the information selection in the interview design in Appendix A), they selected a few additional information types. Thus, it is important to note that we report on information needs not for a single architecture project, but in general. Figure 7 shows the percentage of architects and managers who required the respective number of information types to support architecture investment decisions.

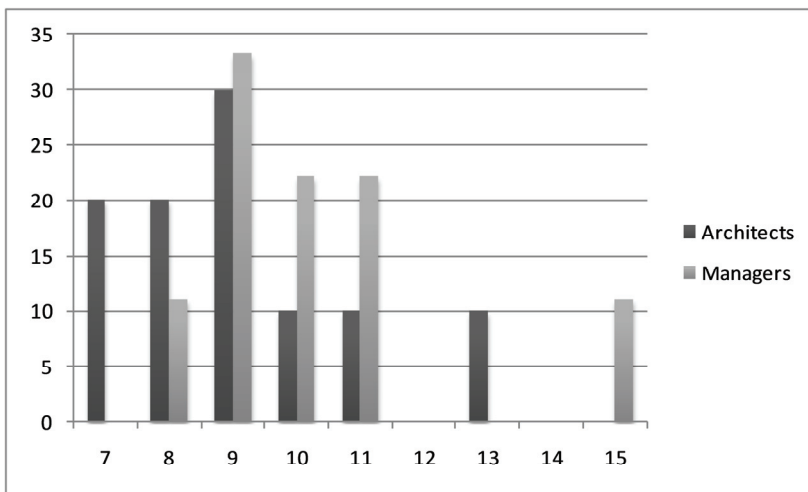


Figure 7. Percentage of information required by the architects' and managers' groups to support architecture investment decisions

As seen in Figure 7, the architects and managers require 7 to 11 information types in general to support decisions on architecture investments. The results show that managers reported that they needed a moderately larger set of information than architects. While 70% of architects used seven to nine information types, more than 70% of managers reported using 9 to 11. Interestingly, two interviewees who used more than 11 information

types were an architect (13) and a manager (15), who had experience in both roles during their careers.

4.5 Step 4: Discussion

The interviews helped to identify the information needs of architects and managers to support architecture investment decisions in the healthcare domain. The analysis shows a need for a rich information set, different for architects and managers, which is enlarged when the decider has experience in both roles.

In total, 14 relevant information types were required by architects and managers to support decisions on architecture investments. A need for seven to eleven information types in general by architects and managers was significantly higher than the number of information cues (one to seven) actually used by other experts in decision-making (Hoffman, Slovic et al. 1968; Slovic 1969; Einhorn 1974). This implies that architects and managers reported a need for larger information sets than the information sets other experts actually used in decision-making. In addition, experience in architecting and management highlighted a need for larger information sets. These findings are difficult to explain given that experts are shown to use less, though relevant, information than a less-experienced person in decision-making (Shanteau 1992). We speculate that the gathered information might be expected to be used by architects and managers in the organization. Nevertheless, the reported information might not necessarily be used when making actual decisions. To draw more conclusions on these observations, we would need to investigate whether the reported information is used in actual decision-making.

Different expertise, in particular in architecting and management, determined different sets of information needs to support architecture-investment decisions. Thus, information needs for architecture evaluation might significantly depend on the expertise involved in the decision-making process, observed also in chapter 3. This is consistent with the literature, suggesting that expertise is domain-dependent (Shanteau 1992; Chi 2006).

Architects and managers strongly agree on a need for customer-specific information to support decisions. We recognized the same phenomenon in the real-world decisions at Philips Healthcare (see chapter 3), in which time-to-market was explicitly used and upside potential was implicitly used in decision-making. Given the customer-centric strategy of the organization (section 3.3), it is no surprise that customer-specific information was so prominent in the findings. We think that the power of using strategy-focused information is not only in aligning decision-makers (architects and managers). In addition, business-strategic information supports the decision-making process by aligning architecture investments with the business strategy, which is the ultimate goal of any architecture changes (Malan and Bredemeyer 2002). With respect to differences in the information sets, each group (managers and architects) used a set of information underestimated by the other group. For example, architects reported a need for system-specific information, which is consistent with information they need in their projects (chapter 3). This is explained by the fact that system-specific information is already available in the architecture evaluation. Actually, system-specific information supports the architect's prime activity to create architecture (Clerc, Lago et al. 2008). It seems easy to continue to

use available system-specific information further in the architectures evaluation. In contrast to architects, managers requested a wide spectrum of financial information to support decisions. A potential use of this information is to support managers in two distinct duties of architecture evaluation (chapter 3): making business cases (cash flow, investments, sales) and planning project implementation (resources and risk). We can conclude that the differences in information needs have to be addressed by providing the relevant information set, which is based on business objectives rather than biased by expertise (in particular architecting and managing decision-makers).

Despite the importance of offering relevant information to support the decision-making process, the main question is still open: do existing methods support a decision on architecture investments based on the required set of information? Drawing on the literature (section 2.2), we noticed that existing methods employ together almost all information needs explicitly or implicitly. Implicit information, such as customer segments, customer satisfaction, upside potential, and downside effects (it appeared to be mainly customer-specific information) are being indirectly used in the methods. For example, the idea of customer segments is exploited in the concept of market scoping to support a decision on investing in product lines (van der Linden, Schmid et al. 2007). Furthermore, customer satisfaction was used as an example of the benefit function to support investments in product lines (Clements, McGregor et al. 2005), although without guidance on how to incorporate this information in an economic decision rule. However, as already explained in section 4.1, each method supports a particular objective of the architecture investment and employs just a few information types. Based on the information needs of architects and managers, we can foresee which methods might be favored by architects and managers. Methods concerned with cost-benefit analysis, such as CBAM (Kazman, Asundi et al. 2002), perfectly address the architect's information needs (quality attribute trade-offs and resources), but are far away from a manager's needs. Next, the business case analysis has been close to the architect's (cost savings, upside potential) and manager's information needs (investments, sales, time-to-market). Interestingly, the information needs on which architects and managers agree—time-to-market and upside potential—could be incorporated in a business-case analysis. Beside a large potential, business cases do not consider information (quality attributes) that is crucial for an architect's decision-making. We postulate that business case analysis could be a common language of architects and managers for architecture evaluation if the business case would incorporate the quality-attribute information type. Finally, real options analysis has been envisioned as a powerful tool to assess an architecture's flexibility by using investments, cash flow and uncertainty. Managers also reported financial information types employed by real options as one of their information needs. However, as seen in chapter 3, real options focus on assessing the value of an architecture's flexibility and neglect the value of other more user-observable quality attributes, such as usability or performance, which makes it challenging to satisfy the main information need of architects.

Although business cases seem like promising approaches, it is unclear how business cases can anticipate the rich information needs reported by practitioners. A need for more than 10 information types was not directly envisioned by any of the existing methods. Furthermore, an unanswered question from the previous chapters is also how to select the right information types (and perhaps fewer) for particular business objectives of architectures investments.

4.6 Conclusions

In this chapter, we investigated the information needs of architects and managers and their implications for supporting architecture decision-making.

Architects and managers differ in how they use information, both among themselves and in comparison to other experts. Their main duties—managing business for managers and creating architecture for the architects—strongly biased information needs. Architects rely on system-specific information and managers trust financial number crunching to make their decision. This implies an enormous gap in communicating and evaluating the architecture by representing the information needs of architects and managers equally. One way to solve this problem would be either to educate architects about business (Clements, Kazman et al. 2007) or managers about architecting or both. Another solution is to propose a method that fits the information needs of architects and managers. Before we draw such a conclusion, we think that it is important to understand whether differences in information are still so apparent when architects and managers make an actual decision on architecture investments, as compared to just mentioning which kinds of information they need. In chapter 5, we investigate how information as reported in the interviews is actually used in decision-making and how information use depends on the participant's profile (domain, years of experience, and role).

Although differences in information needs by architects and managers are significant, there is common agreement on a need to use customer-specific information. Given this importance and the fact that quantifying customer-centric value is the main challenge when using this information in decision-making (chapters 2 and 3), we will explore how to quantify customer value in chapter 6.

Finally, to propose a meaningful method (given the lack of existing methods that fulfill the needs of architects and managers), it is important to anticipate the following requirements in information needs. First, the method should facilitate strategy-focused information to align participants in the process. Second, the method should address in some way attribute trade-offs to support the architect's information needs. Finally, the method should employ information that helps estimate the monetary value of architecture changes, thereby anticipating managers' needs for financial information. Although none of the existing methods can readily anticipate the requirements, it appears that the business case analysis looks the most promising. This aligns nicely with our previous results, as business-case analysis has already been used in practice (chapter 3). In chapter 7, we propose the method based on business-case analysis to support a decision on architecture investments to meet information requirements.

5 Drivers of architecture investment decisions: business and individual perspectives

In chapter 4, we reported on managers' and architects' information needs when making architecture investment decisions. It appeared that architects and managers needed an extensive information set not entirely supported by any existing method. In addition, the information sets appeared to differ for managers and architects. This result was based, however, on what architects and managers said they would need and use, which might differ from what they actually use. Thus, we investigated whether professionals indeed used the information they asked for and how individual characteristics (experience and roles) determined information use.

According to Carroll and Johnson (1990), information is a crucial element in decision-making. Successful decisions require all information cues that can diagnose or predict the outcome of a decision. In complex real-world environments like architecture evaluation, there will be numerous sources of information. However, it is recognized that experts generally base their judgments on a smaller number of cues than expected. For example, medical radiologists use two to six cues (Hoffman, Slovic et al. 1968) and medical pathologists one to four cues to make diagnoses (Einhorn 1974). Stockbrokers relied on six to seven cues in their judgments on stock prices (Slovic 1969). In these studies, analyses of experts produced a small number of significant cues. Yet in each case, (often much) more information was available. This implies that experts may make important decisions without paying adequate attention to a complete set of cues.

A literature review of five studies by Shanteau (1992) confirms previous findings and brings additional insights. The analysis shows that the number of significant cues did not differ between experts and mid-level novices, but the selection of information did. For example, auditors (students and professionals) use on average between 2.6 and 3.3 cues (out of 8) to evaluate the materiality of proposed account adjustments (Ettenson, Shanteau et al. 1987). However, the pattern of cue weights was different with professionals primarily relying on one cue as opposed to the broad spread of cue weights that students used. In a study of medical diagnoses, analysis of verbal protocols showed that medical students gave more diagnostic statements than either physicians or premedical students (Hammond, Frederick et al. 1989). The types of statements differed, however, as physicians were more balanced than students when considering different types of information. The evidence is consistent: where experts differ from non-experts is in what information is used, not in how much information they use.

Given these findings on information use, the question is whether a similar phenomenon is apparent in making decisions on architecture investments by architects and managers.

We study the information use of architects and managers in an experimental setting. The participant is asked to decide on investing in one out of two architecture scenarios based on a given architecture description and business information inputs. Analyzing the answers, we study how the information and personal characteristics of the respondents affect their decision-making.

The remainder of this chapter is organized as follows. Section 5.2 describes the design of the experiment. Section 5.3 elaborates on the measurements used in the experiment. Section 5.4 presents the results of the analysis. Finally, section 5.5 discusses the main findings and concludes with implications of information use in supporting architecture-investment decisions.

5.1 Study Design

5.1.1 Experiment

We asked participants to make an architecture investment decision in three hypothetical cases. Each case is a description of a situation with two architecture scenarios and embedded business information inputs. Based on the case description, the participant decides on one of the architecture scenarios.

Participants. The experiment was conducted using an online survey instrument. We sent a hyperlink for an on-line survey to professional networks of architects and managers, including conference invitations, such as the ESI symposium (www.esi.nl), online engineering magazines, such as Bits&Chips, and different architecture user groups worldwide. The full invitation to participate in the survey is presented below.

Dear Sir/Madam,

[Philips Research](#) and [Embedded System Institute \(ESI\)](#) in the Netherlands have launched a survey of system architects and managers to understand architecture decision making. Please could you therefore follow the link below to take the role of decision maker in the online survey?

[Architecture decision making link to the survey](#)

The survey will take approximately 15 minutes to complete. The data will remain confidential to be used only for the scientific purpose of this project. Your email address has not been added to any list. If you need further information please contact us directly (ana.ivanovic@philips.com).

Thank you for your time and consideration.

Figure 8. The invitation for the survey

We were not able to control the response rate of the participants in the study because of a potential snowball effect. Ultimately, 523 participants started the experiment and 114 respondents finished at least one case, resulting in an average completion rate of 22%. The participation was anonymous and on a volunteer basis. The data were collected in November 2009 over the period of one month.

Procedure. The experiment starts by asking the participant to provide information about their personal characteristics, such as their current role in their organization, their domain knowledge, and their experience. Then the three architecture cases are presented to the respondent successively. The order of the cases was randomly chosen for each respondent. We also randomly introduced a timer to limit the decision time to three minutes per case so that we could analyze how decisions are made under time pressure.

The timer was used in one or two of the three cases per respondent. At any moment in the experiment, the participant was able to exit the survey. In the experiment, 50% of the generated cases were time-limited. If not under time pressure, the participant spent an average of 8-9 minutes on decision-making. Following this procedure, 10% of the respondents completed one case, 3% completed two cases, and 87% completed all three cases, for a total of 114 participants who completed the entire survey.

5.1.2 Case construction

An example of a case description is given in Figure 9. It is a healthcare case. The remaining cases used in the experiment (automotive and consumer electronics) are presented in Appendix B.

The healthcare case

WeCare develops software-intensive systems to view and analyze images of the inside of the human body for a professional use. Each product line consists of dedicated hardware and clinical applications such as body, breast, or cardiac. The main users, radiologists and referring physicians, use applications to make diagnoses and prepare treatment.

Tricorder is a product line that has been on the market for a decade with constant annual sales of SALES.systems and an average system price of the system of 50K euro. The system evolved from a single image viewer application to a system with more than 20 applications nowadays. Last years, with an increasing market pressure to release new applications and add new functionality the Tricorder architecture has been eroding. Consequently, development effort to add new functionality increased and application releases became unpredictable and frequently later than announced. The newest market research about customer insights has shown opportunities for improvement in:

- *Usability*: The system should be *easier to use*; i.e. the applications should have harmonized user interface across applications that is not a case nowadays.
- *Accessibility*: The applications should be *accessible from any workplace*
- *Multi-modality*: The system should offer *viewing of images from other WeCare product lines*

To facilitate customer insights, it has been decided to migrate all Tricorder applications to a successful in-house architecture, either *LabTricorder* or *ViewAll*. The new product, called Tricorder-2, will be the next generation product in the Tricorder product line. Tricorder-2 will be introduced over the next two years in two phases to reduce the technology risk of migrating all Tricorder applications to the new architecture. Both scenarios meet all customer insights and release the product at the same time with different migration strategy.

Scenario 1: LabTricorder

Phase 1:

- Tricorder-2 is one quarter TIME-TO-MARKET on the market than in the ViewAll scenario.
- QUALITY ATTRIBUTE IN S1 UPSIDE POTENTIAL 2 IN S1 applications are released with harmonized user interface on the LabTricorder platform. Other applications are still available on the Tricorder.
- Viewing of images from other product lines is available.
- Thin client access is available from any PC UPSIDE POTENTIAL 1 IN S1. DOWNSIDE EFFECT IN S1.

Phase 2:

- Tricorder-2 offers all Tricorder's applications. Tricorder is not available on the market anymore.

The cost of this migration is INVESTMENT IN S1 MEuro, technology risk is RISK IN S1 and market acceptance uncertainty of the new product is MARKET UNCERTAINTY IN S1.

Scenario 2: ViewAll

Phase 1:

- All Tricorder applications with harmonized user interface are available on the ViewAll platform. Tricorder is not available on the market anymore.
- Thick client access still requires dedicated hardware to use applications from multiple places in hospitals. QUALITY_ATTRIBUTE_IN_S2

Phase 2:

- Viewing of images from other product lines are available
- A thin client access is already on Tricorder's product roadmap after the second year.
- FUTURE_PROOF_IN_S2

The cost of this migration is INVESTMENT_IN_S2 MEuro, technology risk is RISK_IN_S2 and market acceptance uncertainty of the new product is MARKET_UNCERTAINTY_IN_S2.

- Experienced marketers estimated roughly the customer base that will be addressed with different solutions in the migration period, see the graph below. Customer needs
- Stakeholders prioritized the customer insights and the result of quality indicators for LabTricorder and ViewAll scenarios as shown in the table below.
- Cost savings in both scenarios over time is presented in the graph below. Cost savings

Figure 9. Example of the healthcare case description with underlined business information variables, which take inputs from Table 10 on page 69

We distinguish between two distinct elements in the case description: (1) the narrative story unique to the particular domain case, which sets the scene to evaluate two architecture scenarios and (2) the business information inputs upon which the participant makes a decision.

5.1.2.1 *Setting the scene*

Each of the three cases originates from a company rated in the top-five worldwide companies for their domain (healthcare, automotive, and consumer electronics). We decided to include cases from other domains to investigate whether information needs in the healthcare domain (chapter 4) are representative for other domains as well. All companies develop software-intensive products using the product-line approach (van der Linden, Schmid et al. 2007), which demands frequent and significant investments in architecture improvements. To gather relevant information for the case description, we interviewed the system architects and/or managers from the selected companies. Based on the interviews, we wrote a single page description of the architecture investment case. To ensure the correctness of the information in the case description, we asked the interviewees to review the case description.

The narrative story has a repeatable structure across the cases. First, we present to the participant information about the organization type, market, strategy, and the objectives of the architecture investment. Then, we describe two architecture scenarios, indicating possible solutions for architecture improvements. The structure is indicated by the empty line separation in the case description seen in Figure 9.

5.1.2.2 Business information inputs

A selection of business information inputs is based on the information needs for decision-making, as identified in chapter 5. A few modifications include:

- removing redundant information, e.g. cash flow (associated with sales) and resources (investment); and,
- merging customer segments and customer satisfaction in a single variable, customer needs. The rationale here is that diverse customer-centric information used for decision-making might be correlated, which is elaborated in more detail in chapter 6.

After modifying the information set conveyed in chapter 5, a total of 13 business information inputs were varied for the experiment, as shown in the table below.

Table 10. Business information in the healthcare case: general values and case inputs

Information	Values	Case-specific inputs
Sales	Low	100
	Medium	500
	High	1000
Customer needs	off/on	
Cost savings	off/on	
Investment in s1 (Is1)	(Is1~Is2)	(4.5, 4.1)
Investment in s2 (Is2)	(Is1<Is2)	(3.7, 5)
	(Is1>Is2)	(5, 4)
Time-to-market	T(s1) < T(s2)	earlier (3 months)
	T(s1) > T(s2)	later (3 months)
Downside effect in s1	off/on	The service is provided only for PC configurations with minimum specifications.
Upside potential 1 in s1	medium	in a hospital.
	high	connected to internet.

Information	Values	Case-specific inputs
Upside potential 2 in s1	off/on	Most frequently
Quality attribute in s1	medium fulfillment	7
	high fulfillment	15
Quality attribute in s2	off/on	The dedicated hardware guarantees stability of the running applications and full service-ability
Future proof in s2	off/on	The new platform will be based on service-oriented principles
Risk in s1	(high, low)	=
	(high, medium)	=
	(medium, high)	=
Risk in s2	(low, high)	=
	(high, low)	=
	(high, medium)	=
Market uncertainty in s1	(medium, high)	=
Market uncertainty in s2	(low, high)	=
		=

It is important to notice that *sales*, *customer needs* and *cost savings* are common information types for both scenarios used to set up the context in which the architecture scenarios are evaluated. In this setting it would be difficult to analyze how they determine the “right” business decision. In contrast, the effect of 10 information types on the decision can be observed.

We expect that the relative value of the four correlated information sets (investment, time-to-market, risk, and uncertainty) determines the business-driven decision. For example, a relatively higher risk in a particular scenario would predict investments in an alternative scenario. The correlation between the four-business information inputs in scenario 1 and scenario 2 implies that not all separate items have zero correlation, as is customary in most research that uses this approach. The reason is that we aimed to construct cases with meaningful input for decision-making. Therefore, we selected a realistic set of combinations for variables in scenario 1 and scenario 2 (as shown in Table 10) and then randomly generated one combination for each participant.

Similarly, we expect that a remaining set (6) drives a sound business decision. The interpretation on what is a sound business decision will be elaborated in more detail in the study analysis. For example, a downside effect is defined in general as a negative business consequence of the proposed architecture design (chapter 4). In the experiment, the downside-effect variable can be “off” or “on”. Thus, it is expected that the presence of information about the downside effect in one scenario will more likely predict a decision to invest in an alternative scenario.

To ensure the realism of each case, we aimed to generate realistic business information inputs for each case. A baseline value for the inputs was gathered in the interviews and then manipulated. For example, in the healthcare case, the real *Sales* value for the product was originally 500, and so we generated three possible sales inputs: *low*=100, *medium*=500, and *high*=1000. Many information variables were binary, for instance, particular information in the case was either presented (“on”) or omitted (“off”). Risk and market uncertainty were the only information types that had the same qualitative values across the cases, such as low, medium, or high.

One could argue about the realism of architecture decision-making simulated in a few minutes time by presenting information in a single page. Indeed, in practice, a decision on architecture investment can take more than 10 man-days and requires complex data collection procedures (Moore, Kazman et al. 2003). However, we argue that the amount of information required by practitioners presented in the case simulates the complex reality in which a decision is taken. This was confirmed by practitioners who reported that the realism of the case was greater than four on a seven-point likert scale (1=Not at all and 7=Absolutely) in more than 75% of the cases.

5.2 Measurements

Per respondent, over 100 issues were measured and classified into four categories: personal characteristics, business information, decision, and time measurements.

Personal characteristic are measurements gathered by requesting participants to answer questions about their current role and experience (see Figure 10). Role refers to one of the predefined values: architect, manager, and others. Experience refers to the number of years working in the domain of development or management.

What is your current role in the organization?

- Architect
- Manager
- Other

In total how many years of management experience do you have?

years

In total how many years of development, design, architecting experience do you have?

years

Figure 10. An example of questions for gathering personal characteristic measurements

Business information inputs are case-specific measurements embedded in the case description as shown in Figure 2 (a definition of information types is provided in section 6.3.2). The business information inputs are randomly generated for each participant in the experiment. To check how the difference of the correlated variables in scenario 1 and scenario 2 predicts the decision, we also defined relative measures across scenarios, in particularly for risk and market uncertainty.

Decision measurements are gathered by asking the respondent to judge the architecture case by selecting a single architecture scenario to invest (see Figure 11).

If you were a decision maker which scenario would you select?								
<input type="radio"/> Scenario 1								
<input type="radio"/> Scenario 2								
How certain are you about this decision?								
“It is just a guess”	1	2	3	4	5	6	7	“Virtually certain”
Does this case look realistic?								
“Not at all”	1	2	3	4	5	6	7	“Absolutely”
Do you have any experience with similar decisions?								
<input type="radio"/> Yes								
<input type="radio"/> No								

Figure 11. An example of questions for gathering decision measurements

Time measurements include several measurements related to the time spent on each page/case in the experiment. These measurements were used to analyze the decisions under time pressure and to control the validity of the experiment.

5.3 Results

A detailed profile of the participants in the experiment is presented in Appendix C. In total, 35 managers, 50 architects, and 29 people with other roles participated in the experiment. All respondents had experience in development and 80% of the participants had experience in management. The average time spent in development was 14.6 years and 9 years in management. 43% of participants had experience in the healthcare domain, 17.5% in automobiles, and 28.1% in consumer electronics.

5.3.1 Analysis

We use logistic regression to determine the impact of the case characteristics on the respondent's decisions. A more detailed analysis can be found in Appendix C. Before we turn to the analysis of the case characteristics, we must first analyze which factors correlate with the respondent's decision confidence (using ordinary regression).

As expected, the participant's perception of the case's realism ($p < 0.001$) and their previous experience with decision-making ($p = 0.008$) increases their confidence in their decisions. Furthermore, when the participant was forced to make a decision under time pressure, their confidence significantly decreased ($p = 0.009$). Next, people not involved in the architecting business have less confidence in their architecture decisions than the others, which is also to be expected ($p = 0.012$). These results suggest that our business case set-up triggered the appropriate sense of realism for our participants. With respect to the individual cases, the decisions taken in the healthcare case exhibited a somewhat lower decision confidence ($p = 0.090$) while the automotive case did not significantly affect decision confidence.

Here, we would like to draw special attention to the consumer electronics case. This case refers to a decision to extend the product portfolio from the business-to-consumer (B2C) to the business-to-business (B2B) market. In this case, we did not identify any significant

impact of business information on the respondent's decision. There are two possible ways to interpret this result. First, participants did not use any of the business information presented in the case when making their decision, but rather based their decision on other cues we did not investigate. Given that we already found significant information in two other cases, this is difficult to believe. Alternatively, the participants used the business information, but the importance of the particular information was inconsistent across the participants, resulting in a low average impact on the decision of each separate cue. One explanation for such an effect might be that fewer respondents had experience with such a decision: 44% of those in the consumer electronics domain had experience versus 53% on average who had experience in the other domains (see Appendix C, Table 24). This would mean that people could not rely on their previous experience to make a decision, so the particular information was inconsistently used across the population.

For our further analysis, we restrict our sample size to decisions with a confidence level higher than three. This accounts for 75 participants in healthcare and 77 participants in automotives.

5.3.2 Drivers of architecture investment decisions

To answer the first research question on *how business information and personal characteristics of deciders affect a decision*, we conducted a statistical analysis—logistic regression—on the decision predictors for the healthcare and automotive cases. A detailed analysis for each case is presented in Appendix C.

5.3.2.1 Decision drivers

First, we investigate business information predictors of the participant's decision (Table 11, columns Coef). Second, we analyze how time pressure (Table 11, columns T) additionally affects the decision determinants.

Table 11. Predictors of the decision to invest in scenario 2 with a confidence level greater than three in the healthcare and automotive case. Columns T (time pressure), A (architect), M (manager), and E (development experience) denote interaction effects of these variables with personal characteristics and business information.

	Healthcare case (n=75)					Automotive case (n=77)				
	Coef.	Interaction				Coef.	Interaction			
		T	A	M	E		T	A	M	E
Personal characteristics										
Development experience	0.19***									
Management experience										
Manager										
Other roles										
Business information										
Investment in scenario1										+
Investment in scenario2										
Sales				+						

	Healthcare case (n=75)					Automotive case (n=77)				
	Coef.	Interaction				Coef.	Interaction			
		T	A	M	E		T	A	M	E
Time-to-market	1.68*									
Customer benefits										
Cost savings										
Downside effect in scenario 1	3.00***				-	1.41**				
Upside potential 1 in scenario 1										+
Upside potential 2 in scenario 1										
Quality attribute in scenario 1		+			+					+
Quality attribute in scenario 2										
Future proof in scenario 2										
diffR1R2	0.53*	-	-							-
diffMU1MU2						-				

Note. Empty cells refer to variables with no statistical significance. The Coef column shows the strength (p) and significance, such as * $p < 0.1$ ** $p < 0.05$ *** $p < 0.01$

In the interaction analysis, (+) and (-) refer to the significance of interaction between business information and a particular variable (T, A, M, and E) to predict the decision to invest in scenario 2. Interaction effect is calculated one-by-one. Given the number of cases, we selected the interactions with a significance larger than [1.87]

We expected to find fewer significant information predictors in the analysis than what practitioners had reported in the interviews (chapter 4); this is consistent with information use of other experts (Shanteau 1992). The results are actually even stronger than that: just a single predictor, the downside effect, has an effect that is consistent in both cases.

In the automotive case, we found one significant information cue, the downside effect (Coef=1.41; $p=0.032$). In the healthcare case, we identified three information cues, downside effect, relative risk, and relative time-to-market. Interestingly, *downside effect* is an even more significant predictor (Coef=3.00; $p=0.006$) than in the automotive case while *relative time-to-market* (Coef=1.68, $p=0.093$) and *relative risk* (Coef=0.53, $p=0.065$) were less significant. This means that either the experts focus on just one part (or perhaps two parts) of the information, or information use is inconsistent across the respondents.

Decision-making under time pressure made the *quality attribute in scenario 2* (-2.43) and *relative uncertainty* (2.22) variables more relevant for respondents in the automotive case. In the healthcare case, *quality attribute in scenario 1* (2.02), and *relative risk* (-1.92) became more important (Table 11, columns T).

In general, we can say that similar kinds of information are more likely to predict the decision under time pressure in both domains. Let us call them quality (in scenario 1 and 2) and relative uncertainty (risk and market uncertainty). Unexpectedly, the impact of these information types on the decision was not aligned with the business objectives in both domains. In the automotive case, unexpectedly, participants tended to invest in a scenario with relatively higher uncertainty and lower quality. Similarly, in the healthcare case, the participants' decision was more likely to be predicted by relatively higher risk and less attainment of quality attributes, which is again illogical. In this particular case,

we expected that implementing a larger number of migrated applications would bring added value to customers. Given that customer value is one of the main business objectives (Kotler and Keller 2008), it should have been favored by the decision-maker to invest. One explanation of the unexpected result is that the participant, under time pressure (all of them had development experience), foresees difficulties in quality improvements under high uncertainty and reacts defensively by not investing in the given scenario. More time might provide practitioners a possibility to think about risk mitigation strategies and the feasibility of quality changes that would make them more comfortable to invest. This is an important finding, suggesting that under time pressure, information use of decision-makers is consistent across domains, but the way information is combined (in a decision rule) contradicts business objectives.

Beside the small amount of information used, the large number of information inputs was insignificant. Four explanations account for these results. The first is that the “experts” in these studies were not really experts in architecture evaluation. We found that approximately every second respondent had experience with such decisions (see Appendix C). However, a selection of the cases with a large confidence level in the decision helps refute this possibility. The second explanation is that the information set offered is not representative for architecture evaluation. This is also very unlikely, at least for the healthcare domain. There is no reason to suspect that the practitioners in other healthcare studies (chapter 3 and 4) would systematically choose atypical information. Third, it could be that the methods we used for measuring regression analysis do not detect opposite weights on information use, which resulted in the zero-effect on the decision. The final and most compelling explanation for the results is simply that the participants with development expertise were not different than other experts. They use less of the available information than expected. Although, we do not know for sure which and how much these effects play a role, a larger sample size of respondents might help to address the issues and draw stronger conclusions.

5.3.2.2 *Decision drivers and personal characteristics*

The elaborate analyses on the impact of human aspects on decision-making, in particular experience in management/development and their role in the organization, shows a relatively weak link. Management experience does not have an effect on the respondent’s decision in either the healthcare or the automotive case (Appendix C, Table 26 and Table 27). One explanation might be that despite the average 7.6 years of management experience, all participants had development experience that defined them as tech managers. Thus, they were not so different from architects. An interesting question to investigate would be whether the results would be different if managers did not have a technical background. Unlike management, development experience is a significant predictor (Coef=0.19, $p=0.004$) of the participant’s decision in the healthcare case, but not in the automotive case (Appendix C, Table 26).

Additional independent analysis of the interaction between development experience and information shows that regardless of the different information sets used in each domain, the decision was not aligned with business objectives.

In the healthcare domain, development experience emphasized *quality attribute in scenario 1* (2.53) and *downside effect* (-1.91) as information predictors of the decision. Despite our

expectation that higher degrees of quality-attribute attainment would imply investment in that scenario and that downside effect would inhibit investments, the findings were contradictory. Similar to time pressure, development experience drove respondents to the decision that required fewer system changes, regardless of the drawback for customers. In this particular case, downside effect refers to delivering applications only on computer configurations with the minimum specified requirements. This is not desirable for customers that may have an older computer, which would then require an expensive update. However, the respondents with larger development experience tended to have different opinions. Easier development, for instance for “minimum PC configuration” rather than for any PC configuration, drove the decisions. Thus, development experience highlights using information in an unexpected way (decision rules), which is not necessarily aligned with the business goals.

In the automotive domain, respondents with development experience used a larger information set than in the healthcare domain, including *investment in scenario 1* (2.11), *upside potential 2 in scenario 1* (2.11), *quality attribute in scenario 1* (1.87), and *relative risk* (-2.10). Development experience and the larger relative size of investments predicted a decision to invest in the less expensive architecture solution, as expected. Unexpectedly, the information referring to increased customer benefits (upside potential and quality) and the lower relative risk are predictors of investments in the alternative scenario. (In the particular case, the upside potential refers to a promise of high safety systems regardless of architecture changes and quality to shorter time for third party integration). Thus, increasing development experience distinguishes between the information sets needed for different domains. Given that different domains have different business requirements for system design (Bass and Berenbach 2008), there might be a need for different information sets for an evaluation. Regardless of the domain, increased development experience drove unexpected decisions with respect to the business objectives.

When it comes to the role of the participants, the interaction analysis in the automotive case show little significant interaction between a role (architect’s and manager’s) and information used in decision-making. In the healthcare case, the architect’s role significantly interacts with relative risk (-2.05) and the manager’s role showed a more likely use of sales data (2.26) to make a decision. This is consistent with the study showing that in making the auditor’s decisions, weight patterns of experts relied on one cue as opposed to a broad spread of cues used by non-experts (Ettenson, Shanteau et al. 1987). Thus, given the methodological limitations of regression measurements, this might suggest that weighting factors diverged in the remaining cues, resulting in zero-effect on the decisions. Apparently, decision-makers had difficulties agreeing on which information was important for the decision.

In conclusion, with the exception of development experience, there is a weak link between personal characteristics and decision-making. Longer development experience predicts that decision-makers are more likely to use additional quantified information, but that they will do so in unexpected manner with respect to business goals. Ultimately, the individual’s role only has an effect on information use in the healthcare case, in which *sales* predicted the manager’s decision and *relative risk* predicted the architect’s decision.

5.3.3 *Information decision-drivers vs. information needs*

In this section, we come back to the second question *how information decision drivers compare to information needs reported by practitioners* (chapter 4). Given the insights from the analysis that the information predictors might be domain-dependent and that information needs are gathered in the healthcare domain, we focus our analysis on the healthcare domain. The analysis unveils an asymmetry in information reported as needed and information most likely used in decision-making that has little to do with the personal characteristics of deciders.

In the healthcare domain, three information types are more likely to predict the decision: downside effect, time-to-market, and risk. Compared to the interviewee findings, practitioners use less information than the average amount required (7-11). The *downside effect* was statistically the most significant predictor of the decision in the experiment. Apparently, this information was strongly needed by managers (40% of architects vs. 78% of managers). One explanation might be that managers could better anticipate the business consequences of the downside effect (for instance, limited customer penetration caused by minimum PC configurations for installation). In the real-world project (chapter 3), we observed an architect using the downside effect to argue about negative consequences if a decision on architecture investments were to be abandoned. Given that downside effects relate business consequences to the architecture design (chapter 4), this information seems relevant for both architects and managers in new architecture evaluation. The *time-to-market* information is also a predictor of the respondent's decision. Both architects and managers unanimously reported a need for this information. Finally, *relative risk* was a predictor of the participant's decision to decide on the less risky scenario. At the same time, practitioners (100% of architects and 78% of managers) acknowledged risk as highly needed. As explained in chapter 4, risk is used as an indicator of possible difficulties in implementing technical solutions. In this respect, risk is part of project management—acknowledging the risk and creating an adequate risk mitigation strategy.

The time pressure highlighted two relevant information types: quality and risk. Compared to the interview results, quality was strongly needed mainly by architects (100% architects vs. 22% managers) and risk was needed by a majority of practitioners (100% architects and 78% managers). As seen earlier, the identified information drives unexpected business decisions. This implies that under time pressure, people make decisions using personal rather than business-decision rules. This means that under time pressure, guidance on selecting relevant information and explicit decisions rule are especially needed to support architecture investment decisions in a more objective way.

Development experience emphasizes *downside effect* and *quality attribute in scenario 1* as information predictors of the respondent's decision, again in an unexpected way. Interestingly, these predictors reveal a strong polarization on whether they are needed by architects and managers. While a majority of managers explicitly needed downside effect (78% managers vs. 40% architects), all architects (vs. 22% managers) needed quality. Use of quality naturally follows from higher development experience. In contrast, it is difficult to believe that with longer development experience, people use information needed by managers in decision-making. The explanation lies in the fact that increasing development experience changes the way in which the downside effect is considered in the

decision. Undesirably, with development experience, similarly to time pressure, information predictors are driving unexpected decisions.

Information use by those in a particular role highlights a single information type, *sales* for managers and *relative risk* for architects, which would more likely predict the decision. These findings are consistent with the interview results showing the manager's strong need for sales data (78% managers) and the architect's need for risk data (100%). Given that experts differ from non-experts not by the amount but by the relevance of information (Shanteau 1992), and the large consistency between the empirical and interview data, it can be said that sales and quality are highly relevant for architecture evaluation.

5.4 Discussion and Conclusions

The delivery of relevant information is important to support architecture investment decisions in a more informed way that is better aligned with business goals. In chapter 4, we identified information sets for architects and managers in the healthcare domain. This result was based, however, on what architects and managers said they would need and use, which might differ from what they actually use. In this chapter, we conducted an empirical study to investigate whether professionals do indeed use the information they ask for and how their individual characteristics (experience and roles) determine information use. Based on these findings, we analyzed to what extent information decision-drivers align with the information needs of professionals (chapter 4) and what this mean for supporting architecture investment decisions.

We investigated information predictors of the decision in three different domains. The analysis highlighted the significant impact of information on the decision in two domains, healthcare and automotives. We expected to find fewer significant information predictors than what practitioners had reported in the interviews (chapter 4); this is consistent with the information use of other experts (Shanteau 1992). The results are actually even stronger than that: just a single predictor has an effect that is consistent in both cases.

A closer look at the results shows that the number of information sets used in the automotive domain was less than in the healthcare domain (one vs. three). Participants used less information in our experiments than offered (13), which is consistent with the actions of other decision-makers (Hoffman, Slovic et al. 1968; Slovic 1969; Einhorn 1974). Interestingly, under time pressure, the same information set (quality and uncertainty) predicted the decision in both domains. However, the impact of information on the decision in each domain was counter-intuitive with respect to the business goals. Thus, time pressure causes decisions to be driven by personal rather than business objectives.

When considering personal characteristics, only development experience (next to management and roles) had a significant impact on information use in the decision. Longer development experience implied that respondents would use different information sets (in size and selection) in the automotive compared to healthcare domain. Similar to time pressure, with increasing development experience, the impact of information use on the decision was unexpected with respect to the business objectives in both domains. This implies that supporting architecture investment decisions with respect to information

requires not only offering relevant information sets, but also proposing how to combine information, to make a decision rule aligned with business objectives.

Beside the small amount of information used, the large number of information inputs was not significant. Four explanations account for these results. The first is that the “experts” in these studies were not really experts in architecture evaluation. However, a selection of the cases that showed a large confidence level in the decision helps refute this possibility. The second explanation is that the information set offered is not representative for architecture evaluation. This is also very unlikely, at least for the healthcare domain. There is no reason to suspect the practitioners in other healthcare studies (chapters 3 and 4) would systematically choose atypical information. Third, it could be that the methods we used for measuring regression analysis do not detect when respondents had diverging opinions on information use that resulted in the zero-effect on the decision. The final and most compelling explanation for the result is simply that the participants with development expertise were not different than other experts. They use less of the available information than expected. Although, we do not know for sure which and how much these effects play a role, a larger sample size of respondents might help to address the issues and draw stronger conclusions.

To ensure consistency in the discussion on information used vs. information needed, we elaborated on the findings only in the healthcare case. Decisions in the healthcare case were predicted by the three information types (downside effect, relative risk, and relative time-to-market) as well as the development experience of the respondents. A need for information used in the decision was reported differently among architects and managers. Managers strongly needed downside effect to link architecture design to business consequences, while architects and managers together agreed on time-to-market and risk. We observe that the downside effect was information that bridges business consequences with architecture design, and as such, is highly relevant for the new architecture evaluation. Interestingly, we found that managers use sales and architects quality consistently with their needs. According to Shanteau (1992) experts are able to discriminate relevant from irrelevant, thus we conclude that sales and quality are relevant information in decision-making.

In a nutshell, from chapter 4 we know that architects and managers find that a lot of information is necessary and our experiment shows that there is hardly any consistency as to how they use this information. That is on the one hand worrisome—it looks like everybody is doing something different. This is especially apparent in driving unexpected business decisions under time pressure or with larger development experience. On the other hand, it may indicate that these decision-makers primarily rely on one information cue. This implies that for sound business decisions, there is a need for a more structured approach to support architecture investment decision-making. To support a decision in a more structured way, we offer a guidance to identify relevant information and to prescribe how this information is combined (decision rules) and aligned with business objective in chapters 6 and 7.

PART III: Best practices

6 Modeling customer-centric value to support architecture investment decisions³

The main theoretical and practical challenge in using the existing methods to support architecture investments is a lack of guidance on identifying and quantifying customer value (chapter 3 and 4). Despite the practitioners' needs for customer-centric information (chapter 4), there is no evidence on its use in making decisions (chapter 5). The few methods that propose to incorporate customer value (Clements, McGregor et al. 2005; van der Linden, Schmid et al. 2007) in architecture evaluation are far removed from practical processes and experiences. Given this fact, we explore how to use common best practices in management and marketing to identify and quantify customer value. Hence, we aim to incorporate customer value in architecture evaluation as close to standard practices as possible to increase its adoption by an organization.

The concept of customer-centric value brings a large corpus of literature, mainly from two perspectives: management and marketing. We describe some of the highlights below.

According to Kotler and Keller (2008), the main aim of any organization is to deliver customer value at a profit. Note that, however obvious this may seem, this paradigm changes the economic model of the organization. The “old economy model”, typically organized by product units, focused on profitability and transactions while primarily being concerned with financial scorecard. The new economy model is focused on customer lifetime value and organized by customer segments (marketing scorecards) in addition to financial scorecards. However, not all organizations use marketing scorecards. A decision on using marketing scorecards to evaluate any investments will strongly depend on the highest business goals of the organization. To ensure the right scorecards are used, Kaplan and Norton propose to use “strategy maps” (2004) and balanced scorecard tools (1992). Strategy maps translate a business strategy to the financial objectives of an organization, which are linked to operational objectives, including customer, internal, and learning and growth objectives. Kaplan and Norton claim that using the proposed tools allow organizations to assign scorecards for each objective and monitor progress in meeting objectives aligned with the business strategy.

To clarify the concept of marketing scorecards, in particular customer value, we take the organization's perspective. The organization aims to deliver a system with intended benefits, such as improved evolvability or usability. However, quality improvements of the system might not be directly perceived by customers as beneficial. For example, system evolvability improvements are beneficial for the organization to deliver the system with a shorter time-to-market. However, the customer perceives evolvability improvements beneficial only if the late delivery of the system is important for the customer. The customer perceives the system quality improvements as a bundle of benefits derived from buying, using, or consuming a system (Hooley and Saunders 1993). This view on the benefits of architecture changes is not a common practice in the organization. To overcome

³ An adopted version of this chapter was published as a paper at the 4th European Conference on Software Architecture (ECSA2010), Copenhagen, Denmark. This paper received the best paper award and was selected for a submission to the Journal of Software and Systems Modeling.

this challenge on what a customer wants, organizations measure perceived customer benefits, such as perceptual customer metrics (e.g. customer satisfaction) and observed or behavioral metrics (e.g. customer retention and lifetime value) (Gupta and Zeithaml 2006). For example, customer satisfaction is measured by net promoter score metrics (Keiningham, Cooil et al. 2007) at Philips Healthcare, which are then used as a supporting argument in the architecture evaluation (chapter 4). Despite empirical evidence demonstrating that increased customer benefits lead organizations to better overall financial performance (Gupta and Zeithaml 2006; Keiningham, Cooil et al. 2007), it is difficult to make a relationship between benefits and value. Thus, it is important to identify the sources of benefits and to make explicit how benefits create value for customers. Customer value is a level of return from product benefits for a certain amount of customer's money (Day 1990). In the architecture context, this implies that architecture changes are meant to benefit customers, but architecture creates customer value only if the customer can use improvements as inputs to leverage their own perceived value creation (Normann and Ramirez 1993). The customer value concept has not only been a theoretical exercise. An extensive review of the state-of-practice in customer-value assessment in business markets shows a high adoption of customer-value concepts in making business decisions (Anderson, Jain et al. 1993). For example, to support business decisions on product modification and redesign, organizations apply different assessment techniques, such as internal engineering, value-in-use, focus group value, or importance rating. Among those techniques, the value-in-use assessment was used the most frequently for supporting new product redesign investments, which qualifies this technique for architecture investment assessments.

Not only do organizations aim to deliver customer value to a particular customer but they also want to deliver benefits to selected customer segments to maximize profit. Segmentation theory proposes that groups of customers with similar needs and buying behaviors are likely to demonstrate a more homogeneous response to marketing programs (Dibb and Simkin 2001). This allows for a more efficient application of resources and ensures that customer offerings are carefully targeted. The process of market segmentation is well established, usually described as the STP (segmenting, targeting and positioning) of modern marketing (Kotler and Keller 2008). During the first stage (segmenting), customers are grouped by applying one or more base variables. This stage aims to group customers into segments with similar needs and buying behavior. In the second stage (targeting), decisions are made about where resources should be prioritized, whereas the final stage (positioning) focuses on designing marketing programs to match the requirements of customers in the targeted segments. Although the benefits that customer segmentations offers are well documented, business still encounter barriers when putting segmentation schemes into practice (Dibb and Simkin 2001; Blocker and Flint 2007). Barriers include a lack of (1) management support; (2) established processes for data collection, and (3) expertise to drive the process.

Based on the findings of the previous chapters and the literature overview, we aim to investigate how to use best practices in architecting, management, and marketing to model customer value in order to support a decision on architecture investments in practice.

This chapter reports on modeling customer value and evaluating its possible acceptance in practice based on two real-world case studies at the MRI business unit of Philips Healthcare (2010). To identify the benefits of architecture changes, we exploit management tools, in particular strategy maps and balanced scorecards, to map architecture decisions to customer-centric objectives and measures. Furthermore, we adopt two marketing concepts, customer value-in-use and customer segments to quantify the value of architecture changes for a single customer and multiple customers with the same needs. To assess the potential acceptance of the customer-value concept in the organization, we compare existing and proposed customer-value indicators on the same real-world case and let them be evaluated by decision makers. These findings are used to propose a new method to support architecture investment decisions (chapter 7).

The rest of this chapter is organized as follows. Section 6.2 presents steps to model customer value and evaluation processes as a baseline for conducting our study. Section 6.3 describes the first study on modeling and evaluating customer value by exploiting the customer value-in-use concept. Section 6.4 describes the second study on modeling and evaluating the customer value by exploiting the customer segment concept. Finally, section 6.5 elaborates on the applicability of customer value to assess architecture investments and concludes with recommendations for improvements.

6.1 Study design

We use a case study research methodology, which helps in exploring and documenting real-world phenomena, such as decision-making on architecture investments (Yin 2003). For each of the two studies presented in this chapter, we follow the study-design steps as presented in Figure 12. Two distinct parts of the study are modeling customer value and an evaluation of the proposed model by practitioners for potential improvements.

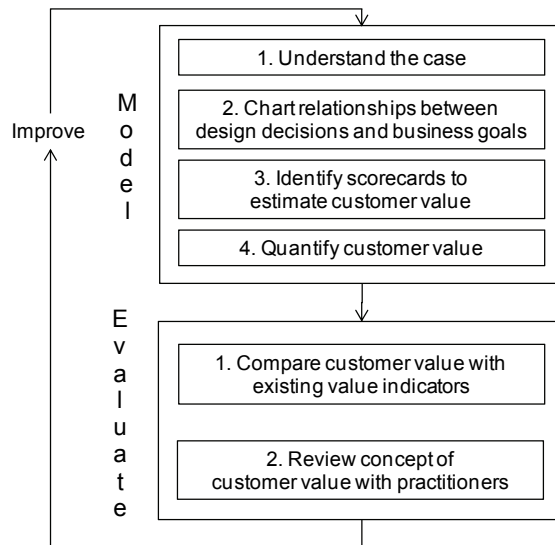


Figure 12. Study design

6.1.1 Model

To model how customer value supports a decision on architecture investments, we propose to identify the intended benefits of design decisions for system architecture and to quantify customer-centric value. The modeling process is elaborated in four steps.

In the first step, *Understand the case*, we aim to (1) clarify the business goals of architecture investments, (2) identify design decisions intended to deliver customer benefits, and (3) identify value indicators that might have supported architecture-investment decisions in the organization. We start from the architecture definition to explain in more detail how these findings help us to understand the case. Architecture is a set of the most significant design decisions (Jansen and Bosch 2005; Tyree and Akerman 2005) in fulfilling business goals (Bass, Kazman et al. 2003). First, to clarify a motivation for architecture investments, it is important to identify the business objectives of architecture investments. This is done by using best practices in architecture evaluation in the wider business context, such as BAPO/CACFR (Muller 2003; Rommes and America 2006), which can also be found in other organizations in similar form but under different labels (Hofmeister, Kruchten et al. 2007). Second, given the architecture definition, we need to identify design decisions that are the source of architecture value, including customer-centric value. Finally, to accommodate the practitioner's request (chapter 3) to explore new concepts built upon the existing processes, we sought to understand existing value indicators used to support customer-centric architecture investments in an organization. This knowledge would help us to propose a concept of customer value that would not depart significantly from existing indicators, therefore, accelerating the concept's adoption.

In the second step, *Chart relationships between design decisions and business goals*, we use the concept of strategy maps (Kaplan and Norton 2004) to translate the business goals identified in the first step to a chain of cause-and-effect relationships of objectives that are linked to design decisions. The chain starts with the organization's long-term financial objectives, and then links to the operational objectives from three perspectives: *customer*, *internal business*, and *learning and growth*. Then the design decisions identified in step one are mapped to the objectives. By linking customer-centric objectives to design decisions, we make the impact of architecture investments on customer value explicit. If design objectives are not mapped directly or indirectly to the customer-centric objective, the organization is advised to reevaluate the architecture's design. It is important to note that knowing how the architecture creates value helps in selecting a marketing concept that is adequate to assess customer-centric value. This is a step where best practices in management (strategy maps) and marketing (customer value concepts) meet.

The third step, *Identify scorecards to quantify customer value*, proposes to apply the balanced scorecard tool (Kaplan and Norton 1992) to assign measures (scorecards) to the customer-centric objectives identified in the second step. These measures guide the data-collection process in an organization.

Finally, the last step, *Quantify customer value*, aggregates all measures identified in step three to quantify customer value. Note that this step closes a modeling loop. We start by identifying business objectives and design decisions (step one) and then we map design decisions to the source of customer value (step two). Once the link between design deci-

sions and value is established, we identify measures (step three) to quantify customer value (step four) to meeting the ultimate business goal (step one). In this way, value is explicitly mapped to the business objective of architecture investments.

In this step, we also assess the total elapsed time and effort spent by the team to support all steps in quantifying customer value, which is relevant for the evaluation of the model.

6.1.2 Evaluate

Innovation, including the new concept of quantifying customer value, can only be diffused if it is based on small, incremental changes (Rogers 2003). To examine acceptance of the customer model and exploited marketing scorecards by Philips Healthcare, we propose a two-step evaluation process.

The first step, *Compare customer value with existing value indicators*, refers to examining value indicators in the organization (identified in the first step of the customer-value modeling) and then analyzing similarities and differences with the customer value concepts proposed by the model. Then, the second step, *Review customer value model by practitioners*, starts with sharing findings about customer-value models, effort and time spent in quantifying customer value, and comparing the customer-value and existing-value indicators with practitioners. The aim of this step is to gather feedback on the pros and cons of the customer-value proposals and to scan potential adoption of the customer model by the organization. In our study, the review process involved initiating and observing a discussion between business decisions-makers about the study findings at a review meeting. Two researchers observed the discussion and cross-checked their observations immediately after the meeting.

We quantified the value of quality improvements in two real-world architecture investment projects at Philips Healthcare (see section 3.2.1), in which the value of architecture investments was exclusively associated to customer value (cost savings or new functionality is not envisioned). In conducting these studies, we made liberal use of both internal and external documentation, interviews with decision-makers, attendance at group meetings, and partly participatory observations. We elaborate on the sources of evidence in more detail in each study.

6.2 Study 1: Customer value-in-use

In this study we investigate how the customer value-in-use of architecture improvements, in particular efficiency improvements, can be quantified and used in architecture decision-making. We describe the case and follow the steps of the study design (Figure 12 on page 85) presented in the previous section.

6.2.1 Explorer case

*Explorer*⁴ is a workstation consisting of dedicated hardware and clinical applications used to view medical images acquired by a scanner and then post-process these images to support radiologists and cardiologists in making a diagnosis.

Using Explorer in a hospital can easily take an hour per patient. One of the reasons is that the user needs to delineate manually up to 3,500 myocardial contours (boundaries of the heart muscle) to make a diagnosis. Therefore, although Explorer was proven to be clinically beneficial, it has been used mainly for research purposes by academic hospitals and rarely for routine diagnostics in community hospitals where throughput has the highest priority. Philips Healthcare, in cooperation with clinical partners, decided to do an architecture redesign to improve the usability and simplify the use of Explorer (Breeuwer, Hautvast et al. 2008). No new clinical application areas were added. The usability redesign involved (1) minimizing the amount of interaction needed for post-processing through judicious use of automation and (2) introducing new viewing protocols that better reflect the users' way of working. The engineering assessment of the redesign in a laboratory setting has shown significant efficiency improvements (Table 12).

Table 12. Time required delineating an exam manually and with automation (Breeuwer, Hautvast et al. 2008)

	Images	Contours	Manual (minutes)	Auto (minutes)
Procedure 1	500	1500	90	5
Procedure 2	420	6	6	3
Procedure 3	20	40	10	1
Procedure 4	600	1800	120	10

Despite strong evidence that the quality improvements were significant, the main question in the business was whether such improvements make a difference once the product was used in the hospital

The study question was: *How to quantify the customer value of efficiency improvements when Explorer is being used in hospitals?*

The BEST hospital was selected to conduct the case study. BEST was a preferred customer of Philips Healthcare because of their strong cooperation and most-efficient use of Explorer in a clinical workflow. In addition, Philips Healthcare had already gathered estimates from the senior doctor at the BEST hospital that new viewing protocols could speed up the clinical workflow. Time savings were estimated at 10-15% for experienced cardiologists and 50-60% for novice cardiologists. Thus, Philips Healthcare had some evidence that efficiency improvements of Explorer could make a difference in the hospital's business. Finally, the assumption was that if we would show that architecture improvements had significant impact on BEST hospital businesses (as an example of "best

⁴ The major identifying details for this case, such as product name and hospital name, have been replaced with pseudonyms for confidentiality reasons.

practices”), all other hospitals could also experience improved efficiency when using Explorer.

To estimate the value of this improvement in the context of the study, we looked for a suitable concept for this estimation. A state-of-practice study (Anderson, Jain et al. 1993) about customer value assessments in business markets highlights that the value-in-use assessment was the most frequently used technique for supporting business decisions about product modification and redesign investments. Therefore, we selected value-in-use as a suitable technique for architecture investment decisions. We defined the value-in-use to suit the scope of our study as the differential cash flow generated in using the product with improved quality in the customer’s organization.

We expected that customer value-in-use would help Philips Healthcare in two ways. First, value-in-use can be used to demonstrate the added value of a new product that incorporates quality improvements for the customer and to indicate the value of the architecture. Second, value-in-use can be used to estimate the customer’s willingness to pay for such improvements, and therefore to compare the potential cash flow of quality improvements with the architecture investment.

This study required the researchers be closely involved both at Philips Healthcare and the BEST hospital (a customer). At Philips Healthcare, we interviewed a product marketer and a clinical scientist responsible for understanding customer requirements and setting up an assessment of architecture improvements. We also visited the BEST hospital to interview cardiologists who used Explorer and the department head who ran the cardiology business and was also in charge of making a purchase decision on the Explorer. Next, in a two-day observation session, we shadowed the cardiologist who used both the existing Explorer and a trial version of the improved Explorer to diagnose 30 patients. The main source of evidence on hospital business and product improvements was internal documentation and scientific publications.

6.2.2 Model

The first part of the case study involves an analysis consisting of four steps (Figure 12 on page 85), which are discussed in the next subsections.

6.2.2.1 Step 1: Understand the case

In this case, a decision on architecture investment and follow-up architecture implementation had already been done at the moment of our study. This implied that we had a relatively easy time in conducting this step.

According to the product manager of Explorer, who was in charge of marketing and sales for the product, the main business objective of such an investment was boosting sales. This business objective was aimed at the particular customer segment of hospitals that needed to improve clinical workflows. It was interesting to note that customer segmentation was used implicitly to group customers that would potentially benefit from the architecture changes.

To better understand design decisions as a potential source of customer value, we interviewed the architect and clinical scientist who drove the system redesign. It appeared that there were two main design decisions intended to create customer benefits: better viewing protocols and automated delineation. (An explanation on how these decisions drive value is elaborated in more detail in the next subsection.)

Finally, internal documentation and external publications highlighted that the efficiency improvements were assessed using technology-assessment techniques and expert opinion. The validation study, conducted in a lab, had shown that users needed significantly less time (up to 18 times) to verify and fully correct the automatically detected contours than for drawing these contours manually in the four main procedures, as shown in Table 12 on page 88. Furthermore, in the BEST hospital, experts estimated time savings when using the new Explorer at 10-15% for experienced cardiologists and 50-60% for novice cardiologists.

It is important to note that these assessments were not explicitly aimed at the architecture evaluation. They were used to promote the product to the customer, to demonstrate Philips Healthcare's willingness to anticipate customer needs, and to foster cooperation, which would also indirectly affect product sales.

6.2.2.2 Step 2: Chart relationships between design decisions and business goals

This step involves establishing a relationship between system-design decisions and the business goals of a developing organization. As seen earlier, design decisions added an automatic delineation algorithm for myocardial contours and adapted the viewing protocols (descriptions of screen layout and behavior) to match and guide typical user workflows. The general goal of these changes was improved usability in order to increase customer value. By increasing customer value, Philips Healthcare wants to increase customers' willingness to buy the product and thus its sales.

To identify suitable usability measures, we used the established concept of measuring usability by looking at user satisfaction, effectiveness, and efficiency (Bevan and Macleod 1994). In the Explorer case, we expected most benefits to reside in efficiency improvements; therefore, we simplified our investigation to understand the impact of Explorer efficiency improvements in the BEST hospital business.

Now, we had to turn our attention to the hospital business. To identify BEST's business goals, we interviewed the head of the cardiology department. The global trend of improving quality-of-care and reducing costs was apparent in BEST. The quality-of-care improvements desired were reduced patient waiting lists combined with increased productivity to gain enough time for an additional exam per day. Such an improvement would also affect BEST's revenue, as each exam would be reimbursed for about €800. Therefore, it was important to improve the workflow during the scanning and post-processing of images.

Figure 13 shows the relationships between the various concepts in the form of combined strategy maps of Philips (the developing organization) and the hospital (the customer). Gray shading indicates the design decisions. In this context we also see that customer value-in-use is actually a suitable marketing concept by which we can assess customer

value, because this is the point where the strategy maps of Philips Healthcare and BEST hospital connect.

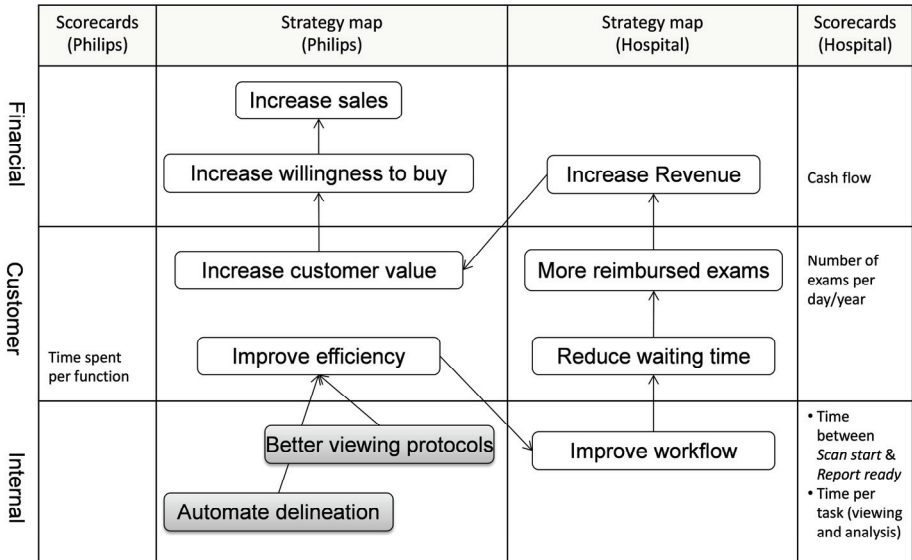


Figure 13. Strategy maps and scorecards of Philips and the BEST hospital

6.2.2.3 Step 3: Identify scorecards to estimate customer value

The next task is to find measures that can serve as indicators for the various elements in the strategy maps of Philips and the hospital. These are also shown in Figure 13. On the Philips side, we started from the findings about the efficiency of the new architecture as given in Table 12 on page 88, and further identified the time spent for each function (as measured in a laboratory) as an indicator for the product's efficiency. At a higher level in the strategy map, we found customer value, which is related to the revenue gained by the customer, which we will discuss below. In the financial area, we identified product sales and the customers' willingness-to-buy, which in turn depended on how well the company can *convince* the customers of the product's added value. To deal with these aspects, one would need marketing expertise that we did not have access to in this study, so we therefore had to leave this aspect out of our study.

Now we turn to the hospital side of Figure 13, above. From the interview with the department head, we learned that examination volume per modality was the main business indicator monitored regularly in BEST. That agrees with the literature about the most frequently used productivity indicators (Ondategui-Parra, Bhagwat et al. 2005).

The examinations can, of course, be counted per day or per year (where we make the simplifying assumption that all exams performed are also reimbursed by health insurance). In order to find indicators for improving workflow, we first need to understand how Explorer is used. For this purpose we observed an experienced cardiologist in the clinical workflow. We also identified three parallel activities in the clinical workflow: (1) image acquisition from the scanner, (2) image viewing and post-processing using Explor-

er, and (3) patient administration as done on the cardiology information system (see Figure 14).

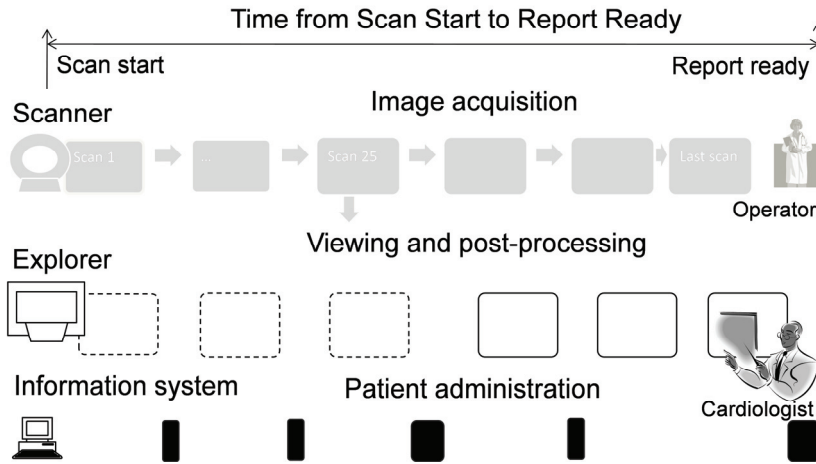


Figure 14. Explorer in the clinical workflow in BEST hospital

We model the clinical workflow as the time spent on parallel activities (represented by the rectangles in the figure) in the hospital to address the potential contribution of Explorer’s usability improvements to minimize the time from the scan start to report ready. The clinical workflow can be described as follows. The image acquisition begins with “scan start” initiated from the console by the operator, who is sitting next to the cardiologist. It takes some time until the acquired images are available for viewing and post-processing on Explorer. The cardiologist usually uses this gap time to check old exams (dashed rectangles in the figure) or to administer patient data on the information system, such as writing a report (black rectangles in the figure). Once the scan is available in Explorer, the cardiologist starts viewing and post-processing images. If he or she notices some irregularity in the images, the individual might request that the operator repeat the image acquisition or look at the console to help the operator to define the right acquisition parameters. We observed that the end of all three activities—image acquisition, image viewing and post-processing, and reporting—almost coincide. When the patient leaves the scan room, the report is ready. During the procedure, there are several moments where one of the activities is waiting for another. This clinical workflow applies to most routine exams and takes about 15-25 minutes from start to finish.

In addition to these typical exams, however, there are also exams where a longer procedure is followed, comparable to procedure 2 or 3 in Table 12 on page 88. Here the post-processing takes more time and therefore there is more opportunity for improvement.

We concluded that to achieve the business goal of increasing the number of exams, the most urgent issue in the department was to shorten the time needed from the scan start to the final report without compromising the quality of image analysis. In such a highly efficient workflow, improving the efficiency of image viewing and post-processing during scanning was critical to be able to fit in another exam. The time needed for each task in viewing and post-processing would therefore be the basic contributing factor related to the Explorer system.

6.2.2.4 Step 4: Quantify customer value

After identifying the indicators linked to the strategy maps (see Figure 13 on page 91), we now need to estimate their numerical values. At the moment of the study, BEST conducted, on average, about 2,000 imaging exams per scanner annually. We already mentioned that each exam was reimbursed for about €800 and took between 15-25 minutes.

We analyzed the different exams in the clinical workflow to identify when and how usability improvements of Explorer would achieve the greatest time savings. We realized that different exams in the portfolio benefit differently from usability improvements. Regarding viewing improvements, all exams would save 1.5 minutes, on average. On the other side, automation improvements would significantly contribute to only one exam, which was performed every second day. The savings would total approximately seven minutes per exam, considering the technology assessment of task efficiency improvements in procedures 2 and 3 in Table 12 on page 88. In other exams, delineation was performed rarely or never because of the tedious manual work. Similarly, the very laborious procedures 1 and 4 were never performed at the hospital. Thus, automation would not bring significant improvements to the BEST hospital except for the one exam type. Introducing new procedures, now made feasible by technical improvements, would be more cumbersome because they would require agreement with the health-insurance establishment about reimbursements.

We presented the results of interviews and shadowing to the participants in the study in BEST, and they confirmed our findings about the clinical workflow model and productivity improvements due to the usability changes in Explorer. Since the 1.5 minutes improvements were too short to schedule a new exam, only the automation improvements were considered for potential scheduling of an additional exam every second day. This resulted in two additional exams over 50 weeks, amounting to €80,000 per year. As an estimate of our own activity, we can state that this study required one person-month for a researcher to quantify the customer value-in-use.

6.2.3 Evaluate

After the modeling phase, we evaluate our approach, following the steps shown in Figure 12 on page 85. Note that this evaluation was part of our case study, but it would normally not be part of an architectural approach to estimate customer value.

6.2.3.1 Step 1: Compare customer value with existing value indicators

When comparing these existing indicators to our customer-value concept, we realized that the expert opinion about productivity improvements (10-15%) for the new viewing protocol is surprisingly close to the estimated time savings in the clinical workflow (1.5 minutes in the 15-25 minutes exam). On the other hand, estimates about task efficiency of automation (Table 12 on page 88) in the lab did not relate directly to improvements in clinical practice. This difference can be explained by the fact that procedures requiring manual delineation of many contours were used only a few times; therefore, automation improvements would not be realized directly in the existing clinical workflow. Nevertheless, once the automation becomes available, the cardiologist may start using these procedures more frequently.

However, we must conclude that engineering assessment and expert opinion are insufficient to understand the potential customer value created in a real-world setting (the customer value-in-use). Only by understanding the hospital workflow can the relationship between usability improvement and customer value-in-use be established.

6.2.3.2 *Step 2: Review concept of customer value with practitioners*

An evaluation of the Explorer case findings was conducted with the product marketer and a clinical scientist responsible for estimating the efficiency improvements at Philips Healthcare. We presented our findings and asked the review team to discuss how the proposed framework for quantifying the customer value-in-use might support the decision-making process. Two themes emerged from the discussion: the cost of applying the concept of quantifying customer value and the importance of such a concept.

Regarding the time spent quantifying the customer value-in-use, the organization has to account for the additional effort of one person-month if the efficiency indicators are already available. This time spent could be shorter for an expert knowing the domain or having already modeled the workflow of the hospital.

In the Explorer case, the practitioners found the customer value-in-use promising and at the same time incomplete for decision-making. Making the value of quality improvements in the hospital business explicit was perceived positively. However, analyzing a large diversity of hospitals and their workflows would be very labor-intensive.

Nevertheless, if improving the business of existing customers is the main strategic goal of the organization, this analysis can be used for selected representative hospitals to support the right architecture changes. Another use is envisioned in the case when quality improvements are so large that details of the hospital workflow do not impact the customer value-in-use. Then the customer value-in-use can be used generically for all hospitals and therefore become a relevant value indicator.

6.3 Study 2: Customer segments

In this study we demonstrate how the customer segments can be used to quantify the number of customers affected by architecture investments and to support architecture-investment decisions. We describe the case and follow the steps of the study design in Figure 12 on page 85. We use a real-world case, the migration of a product line towards the architecture of a parallel product line to demonstrate how the customer segments of various product lines would be affected. The following subsections show how we addressed this issue.

6.3.1 *Tricorder case*

*Tricorder*⁵ is a product line of medical workstations consisting of dedicated hardware and clinical applications to make diagnoses and prepare treatment. Over the last years, with

⁵ The major identifying details for this case, such as product names and data, have been replaced with pseudonyms for confidentiality reasons.

increasing market pressure to release new applications quickly, the Tricorder architecture has been eroding, resulting in increased development effort and difficulties to predict time-to-market of new application releases. Furthermore, the newest market research about customer insights has shown opportunities for improvement in:

- *Usability*: The system should be *easier to use*. In particular, the user interfaces of the various applications should be harmonized.
- *Accessibility*: The applications should be accessible from any workplace.
- *Multimodality*: The system should view and process images from other product lines.

To meet these challenges, it was decided to migrate all Tricorder applications to the architecture of another successful product line. This decision to merge product lines was also made to strengthen the competitive advantage of Tricorder because applications from another product line could then be offered on Tricorder as well.

The architects selected two potential architectures from existing product lines, *LabTricorder* and *ViewAll*. Regardless of the architecture choice, the marketers requested phased development to offer a few market releases of the new Tricorder to incrementally meet the customer needs during the migration. It was estimated that in both scenarios, the migration process would last for two years.

At the moment of our study, the lead architect had already made the first multi-attribute ratings of scenarios and favored the LabTricorder scenario. To support this informal decision to invest in the LabTricorder scenario, the product marketer was asked to make a business case for the LabTricorder investment.

Although the decision to invest in the LabTricorder scenario was already made, it was not clear to decision-makers if, how, and to what extent the quality improvements would generate customer value in both the LabTricorder and ViewAll scenarios. Therefore, we were asked to estimate how the LabTricorder and ViewAll scenarios would affect customer segments during the migration, as an input for evaluating the ongoing architecture investment decision-making process.

Thus, the study question was: *How will Tricorder's quality improvements impact customer segments during the migration process in the LabTricorder and ViewAll scenarios?*

In this study we actively participated in weekly project meetings for six months while preparing the project for an official review on architecture investments. The project meetings involved the system architect, a product manager, and application scientists. Our role was not only to observe the architecture evaluation process, but also to help in data collection, e.g. by reviewing the external market documentation. Furthermore, we interviewed the program manager responsible for merging product lines at different stages of the project to understand the decision process. Other interviews involved managers and architects of the product divisions in charge of delivering architecture changes, application scientists responsible for the user-interface design, and clinical scientists responsible for planning the application portfolio. We should not underestimate evidence we gathered from the internal documentation as well as the publicly available evidence.

6.3.2 Model

Again, our analysis follows the four steps indicated in Figure 12 on page 85.

6.3.2.1 Step 1: Understand the case

As opposed to the retrospective analysis used for the real-world case in the previous study, in this study, we worked together with practitioners directly involved in the architecture evaluation.

To identify business objectives, we interviewed several business stakeholders and read project documentation that resulted in the high-level business goal of increasing revenue. The business stakeholders envisioned reaching this business goal by increasing sales and/or influencing the product price. This objective was the same as in the previous case, and is apparently the ultimate goal of any organization (Kaplan and Norton 2008).

However, identifying architecture design decisions that generate customer value was more difficult than in the previous study. In contrast to the first study in which the decision on the architecture had already been taken, in this case, we were involved in a real-world architecture evaluation. Finally, the consensus between the marketer and architects produced three design decisions, *Harmonized UI*, *Access anywhere*, and *Multimodal applications*. A more elaborate explanation on challenges to identify the design decisions is presented in the following section. Finally, we identified two value indicators used in the organization to support architecture investments: multi-attribute assessment that can be closely associated to cost benefit and business case analysis (section 2.2).

6.3.2.2 Step 2: Chart relationships between design decisions and business goals

An important step when analyzing any architecture investment is to identify not only the high-level financial objective, but also the customer objectives in reaching the financial goal. In multiple one-to-one interviews with the program manager, the system architect, and the product marketer of Tricorder, we spent a significant amount of time clearly identifying the customer-centric business goal. In our experience, the potential migration to another system architecture has often started as a business process long before the actual goals are made explicit. The same phenomenon was also observed in chapter 3. One explanation was that the Tricorder project had a large impact across several business units resulting in diverse business incentives for the project, such as quicker time-to-market, meeting customer needs, and improving customer satisfaction. Finally, a consensus was reached on the customer-centric objective to *increase the number of potential customers whose needs regarding the processing of medical images were met*, including not only Tricorder customers but also customers using LabTricorder or ViewAll. In that way, sales (and therefore revenue) would increase. To see how this could be achieved by merging product lines, we consider the effects on existing customer segments.

The existing Tricorder market segment would benefit in three ways by migrating their applications to the LabTricorder or the ViewAll architecture: First of all, after migration, the user interface would conform to the standards of the new architecture, which means that it would be harmonized across applications. Second, both LabTricorder and ViewAll already offer access to their applications from any workplace in the hospital, so after mi-

gration, the same would hold for Tricorder applications. Finally, by moving to the LabTricorder or ViewAll platform, the applications already existing on those platforms, including the multimodal ones, would become available to Tricorder users. In addition, the existing LabTricorder or ViewAll market segments would benefit from the Tricorder migration by making the Tricorder applications available to them.

Figure 15 shows the strategy map related to the Tricorder architecture migration, where gray shading indicates the design decisions of the target architecture for migration.

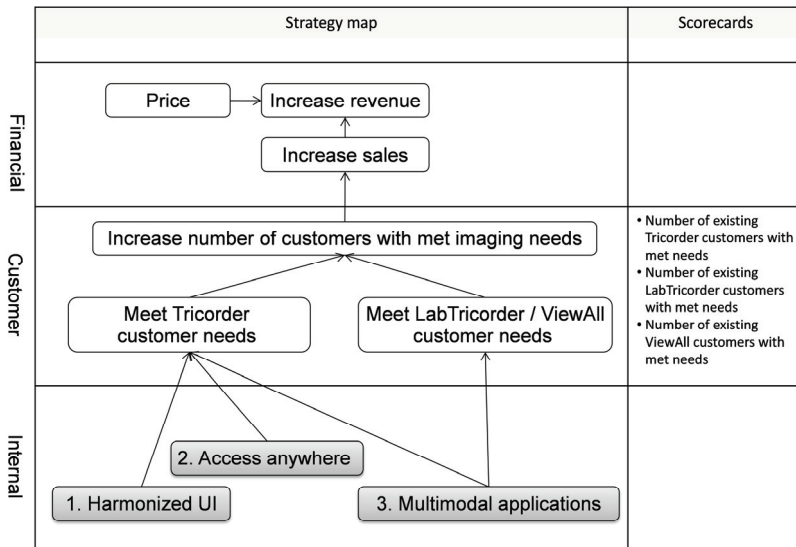


Figure 15. Strategy map and scorecards of the Tricorder case

6.3.2.3 Step 3: Identify scorecards to estimate customer value

Following our study design described in section 6.2, we identify scorecards used for assessing the impact of architecture changes on the customer segments. In this case, the choice of scorecards is relatively straightforward: we simply consider the number of customers in the various segments whose imaging needs are met (Figure 15). The complicating factor is, however, that the two candidate target platforms for the migration of Tricorder applications do not differ significantly in the number of customers whose needs are met *eventually*, but they only differ in their *timing*.

Since the marketer requested phased development to maximize customer value before all applications would be migrated to the new architecture, we needed to make two time-dependent scenarios to understand how the products offered in different phases would affect customer segments. We interviewed 20 stakeholders involved in this project and read product documentation to reconstruct the time-dependent LabTricorder and ViewAll scenarios, shown in Figure 16.

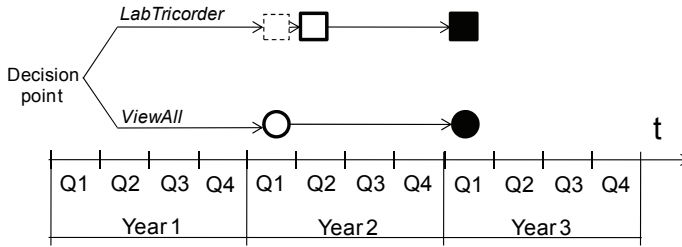


Figure 16. Scenarios used for quantification of customer segments

The LabTricorder scenario was envisioned in three phases. Phase 0 (dashed square in the diagram) enables viewing but not post-processing of all Tricorder images on the LabTricorder platform in a year. Phase 1 (empty square in the diagram) offers a few Tricorder applications with a harmonized user interface in the next quarter, while the remaining applications would still be available on the existing Tricorder. Finally, in Phase 2 (filled square in the diagram) the remaining Tricorder applications would be available on the LabTricorder architecture in two years from the moment of this study. All applications would be accessible from any PC in the hospital (a so-called thin client setup).

The ViewAll scenario was envisioned in two phases. Phase 1 (circle in the diagram) enables migration of all Tricorder applications to the ViewAll architecture in a year. Tricorder would not be available on the market anymore. In Phase 2 (filled circle in the diagram), the Tricorder applications could be used on multiple dedicated hardware terminals (thick clients) in two years. The Tricorder applications would then become available to ViewAll customers.

6.3.2.4 Step 4: Quantify customer value

As we have seen, in both scenarios, customer needs are met but with different solutions (thin vs. thick client) and different timing of releases, which satisfy different customer segments. To quantify the number of customers whose imaging needs are met, we used sales of Tricorder and LabTricorder/ViewAll products from the previous year as proxies for the number of customers (Table 13).

Table 13. Number of customers with met imaging needs over time in LabTricorder and ViewAll scenarios

		LabTricorder scenario									
		Y0	Phase 0	Phase 1				Phase 2			
			↓	↓ Year 1				↓ Year 2			
Segmented customers		Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	
Tricorder		66	68	75	75	77	79	80	80	80	
LabTricorder		30	34	34	34	34	34	34	34	34	
Total		96	102	109	109	111	113	114	114	114	
		ViewAll scenario									
		Tricorder	66	66	69	71	71	71	72	73	73
		ViewAll	38	38	38	38	38	40	40	40	40
Total		104	104	107	109	109	111	112	113	113	

The estimates were made by an architect, who corrected the individual quarterly sales using information from Figure 15 and Figure 16, resulting in the total number of customers whose imaging needs are met in both scenarios (see Figure 17).

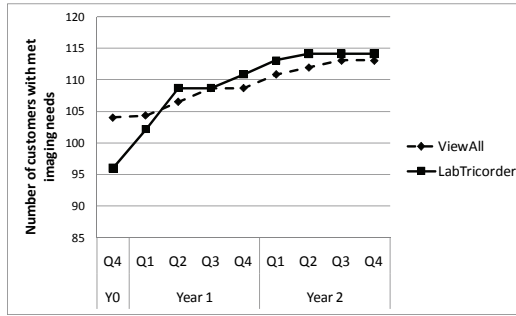


Figure 17. Total number of customers whose imaging needs are met over time

Our own total effort to quantify the customer segments affected by the architecture changes was three person-months for a researcher.

6.3.3 Evaluate

In this section, we evaluate our approach following the steps shown in Figure 12 on page 85.

6.3.3.1 Step 1: Compare customer value with existing value indicators

As we have mentioned before, the business case was made but only for the LabTricorder scenario, according to the informal decision that had already been made. The total sales of the LabTricorder and Tricorder product was used to estimate the present value (PV) of the difference in cash flow when migrating to the LabTricorder versus keeping the existing Tricorder architecture over four years, as shown in Figure 18.

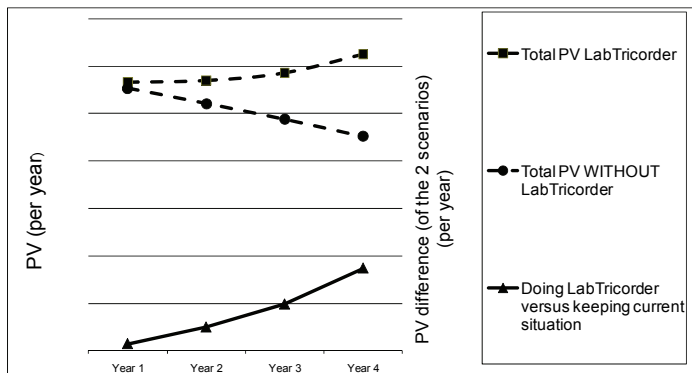


Figure 18. Present value difference upon introduction of Tricorder

This calculation was based on future sales figures estimated by extrapolating market trends and considering the requirements mentioned in section 4.1.1, but without taking into account changes in customer segments because of merging product lines. The business case confirmed the LabTricorder informal decision.

According to Figure 17 on page 99, the LabTricorder scenario meets the imaging needs of more customers, averaged over the migration period. That can be used as a value indicator for the LabTricorder investment, which was consistent with the business case analysis. When we compare this business case analysis with our customer segment analysis, we see that they studied different things. The business case analysis confirmed the desirability of *some* architecture improvements in order to meet the requirements in section 6.4.1 (usability, accessibility, and multimodality), whereas the customer segment analysis compared two possible scenarios for architecture improvement, showing that the LabTricorder would be preferable. In this case, the studies complemented each other.

On the other hand, we mentioned multi-attribute ratings for the LabTricorder and ViewAll scenarios that the architect had already done before we started our study. Those ratings only included technical criteria and effort estimates and did not explicitly address the value created by the investments. As such, multi-attribute analysis is very similar to cost-benefits analysis (section 2.2.1). Moreover, the timing analysis, as mentioned in section 6.4.1, was not included.

6.3.3.2 *Review of the procedure with practitioners*

We presented our findings to the program manager, the system architect, and the marketers in a one-hour review meeting, asking them to discuss whether and how the customer segments could support decision-making processes in the organization, based on their and our experiences with the Tricorder case.

The main conclusion to draw from the analysis is that an explicit link between design decisions on quality improvements and customer segments can support a common understanding between decision-makers on how design decisions create customer value in different scenarios. Furthermore, such structured analysis would prevent individual business incentives from dominating the decision-making process, and would therefore facilitate more objective decisions. The marketer especially emphasized that the customer-segments analysis could be used to fine tune estimates in the business case modeling to improve the accuracy of the existing data. The architect also valued the explicit relationship between quality attributes and customer segments on the one hand and the timing analysis on the other hand. We expected these results based on the information needs of architects and managers (chapter 4). Customer segments provide a more guided process on data collection for a business case analysis that fulfills the need for customer-specific and financial data for managers. At the same time, design decisions make explicit how decisions on improving quality attributes affect the value that was desired by architects. Regarding the time spent collecting data, the practitioners were not too concerned, as they envisioned that quantifying customer segments would be part of the existing business case modeling process, so this time would pay off over a longer period of time and even potentially shorten the whole decision process in the future.

6.4 Discussion and conclusion

We proposed how to model customer value to support a decision on architecture investments by applying common best practices in management and marketing. We modeled customer value in two real-world cases and each model was evaluated by practitioners.

By building on best practices from related disciplines, we aimed to increase the potential for these models to be adopted to support architecture-investment decisions in practice. In this section, we will discuss our general observations about the proposed customer models, evaluation results, and possible improvements.

Generally, the models of customer value provided systematic guidance to identify sources and quantify customer value. For each case, we identified the source of customer value by mapping design decisions to customer-centric objectives and quantified the value by exploiting marketing scorecards, in particular customer value-in-use and customer segments. It is important to note that a selection of marketing scorecards driven by the objectives of architecture investments is consistent with the literature on decision-making; measures should be mapped to goals (Berry and Aurum 2006). In this way, quantified customer value becomes a tool to re-evaluate design decisions for maximized architecture utilization in meeting business goals (Clements and Shaw 2009). Hence, the more standard approach of mapping architecture investments exclusively to cost-savings value can now be revised to include explicit, customer-centric value.

The evaluation process brought a consensus among practitioners about the advantages of customer-value concepts over the existing value indicators. They suggested that customer-value concepts could be used in future decision-making on architecture investments.

Throughout both our case studies, there was an agreement that customer-value modeling might help make decisions on architecture investments better than with the existing indicators. It was pointed out that the existing value indicators were not tailored for supporting a decision on architecture investments, but rather, they were used because of their availability in the organization. Furthermore, we observed the techniques used to assess the value indicators were biased by the stakeholders' expertise. For example, the clinical scientist applied technology assessment, the architect used multi-attribute parameter analysis, and the managers preferred the cash flow of business case analysis. Bias is probably one of the most serious handicaps of experts that has been recognized in the literature (Chi 2006). Thus, using strategy maps and balanced scorecards bring an advantage by providing a possibility to identify the right measures (scorecards) to evaluate design decisions in different architecture solutions regardless of the expertise involved in the decision process. The second advantage refers to mapping design decisions about quality improvements to customer-centric objectives and measures. As seen in chapters 2 and 3, this was one of the main theoretical and practical challenges to using the customer-centric value. Quality attributes in the evaluation met the main architect's information needs (chapter 4) to support the decision process. This explicit link between design decision and business goals facilitated discussions between the practitioners on how the architecture changes affected customer value (that was measurable) to eventually optimize the design decisions. According to Nord et al. (Nord, Clements et al. 2009), this is exactly how architecture evaluation should support managers and architects to identify the impacts of design decisions on the business goals of architecture investments.

When referring to the two proposed marketing concepts for quantifying customer value, practitioners preferred customer segments rather than the customer value-in-use concept. The main explanation is, we feel, that the customer segment concept had already been introduced at Philips Healthcare to support business case modeling; therefore, it was closer to their way of thinking. At the same time, quantifying individual customer

value with value-in-use would be only used “to keep a particular customer happy”. For example, if a business goal is to retain a very important customer or conduct product benchmarking, value-in-use would be used. Given that time spent in data collection plays an important role in value assessment, additional labor spent quantifying the value-in-use appeared to be costly in practice. As expected, assessing the customer value of one customer is insufficient for evaluating the architecture design if an organization has more than dozens of customers. On the other side, time spent quantifying customer segments was acceptable because it was closely aligned with existing processes of business case modeling. Hence, it was expected that time spent on data collection processes would change little compared to existing data collection procedures. In general, modeling customer-centric value should be used for decision-making on architecture investments when customer value is closely aligned with an organization’s business strategy and the time spent on data collection is acceptable.

Practitioners envisioned a potential for customer segments to support architecture investment decisions. According to them, the customer-segment concepts in our studies provided more accurate data than the customer segments used by practitioners when making a business case. Thus, our concept can be used as fine-grained input for making a business case. One explanation is that marketers regarded segmentation simply as a convenient way of dividing markets into more manageable pieces based on product-market sectors. Hence, segments used in the business case as value indicators were more meaningful to business than to customers. In contrast, we focused on homogeneous customer segmentation to demonstrate the impact of architecture changes on the size of customer segments with particular needs. However, we have to say more work is required before business case modeling tools can be used on the proposed customer segments. One aspect is the *willingness to buy*, which should link customer segments and sales. Estimating this requires marketing expertise that we do not have. Although the importance of customer segments was recognized, the practitioners would still prefer to translate quality improvements directly to financial (sales) data to directly compare the monetary value to the architecture investments to support architecture decision-making.

Drawing upon the findings of our study, some ways to advance architecture investment decisions can be suggested.

First, we think that strategy-map and balanced-scorecard tools can be successfully used to link quality attributes with business objectives and measures for any type of architecture investments in general. In this way, we can show how design decisions align with a business strategy (Malan and Bredemeyer 2002), and we can also measure the impact of design decision on business. Furthermore, these tools would accommodate the information needs of architects for quality attributes and managers for financial data (chapter 4). Hence, the selection of information is driven by business strategy objectives rather than by personal preferences while at the same time accommodating the information needs of architects and managers.

Second, to exploit customer segments, it is important to translate the design decisions of quality improvements directly to financial (sales) data. This would enable a direct comparison of the monetary value of design decisions with architecture investments to support an architecture investment decision. Furthermore, it is important to address the whole customer segmentation process, which is described as the STP (segmenting, target-

ing and positioning) (Kotler and Keller 2008). In this chapter, we only explored the potential of the first stage (segmenting) by demonstrating how to group customers affected by architecture design decisions to meet customer needs. To fully explore the benefits of customer segmentation, we should consider the second stage (targeting) by proposing how to make decisions about where resources should be prioritized, and finally in the final stage (positioning), we should consider how to plan the architecture implementation to maximize the requirements of customers in the targeted segments.

Third, it emerged again (chapters 2 and 3) that business-case analysis is the established tool for supporting architecture investments on an economic basis. To support the practitioners in their way of working, we need to advance the business-case analysis by incorporating the previous findings. The new concepts should aim at small incremental changes to accelerate adoption and acceptability in industry.

Hence, in the following chapter we encapsulate knowledge from this and previous chapters to propose how to use business-case analysis to support architecture investment decisions driven by a business strategy.

7 Strategy-focused architecture investment decisions: A real-world example⁶

7.1 Introduction

Throughout the previous chapters, we recognized a consistent need for a systematic approach that would guide architecture evaluation and align it with a specific business strategy. Furthermore, it was apparent that this systematic approach should incorporate several requirements in best practices for management and architecting. First, to accelerate industry adoption, the method should fit within existing processes, requiring only small incremental changes (chapter 3). Second, architecture value should be identified and quantified (chapters 2, 3 and 6). Third, information selection should be driven by business objectives that accommodate both architects' and managers' needs (chapters 4 and 5). Finally, any new decision-making process should be more efficient than existing methods. Given that, we propose a strategy-focused architecture method, termed StArch, to meet requirements in supporting architecture investment decisions. StArch has been applied and evaluated in a real-world example.

As seen earlier, architecture investment decisions are supported by cost-benefit, business-case, and real-options analysis (section 2.2). Among those, business case analysis is the key element of value-based software engineering (Boehm 2006), which is also commonly used in practice (chapters 4 and 6). In business case analysis, decisions are made based on economic-decision rules such as Return on Investment (ROI) or Net Present Value (NPV). As seen earlier, the literature suggests using ROI to support a migration to software-product-line development (Böckle, Clements et al. 2004; Clements, McGregor et al. 2005) or to product-line adoption (Schmid 2003). Given the long-term benefits of architecture investments, NPV has been increasingly used to account for depreciation of value over time (Wesselius 2005; Kreuter, Lescher et al. 2008). The existing methods show that research on architecture investment decision-making has most often been linked to economic theories. When applied to well-specified problems, such theories lead to unique solutions (for instance, cost models in product lines). However, in real-world decisions, when experts work on problems that are less well defined (for instance, a question on the source of architecture value) the relevance and applicability of economic theories can be questioned (Shanteau 2000).

According to Tennent and Friend, business case analysis is just part of a complex framework, so-called business case modeling, which supports project evaluation in a broader context. Business case modeling proposes several steps to guide how to identify sources of value and the inputs needed to start a business case analysis (Tennent and Friend 2005). We think that by extending the business case analysis with guidance on how to identify relevant information aligned with business goals, we can improve architecture evaluation in practice.

⁶ An adopted version of this chapter was published as a book chapter in van de Laar and Punter (Eds., 2011) "Views on Evolvability of Embedded Systems", Amsterdam, Springer.

The success of any business modeling exercise depends on getting the various assumptions and relationships (or at least the important ones) as accurate as possible (Tennent and Friend 2005). In the architecture context, we need to clarify the relationship between architecture as a set of the most significant design decisions (Tyree and Akerman 2005) and the business strategy as the ultimate goal of investing in architecture (Malan and Bredemeyer 2002). As seen earlier, the strategy map tool (Kaplan and Norton 2004) has been effectively used to establish cause-effect relationships between business objectives (financial, customer, internal, as well as growth and learning) and design decisions (as seen in chapter 6). Furthermore, balanced scorecards (Kaplan and Norton 1992) helped to identify relative measures for meeting each objective. It is important to notice that a diversity of objectives (e.g., customer or financial) brought a wide span of information, which could accommodate the information needs of both architects and managers (as seen in chapter 4). However, not all information is associated with an observable and measurable input variable for business case modeling. For example, design decisions on quality attributes are contextual, and we cannot measure the quality of design decisions. Scenario planning is used to establish the context for data estimation and makes it easier to understand for various audiences (Tennent and Friend 2005). Scenarios have also been a part of architecting practice (Bass, Kazman et al. 2003; Ionita, America et al. 2005) (see section 6.3). In general, scenario planning offers decision-makers more choice through the creation of alternative scenarios. The economic elements within the scenarios provide the foundation for business case modeling. The literature has shown that numerous approaches benefit architecture investment decisions (as reported throughout the previous chapters). Our challenge in this chapter is to exploit the literature and chapter findings to propose how to model business case to support strategy-focused architecture investment decisions.

In this chapter, we propose a structured approach to support strategy-focused architecture investments by integrating established management techniques, strategy maps and balanced scorecards with established architecting practice, namely scenario and business case analysis. We have named this the Strategy-focused Architecture (StArch) approach. StArch is a four-step process. The first step is crucial: (i) to map design decisions to business objectives and to other related measures using strategy maps and balanced scorecards and (ii) to reach a consensus on evaluation criteria. The second step aims to create business-distinct scenarios that have different impacts on scorecard values. The third step involves assessing the scorecards that are used to estimate the architecture value. The fourth step aims to evaluate proposed architecture scenarios based on the evaluation criteria and then to provide recommendations.

In this case study, we supported practitioners to apply StArch in a real-world project at Philips Healthcare to provide recommendations on architecture investments. The same practitioners then evaluated StArch by comparing it to the existing decision-making process.

The rest of this chapter is organized as follows. Section 7.2 outlines the strategy-focused (StArch) method, which supports architecture investments and describes the study design. Section 7.3 demonstrates the real-world architecture investment decision supported by StArch. Section 7.4 elaborates on the StArch evaluation conducted by the practitioners

who were involved in the study. Finally, the chapter concludes with discussion and study improvements in section 7.5.

7.2 Strategy-focused architecture (StArch) method to support investment decisions

In this section, we aim to explain the strategy-focused architecture (StArch) method in general that will be demonstrated in the real-world case in the following section.

7.2.1 StArch in the process

As seen in chapter 3, any development (including architecture) project must be evaluated. To do that, a dedicated expert team follows a project preparation process to provide a recommendation on investments. The experts' responsibilities in the team are spread across two phases—project proposal and project planning. Only after the second phase can a formal decision on the project commitment be made.

We argue that architects and managers in the architecture project evaluation should jointly provide a recommendation on investments earlier in the process (after the first project proposal phase; see section 3.3.3). We think that an earlier recommendation would save effort in project planning (the second phase). To propose a more efficient process than the existing one, we suggest most activities involve a team to foster information sharing and consensus building.

Before we continue to describe the process, we should not forget (section 3.3) that the expert team does not make a decision but provides a recommendation to decision-makers (for instance, the Business Initiation Team (BIT) at Philips Healthcare (chapter 3)). This is recognized as a common phenomenon in business decision-making (Schmitt 1997) This implies that decision-makers come to a final decision based on experts' recommendations that are shaped during a project portfolio analysis.

Given that, StArch supports architects and business managers in architecture evaluation to provide recommendation on architecture investments. Table 14 shows that all responsibilities in StArch are divided among three “stakeholders”: the team, architects and business managers. Actually, the team “stakeholder” consists of architects and managers and as such is a “virtual” stakeholder. The reason for such grouping is to demonstrate the StArch responsibilities that require teamwork or individual assignments. This can also help to check availability of people and to better plan the architecture evaluation.

Table 14. StArch in the project evaluation process (adopted the official process at Philips Healthcare, see Table 2 in chapter 3)

Project proposal				
	Step 1	Step 2	Step 3	Step 4
StArch	Map business goals to architecture	Propose business-distinct scenarios	Estimate scorecards and value	Evaluate and recommend
Team (architects and business managers)	1) Make a strategy map 2) Decide on scorecards 3) Reach a consensus on evaluation criteria	1) Identify critical factors 3) Review scenarios	2) Share collected data to assess scorecards 3) Estimate value	1) Evaluate 2) Recommend
Architect		2) Propose scenarios	1) Collect data related to internal business scorecards (development effort)	3) Document rationales
Business managers			1) Collect data related to market and sales scorecards	3) Document rationales

Teamwork is required in all StArch steps. Architects and business managers are responsible for preparing the team meeting. In the steps with individual responsibility, we explicitly ask to look at the order of activities to avoid confusion. For example, in step three, data collection needs to be done *a priori* for value estimation. If data are already available, this can be skipped. As seen earlier, the architect’s responsibility to propose scenarios requires input from the team, and then scenarios can be reviewed by the team. The reason the architect completes this activity alone is that they usually already make scenarios as part of their regular duties when creating the architecture. This is a problem-solving activity that requires more time than what is spent in the team meeting. Each responsibility will be described in more detail in the following section.

We cannot say how many meetings or hours are needed to conduct this process, as this strongly depends on the complexity and size of the project. We propose to use consequent meetings with short time intervals between them to improve efficiency in sharing information. Given our experience in previous studies, StArch should only be conducted for projects when the total effort of the expert team in the evaluation is far less than the project investment effort. We think that StArch should be used in projects where investments are larger than several full time equivalents (FTE).

7.2.2 StArch in steps

Architecture evaluation starts when the architect proposes architecture solutions that address all aspects of the proof-of-concept (see Table 2 on page 32). Then, the four-step StArch method (see the previous section) can be applied.

We explain the steps by describing who does what, how and where.

Step 1: Map business goals to architecture

The aim of this step is to reach a consensus on how an architecture project creates business value that is aligned with the business strategy. The team (1) applies strategy maps and balanced scorecards to map architecture decisions to business goals and measures and (2) reaches a consensus on the evaluation criteria. Detailed guidance on using strategy maps and balanced scorecards in the architecture context has already been provided in two examples in chapter 6 using. Therefore, we give a brief explanation of the activities done in the team.

First, to create strategy maps, it is important to understand architecture solutions and business goals. The team meeting starts with the architect's presentation about several feasible architecture solutions and rationales about how they meet the business goals of the project. Then, the business manager triggers a discussion on how to position architecture solutions within the overall business strategy. This discussion often broadens the scope of the initial business goal of the project. To clarify how architecture contributes to the high-level business strategy is not straightforward because of the exploratory phase of the project and it might take some time (as seen in section 6.2). The result of this process is several business goals that come from different perspectives. The main business goal is often financial. Next, there are customers, internal business, or learning and growth goals. In addition to Kaplan and Norton strategy maps (2004), we propose to identify system design decisions (architecture), which are expected to contribute to meeting business goals. Then, in an iterative process, the expert team links the design decisions with the identified goals. If a goal is not linked to the design decision directly or indirectly, this becomes an outlier. The same holds for the design decision. If the design decision does not contribute to any business goals, it should be neglected. This exercise reduces the number of goals and provides a clear picture on how architecture meets business goals and creates value. Finally, to create the strategy maps, high-level strategic goals are translated and linked to other goals that should end with design decisions.

Second, the team identifies scorecards related to the strategy map. Scorecards are performance metrics used to assess the business goals quantitatively (Kaplan and Norton 1992). The scorecard can present any numerical or categorical information. The main advantage of using scorecards compared to other economic methods is the possibility to include measures on intangible benefits, such as customer satisfaction (that was requested as an information need in chapter 4). Furthermore, scorecards related to business goals and architecture decisions accommodate both managers' and architects' information needs in architecture evaluation (chapter 4). It is also important to note that within the list of scorecards, a number of them may be closely related. This implies a decision on a comprehensive set of measures that can be easily assessed in the organization. Because of the diversity of scorecards, it is important to delegate who in the team is in

charge of collecting which data, something that will be described in more detail in the step 3.

Finally, the team decides on evaluation criteria, which are actually decision rules to support a decision. A decision rule shows how to combine information to meet the business goals. Ultimately, the organization is interested in an economic criterion, and we suggest using net present value, which addresses strategic value creation over time (chapter 2). However, there might be a need to balance business goals, which might bring additional criteria.

Thus, the outcome of this step is a consensus of the team on the strategy maps, scorecards and evaluation criteria.

Step 2: Propose business-distinct architecture scenarios

The aim of the second step is to propose architecture scenarios (by considering external and internal factors) that have different impacts on scorecard values. This step is similar to the process of developing a strategy that considers external and internal perspectives (section 2.4).

First, the team identifies critical factors that diversify the behavior of the architecture project with respect to scorecards. Critical factors are sources of unknowns that influence scorecard estimates. We distinguish between internal and external critical factors. Internal factors are risk-related factors in the organization, such as technological feasibility or product roadmap planning. We expect that architects have the most knowledge on internal factors. At the same time, business managers have knowledge on the external factors often related to market uncertainty, such as customer needs, market size, or market growth. Then for each factor, we propose to document (1) the context in which the factors are considered for the architecture project and (2) the underlying assumptions on how the factors affect the identified scorecards in the given context. Explicit critical factors (that are actually risk and uncertainty in a board sense) provide information that was requested and most likely used by architects and managers (chapter 4 and 5). Thus, critical factors capture rationales on design decisions in the business context that are used as input to propose business-distinct scenarios.

Second, the architect proposes business-distinct architecture scenarios based on their understanding of critical factors and assumptions. This is a problem-solving process, which is not straightforward. We rely on the architect's experience in creating the architecture that helps propose architecture scenarios in the business context. To avoid scenario explosion, we suggest proposing architecture scenarios with as much contrast as possible while remaining realistic. Two scenarios (in addition to a "don't invest" scenario) that are diametrically opposite are usually sufficient to reflect business-distinct paths and to avoid a middle ground for analyzing uninteresting scenarios.

Finally, the team meets again to review the architecture scenario proposal and assesses the impact of scenarios on the identified scorecards. The scoring scale is arbitrary. This process serves to identify business-distinct scenarios and eliminate outliers.

Step 3: Estimate scorecards and value

The aim of the third step is to collect relevant data to assess scorecards and estimate the architecture value. Scorecards are actually data to be collected, assessed, or calculated indirectly (for instance by using formulas).

First, architects and managers individually collect data needed to assess the scorecards. Who collects which data will have already been delegated in the first step. We assume that the architect assesses data related to architecture investment or cost saving scorecards by using different techniques that are readily available (Rommès, Postma et al. 2005). Business managers, with the help of other stakeholders, collect data needed to assess market and sales scorecards. Ideally, in organizations with good infrastructure, data collection would be a part of established processes and measure programs.

Second, the team shares the data and assesses the value of the scorecards. It is important to note that some scorecards may be determined by a single data type or derived from multiple data through an estimation model. Because of the diversity of scorecards and different maturity levels of measurement techniques in organizations for data collection, it is impossible to provide a general guideline for estimating scorecards. For the purpose of illustration, we refer to examples of estimating customer-related scorecards in two projects presented in chapter 6. Tennent and Friend (2005) propose using well-known extrapolation, causative, and judgmental techniques for revenue forecasting, which are illustrated in a real-world example in the following section. In general, selecting measurement techniques to estimate scorecards is outside of the StArch's scope.

Finally, after sharing data and combining those into scorecards, the architecture value is estimated. Architecture value refers to the monetary value generated by architecture investments. It is estimated in an interactive process. It requires going through the previous steps of StArch to address the correct impact of design decisions on the value for the scorecards.

Step 4: Evaluate and recommend

The aim of the fourth step is to analyze scenarios in the context of the strategy maps and balanced scorecards, and then apply the evaluation criteria to recommend whether to invest in the architecture project.

First, the team checks whether the economic criterion (if available) suggests that an investment should be made. For example, if net present value is greater than zero, then the recommendation is to invest. Next, the team checks the subsequent criteria. It is important to note that individual criteria might diverge, i.e. point to different scenarios. In that case, the team needs to consider findings from preceding steps (context, underlining assumptions, and business goals) to provide rationales to argue for or against architecture investments.

Second, the team provides a recommendation. In contrast to the economic methods that provide a unique solution based on a single economic criterion, StArch lets the expert team challenge diverse evaluation criteria. In general, we can say that the decision is shaped by the scorecards with the highest value and ones that best match the business

strategy that is confirmed by the expert team. Ultimately, the team reaches a consensus on a recommendation about architecture investments.

Finally, the owner of the process—either an architect or business manager—documents the rationales for the recommendation (usually in a PowerPoint presentation) that will be presented to decision-makers (like BIT at Philips Healthcare).

Possible insights on StArch in regards to a real-world project are described below.

7.2.3 StArch in the study

The aim of this study is to investigate how well StArch supports architecture evaluation in practice. We apply StArch in a real-world project and have practitioners evaluate StArch.

First, we apply StArch to guide practitioners in supporting a real-world architecture investment decision at Philips Healthcare. In total, five stakeholders were involved in the architecture evaluation: two investigators and a team of three practitioners. In several introductory meetings, we presented StArch to practitioners and clarified any ambiguity about the steps. In addition, the system architect presented us an architecture project which had been scheduled for evaluation. Then we started an evaluation process by applying the StArch steps. The StArch meetings were scheduled with two investigators and at least one practitioner. After each meeting, the two investigators crosschecked and confirmed the findings. The practitioners at the meeting depended on their availability and the expertise needed to collect relevant information. The main sources of evidence were the team meetings, interviews, annual-sale spreadsheets, review documents, and product roadmaps. In total, the investigators and the team spent 20 hours each on the process.

Then, the team involved in the process evaluated StArch. The evaluation was organized in a two-hour review meeting shortly after the recommendation was made. In the first half hour, each practitioner in the team was asked to fill in a questionnaire about his or her satisfaction with StArch. In total, there were six questions with predefined answers on the five-point satisfaction scale (“5” for very satisfied to “1” for very dissatisfied). The first two questions referred to the overall satisfaction and completeness of information offered by StArch. The last four questions referred to their satisfaction with each individual step in StArch. For each question, the practitioner was asked to provide rationales behind their scores. The remaining 1.5 hours was spent in an open discussion, starting with the question: *Thinking of the decision-making in the organization, how would you compare the decision-making offered by StArch?* We collected qualitative data about StArch in general, perceived benefits, the potential for adoption in the organization, and possible improvements. Based on the evaluation findings, we recommend possible improvements of StArch.

7.3 StArch: A real-world example

Philips Healthcare had an architecture project proposal that had been on hold for several years. The evaluation was continually postponed because there was little information to support a decision. A business initiation team (BIT) responsible for making decisions on

project investments (chapter 3) decided to make use of StArch to guide a recommendation on the project investment. Therefore, BIT assigned an expert team and two investigators to support a project evaluation. It was the author of this thesis who facilitated the process and another investigator who observed it. Table 15 shows responsibilities of the different stakeholders in the project.

Table 15. Stakeholders in the decision-making process

Stakeholders	Responsibility
Business initiation team (BIT)	Make an investment decision
The expert team	Provide a recommendation on the architecture project investment using StArch
Two investigators	Help practitioners apply StArch

7.3.1 Case: Independent sensor release

Imaging systems have a life of five to eight years. In the imaging, business-to-business market, revenues are generated not only by selling new systems, but also by selling upgrades to existing customers, the so-called install base customers. The upgrades for imaging systems can be categorized as platform and software upgrades. For example, platform upgrades offer up-to-date platform performance improvements while software upgrades enable new clinical applications. Selling upgrades results in significant revenue.

The product line portfolio of imaging systems consists of several products, including scanners, consoles, workstations, and patient tabletops. To manage parallel development, the organization uses a two-lifecycle approach (van der Linden, Schmid et al. 2007), i.e. developing the platform and the clinical applications with their own individual lifecycles. A new platform is released every few years and clinical applications have multiple software releases per year. The benefits of decoupling the application from the platform development are twofold. First, the organization offers clinical innovations to new customers with a shorter time-to market. Second, the installed base customers are offered timely upgrades.

At the time of this study, a new platform upgrade was planned to be released.⁷ The imaging systems required a “sensor” to produce images with high quality and to enable clinical applications. Such sensors are exploited across the imaging product line. Over the past few years, the number of newly-introduced sensors had increased enormously. The new sensors were directly available for customers purchasing new imaging systems. However, existing customers had to wait for the newest software upgrade to be able to use the new sensors. This imposed two problems for the installed base customers. First, they had to wait for the right software upgrade release to use the new sensor, even though the sensor had already been introduced to the market. Second, the installed base customers had to pay the upgrade price *and* the sensor price. The total price would be considered too high if the customer could not exploit other benefits of the software upgrade needed to use the new sensor.

⁷ The major identifying details for this case, such as product name, project names, and release naming, are replaced with pseudonyms for confidentiality reasons.

To address this problem, the organization had considered to invest in architecture changes that would enable a sensor release that could be independent from the software upgrade release in a project called Independent Sensor Release (ISR). This project would improve system evolvability by decoupling the life cycle of sensors from the rest of the system. It had been estimated that decoupling would require 10 person-years. Although ISR was desired by customers, there were conflicting impacts of ISR on the lifecycle business that would first need to be addressed. First, sensor sales would increase because of the lower price threshold. Second, software upgrade sales might decrease because the sensor purchase would no longer require a software upgrade. Because of these conflicting impacts on the business, the ISR project had been put on hold.

We were assigned (two investigators) to guide a team of three practitioners in applying the StArch steps to provide a recommendation on the ISR project investment. The practitioners had the following roles: system architect, imaging manager, and sensor manager.

7.3.2 Step 1: Map business goals to architecture

The first step of StArch is to translate the business strategy into architecture-centric business goals and scorecards, and then to define criteria on how well these goals are reached.

In applying this step to ISR, the team started with the Philips business strategy and identified the main business objective related to the ISR project, namely to *increase revenue from the installed base*, as shown in Figure 19. Two further objectives were to *increase sales* and *increase margins*, which contributed generally to increasing revenue, an established performance objective of the organization.

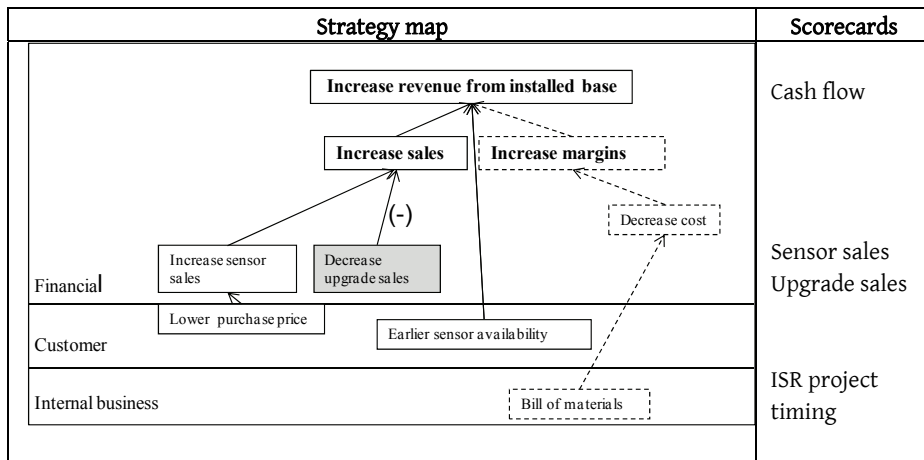


Figure 19. The strategy map and scorecards for the ISR project

More specifically for the ISR project, the team expected an increase of sensor sales and a decrease of upgrade sales. Furthermore, it was expected that the ISR project would increase margins by decreasing costs, because in some cases new, cheaper sensors could replace old broken ones. Since the primary aim of the ISR investment was to manage the installed base business, managing the bill of materials was considered outside of the

scope of this evaluation (dashed lines objectives in Figure 19). The ICR design decisions, related to architecture quality-centric goal such as a lower purchase price and earlier sensor availability, were linked directly to the business strategy goal. Although the business goals of learning and growth were part of the strategy maps, in this project, these goals were not considered important. It is important to note that, in contrast to the Kaplan and Norton strategy maps, business goals might also have negative side effects on the business goals illustrated in the map.

For each business goal, the team assessed related scorecards (measures) that would ultimately be used to quantify architecture value. The scorecard list consisted of cash flow, sensor sales, upgrade sales, and the ISR project's timing, as shown in Figure 19. While sensor sales, upgrade sales, and the ISR project's timing were each a single dataset, the cash flow was derived from multiple datasets, which were then combined into an estimation model. We elaborate on value estimation in more detail in the third StArch step (section 7.4.4).

Finally, with the focus on increasing sales, the team identified two financial evaluation criteria:

- A net present value greater than zero; and,
- Optimized sales to the installed base customers.

The first is a standard evaluation criterion, which is elaborated in more detail in section 7.4.4. The second criterion referred to the negative impact of the architecture on the upgrade business. The team was concerned that the ISR project would be a threat, seriously jeopardizing the upgrade businesses, so that even a need for upgrade business was questioned. Thus with the optimized sales criterion in mind, the team explicitly addressed the cross-business consequences of the ISR project.

7.3.3 Step 2: Propose business-distinct architecture scenarios

The team identified critical factors and described the related context and assumptions as a part of step two. Then, based on the context and assumptions, the architect proposed the business scenario that was reviewed by the team.

Four critical factors—the context in which they are considered and assumptions on how the critical factors impact the scorecards—are shown in Table 16.

Table 16. Critical factors, context, and assumptions for the ISR project

Critical factors	Context	Assumptions
1. Market trend	The installed base customers expect immediate availability of the sensor when it is needed.	The ISR project will enable the installed base customers to <i>buy the sensor earlier</i> .
2. Sensor purchase price	The installed base customers perceive the total price of the sensor and enabling upgrade to be too high if they do not see other upgrade benefits.	The ISR project will enable the installed base customers to buy the sensor without upgrades. Therefore, sensor sales will increase.

Critical factors	Context	Assumptions
3. Release timing alignment	<p>The organization will introduce a new platform and <i>a few sensors</i> on the new platform in year 1.</p> <p>In years after the platform’s introduction, an increasing number of new sensor releases is expected on the new platform</p>	<p>ISR project alignment with the new platform introduction will promote sensor sales that exploit the new platform, therefore, <i>sensor sales will increase further.</i></p>
4. Sensor introduction trend	<p>It is expected that the speed of new sensor introductions will saturate the market in the future; see Figure 20.</p>	<p>Regardless of whether the ISR project is realized, <i>sensor sales might saturate the market.</i></p>

The first two factors, market trend and sensor purchase price, are external critical factors that will be illustrated in the ISR description in section 7.3.1. The last two factors, release timing alignment and sensor introduction trends, are internal factors prone to the risk of development and changing internal business strategies.

We explain the context of the internal critical factors using a roadmap and the trend for sensor introductions provided by the practitioners. A five-year roadmap envisioned the new platform introduction and several software upgrades (see Table 17). In year one, a new platform was planned to be introduced. At that time, only a few sensors would be available that would make full use of the new platform, and more sensor releases were expected from year two onwards. If the ISR project’s timing was aligned with the new platform introduction (that is, included in Release 10), the customers that adopted the new platform could buy and use the new sensors immediately when they were introduced to market without needing to wait for and purchase Release 11. In this case, we could expect higher sensor sales with than without this alignment.

Table 17. Roadmap of new releases related to the ISR project

Releases		Time	0	1	2	3	4
Software upgrades	R9 upgrade		—	✘			
	R10 upgrade			●	—	✘	
	R11 upgrade				●	—	—
New platform				●	—	—	—

Regarding the *sensor introduction trend*, analysis of past sensor roadmaps showed that a large number of the new sensors had been introduced a few years before the study, as shown in Figure 20.

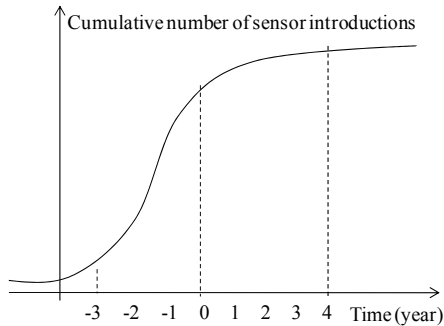


Figure 20. Trend of sensor introductions

This resulted in an enormous increase in sensor sales over the last three years (see “Past” column, Table 19, on page 119). However, looking at the sensor roadmap for the future, the number of introductions will slow down. New sensor introductions would be related mainly to adapting existing sensors to the new platform, resulting in sensor-sale saturation in the future. Furthermore, fewer sensor introductions would mean that fewer customers would be waiting for their use, which would weaken the importance of the first assumption.

It is important to note that different types of software upgrades were offered to the installed-base customers: some were offered only the new sensor while others also received additional applications (the main sales target). As seen in Figure 20, the business strategy is to slow down the introduction of sensors and consequently, decrease the potential upgrade sales regardless of the ISR project. This meant that the ISR would not significantly impact upgrade sales as was originally thought by the expert team. Because of the negligible significance of *decrease upgrade sales* in the strategy map (see Figure 19 on page 114), we focused only on the *increase in sensor sales*.

As we explained earlier, critical factors are used to determine business-distinct architecture scenarios. Following StArch guidance (section 7.2), we considered how the critical factors (see Table 16) affect scorecards: sensor sales, upgrade sales, and the ISR project’s timing, in other words, its cash flow. The previous analysis showed that only the third factor, the timing of the ISR release with the new platform introduction, might have an impact on the sensor-sale scorecard. Given that, the architect—with our help—created three business-distinct scenarios: Sleepy, Sneezzy, and Dopey, as shown in Table 18.

The architects provided the rationales for each scenario that was reviewed by the team, assessing the impact of each scenario on the scorecards. The Sleepy scenario offered business as usual and did not have an impact on the scorecards. The Sneezzy scenario predicted a moderate sensor sales increase (+) and the Dopey scenario predicted a high sensor sales increase (++) because of ISR’s alignment with the new platform.

Table 18. Scenarios and their impact on scorecards

Scenario Description	Sleepy	Sneezy	Dopey
	Do not invest in ISR; do the business as usual	Invest in ISR aligned with releases in year two	Invest in ISR embedded in the new platform
Scorecards			
ISR timing	N/A	In two years	In a year
Sensor sales	0	+	++
Upgrade sales	0	0	0

Finally, the team realized that upgrade sales would be unaffected by the ISR because of the current upgrade strategy and reduced number of sensor introductions. This was the most important finding as it opposed the initial team’s assumption that the ISR project would jeopardize the upgrade business. Given this finding, the business goal of upgrade sales and the evaluation criterion to optimize sales become redundant (see section 7.3.1). In this case (similar to the study in chapter 3), the expert team’s assumptions were wrong and could not be proven wrong without a systematic method like StArch (the real options way of thinking). Thus, a systematic guidance helped the team to revise assumptions and discard irrelevant information. In this respect, StArch focused discussion on relevant information to help form a consensus. Our observation is that the expert team may have been right with their assumption a few years ago when the opportunity to invest in IRS (according to Figure 20) was huge. This was no longer the case when we conducted this study, as the business momentum had been lost. Interestingly, we heard similar anecdotes (like ISR jeopardizes upgrade business) many times in our previous studies. Given this insight, we are tempted to conclude that anecdotes lose relevance over time (for instance, business opportunities are lost in ISR) and the organization should be careful about the negative snowballing effect, which might affect “gut feeling” decisions.

7.3.4 Step 3: Estimate scorecards and value⁸

As we said earlier in the StArch description, ideally, estimating scorecards should be part of established processes of measurement initiatives in the organization. This was not a case at Philips Healthcare.

We realized during the study that data collection was not a problem. Business managers and the architect had already collected data before we started this assignment. The architect estimated an ISR project cost of 10 FTE and the business managers collected both annual sensor sales and the gross margin for the three preceding years.

The team used past sales data and applied extrapolation, causative, and judgmental techniques (Tennent and Friend 2005) to estimate cash flow that would be elaborated in more detail for each scenario.

⁸ The provided estimates are proxies of the real estimates in the project.

Sleepy scenario. The sleepy scenario refers to a future when the organization no longer invests in ISR and continues with business-as-usual. To forecast sensor sales in the future, the team applied two different techniques: extrapolation and causative.

Since there was no expectation to change business in the year of this study, the team extrapolated the sensor sales from the past three years of sales data—see the “0” column in the Sleepy scenario in Table 19, below. Then, given the assumption that the incremental change of future sensor sales would be small, the team applied causative techniques to assess the impact of this assumption on future sales in the following four years. Thus, past annual sales and assumptions determined the dynamics of the market, and consequentially, affected the scorecard estimates. As we can see in Table 19, growth was expected to take place in the second year, but then sales would be stable assuming slower sensor introductions in the future (see section 7.4.3).

Table 19. Scorecard estimation for Sleepy, Sneezy, and Dopey scenarios (thousands of units)

Scorecards	Past			Sleepy scenario					Sneezy scenario					Dopey scenario					
	Time	-3	-2	-1	0	1	2	3	4	0	1	2	3	4	0	1	2	3	4
Sensor sales (total)	81.8	194	248	341	380	390	400	400	341	380	396	412	418	341	380	398	417	425	
Increase in sensor sales										0	0	6	12	18	0	0	8.4	16.8	25.2

Sneezy and Dopey scenarios. The team estimated the sensor sales in the Sneezy and Dopey scenarios by judging potential sensor sales increases based on their previous experience. Such subjective estimates were necessary because of the lack of other data. Estimates on increased sensor sales were based on three premises. First, it was expected that without upgrades, the new sensors would be available in the Sneezy and the Dopey scenarios in year two. In the Dopey scenario, the ISR project would align with the new imaging platform in year one, but the first customers on the new platform would still only buy sensors in year two. Second, it was expected that the impact of the ISR on earlier sensor availability (see Figure 19) would not be so prominent because based on the assumption that fewer new sensors would be introduced in the future (see Table 16). Third, the estimates of the increase in the sensor sales (see Table 19) were based on past experiences in selling sensors. The past has shown that approximately 10% of the installed base customers (120,000) buy sensors every year. It is expected that the increase in sensor sales will be 5% in the Sneezy scenario and 7% in the Dopey scenario. When these premises were considered, it resulted in an increase in sensor sales, as shown in Table 19. Despite the literature suggesting that forecasts can be refined by studying the results of market research and by examining the experience of similar or related projects, for us, it looked like forecasting was more of an art than a science.

The value of ISR is actually the cash flow generated by the project in the subsequent five years. Given that sensor sales are the only scorecard affected by ISR, cash flow can be calculated using the estimates for the increase in sensor sales. For the architecture decision-making process, we are interested in the differences in cash flow between the Sneezy and

Dopey scenarios compared to the Sleepy scenario. Thus the estimation model of the cash flow is:

$$\Delta \text{Cash flow}(t) = \text{Gross margin}(\text{sensor}) * \text{Increase in sensor sales}(t)$$

where $\text{Gross margin}(\text{sensor}) = \text{€}850$. The estimates of cash flow in the Sneezzy and Dopey scenarios are shown in Table 20. Cash flow is used to estimate the evaluation criterion, net present value:

$$NPV = \sum_{i=0}^4 PV(t) - 10 \text{ man year}$$

For this study, the team assumed 1 man year = ~€100,000. Present Value (PV) of the cash flow for the year t is: $PV(t) = \frac{\text{Cash flow}(t)}{(1+i)^t}$. For this case we applied an interest rate of $i = 5\%$. The estimates of PV and NPV for the Sneezzy and Dopey scenarios are shown in Table 20.

Table 20. Cash flow, PV, and NPV estimation for Sneezzy and Dopey scenario (MEuro)

Input	Sneezzy scenario					Dopey scenario				
	0	1	2	3	4	0	1	2	3	4
Cash flow (increase in sensor sales)	0	0	0.51	1.02	1.53	0	0	0.71	1.43	2.14
PV	0	0	0.46	0.88	1.26	0	0	0.65	1.23	1.76
NPV	1.60					2.64				

The Sneezzy scenario is preferable to the Dopey scenario when taking into account their NPVs.

One can argue that estimations are subjective and prone to error. In chapter 3, we already acknowledged this issue, arguing that these kinds of estimations are unavoidable and that they are common practice in the organization. Furthermore, in this case as well as in the study in chapter 3, it appeared that data collection was indeed challenging, but that practitioners felt confident in five-years predictions that were within the product-roadmap timing.

7.3.5 Step 4: Evaluate and recommend

Finally, the team analyzed architecture scenarios given the strategy maps, scorecard values, and evaluation criteria. In a three-hour meeting, the team made a recommendation on ISR investments.

In the first step of StArch, the team identified two economic evaluation criteria: a net present value greater than zero and sales optimized for the installed base customers (section 7.4.2). When the first criterion was considered, it became obvious that both scenarios met the criteria but that the Dopey scenario was preferable to the Sneezzy (Table 20). Following this criterion, the investment in ISR should take place.

In this case, the second criterion became irrelevant. This criterion referred to optimizing upgrade and sensor sales given the team's assumption that ISR might decrease upgrade sales (Figure 19). As seen in section 7.4.3, ISR would not affect future upgrade sales given the expectation that sensor releases would reach their limit in the future. Thus, ISR would boost sensor sales without a negative effect on upgrade sales.

Given the first economic criterion (net present value), we would expect the team to recommend investing in the ISR, in particular the Dopey scenario. However, the recommendation was not to invest in ISR. The team provided two rationales for their recommendation.

First, based on the findings in the previous steps of StArch, the team realized that they made some assumptions that might have been right several years ago, but at the moment of the study, they were no longer applicable. In particular, when the business manager discussed critical factors with respect to the business strategy, the team realized that they were not expecting a large number of new sensor releases in the future (see Figure 20). On the contrary, the sensor release curve after almost exponential growth in the past years showed a slow saturation trend. Thus, if the IRS project had received investment several years ago, the ISR value would have been enormous. However, the saturated number of releases and an expectation of even fewer sensor releases in the future meant significantly fewer install base customers with unmet ISR needs than in previous years. This implied that customer dissatisfaction and decreased sales were expected to diminish slowly in the upcoming years. This was a turning point of the analysis and an eye opener for the team. Thus, given the assumption of shrinking market opportunities, this project was not so "appealing" anymore.

Second, although it was not addressed earlier in the analysis, the team started discussing a potential new project on the roadmap that would partially solve some of the ISR issues. This strengthened the team's recommendation not to invest. It was interesting to observe that although a project portfolio was not part of the analysis, the practitioners used this information to support their rationales. This is consistent with other experts on decision-making who look for supporting evidence to justify a decision they have already made.

Finally, all graphical and tabular information presented in this case was part of the PowerPoint presentation given to the BIT team, including the last two rationales on the recommendation. Based on the recommendation, BIT decided not to invest in the ISR project.

Interestingly, economic criteria in the literature on strategic investments are necessary but not sufficient to make architecture investments in practice. A net present value greater than zero does not determine investment decisions, but one that is less than zero will stop an investment. This implies that when net present value is greater than zero, there is no unique decision, and additional criteria are needed (like assumptions or other projects in portfolio).

In total, there were 10 meetings requiring 40 person-hours (about 20 by the investigators and 20 by the practitioners) to provide a recommendation for the decision. If we compare the effort needed for this assignment with the size of investment, it seems that 2 hours

per FTE of investment can be used as a rough measure of the effort needed for architecture project evaluation. Nevertheless, this needs to be validated.

7.4 StArch evaluation

The two-hour review meeting brought the team and investigators together to evaluate StArch following the procedure described in section 7.2.3. The focus of the meeting was on getting insight about StArch in general, the completeness of information, and the validity of each step in StArch. Two investigators crosschecked the findings. This was a rather crude evaluation where conditions were not well controlled, and we could expect answers that matched participants' existing biases.

Overall, the practitioners were mostly satisfied with StArch. The system architect and the imaging product manager were more satisfied than the sensor manager, who graded it as neutral. We feel that there was a personal incentive of the sensor manager to focus the evaluation on the decreasing cost business goal, which was neglected in the analysis. This internal business goal related to saving maintenance effort and a bill of material would potentially increase the ISR's value. However, as we have seen earlier, the main decision driver was meeting customer needs, in particular by increasing sales. Thus, the internal business goal would not change the recommendation.

The completeness of information provided by the StArch was rated differently by different practitioners. Satisfaction depended on how close the information StArch provided was to what an expert had come to expect in their daily practice. The architect was the most satisfied (4 out of 5), the imaging product manager the least satisfied (2 out of 5), and the sensor product manager was neutral (3 out of 5). StArch focused evaluation on a few financial facts. It seems that this amount of financial information was satisfactory for the architect, who needed system-centric data (chapter 4), but did not use financial data in his daily practice. On the other side, the imaging product manager used large sets of financial information from the strategic reviews, and she perceived the information set by StArch to be limited. The most indifferent was the sensor product manager who used information such as sales regularly and found information provided by StArch to be neutral. Thus, since StArch increased the architect's financial knowledge the most, the architect was the most satisfied. Interestingly, once again (next to our findings in chapters 4, 5 and 6), it seems that the experts are biased by their own kind of information needs in an architecture evaluation.

The *map business goals to architecture* step was the highest-scored step in using StArch. The team explained that the strategy map offered simple guidelines to focus the discussion and helped bring consensus on relevant business goals. Although the practitioners already had all information in their heads, the power of the tool was in how it could visualize the information in a comprehensive way. Furthermore, we observed that the business goals that referred to the business strategy (such as increased growth) were highly respected, which prevented personal preferences from biasing the evaluation (the sensor manager wanted to focus the evaluation on decreasing cost). In this way, strategy maps also helped make assumptions about the relevance of scorecards, helping to determine what data to collect and saving time on collecting irrelevant data.

Table 21. Evaluation of the StArch characteristics

	Role	5 Very satisfied	4 Satisfied	3 Neutral	2 Dissatisfied	1 Very dissatisfied
Overall	Architect		x			
	Imaging manager		x			
	Sensor manager			x		
Completeness of information	Architect		x			
	Imaging manager				x	
	Sensor manager			x		
Step 1: Map business goals to architecture	Architect	x				
	Imaging manager		x			
	Sensor manager		x			
Step 2: Propose business-distinct architecture scenarios	Architect		x			
	Imaging manager		x			
	Sensor manager			x		
Step 3: Estimate scorecards and value	Architect				x	
	Imaging manager		x			
	Sensor manager			x		
Step 4: Evaluate and recommend	Architect		x			
	Imaging manager		x			
	Sensor manager		x			

The *propose business-distinct scenario* step was received satisfactorily. We did not receive too much feedback on this step. One comment we received was that scenario analysis was already an established concept in architecting and product roadmaps, and as such, was considered necessary for evaluation. Interestingly, although the assumptions gathered in this step were the key to providing the recommendations, nobody even remembered that this was important.

The *estimate scorecards and value* was scored differently by the practitioners. The architect was the most dissatisfied with the estimation while the imaging product manager was the most satisfied. We think managers have more experience with subjective judgments while architects consider mainly the types of data used for modeling, like performance measures (section 6.3) or cost estimates (the COCOMO model in chapter 3). Thus, the architect's experience in forecasting sales was not exact enough for him, and caused his dissatisfaction. On the other side, for the imaging product manager, making a sales estimate without guidance is daily practice. For her, StArch provided good guidance for estimation and helped avoid being trapped in the assumptions. Similar to the assessment on the "completeness of information", satisfaction is biased by an expert's expertise.

The *evaluate and recommend* step was perceived to be satisfactory by all practitioners. They all agreed that they were satisfied with the StArch decision rules. The criterion for optimizing sales was strongly appreciated.

The open discussion on how StArch compares to other architecture decision-making methods used in the organization resulted in a consensus that StArch improved the existing decision-making because it brought forward the ISR decision, which had been on hold. The main improvements cited was the structured approach to guiding complex decision-making when multiple impacts of architecture changes are expected and the value of these changes was not so explicit. Furthermore, 20 person-hour spent by practitioners using StArch in the ISR decision-making process was perceived to be less than when a systematic approach was not applied. Unfortunately, time spent on the ISR decision before our assignment was unavailable. The practitioners estimated that StArch could be applied for any architecture projects within a week if information was available prior to meetings. Our confidence that this method would be adopted increased because practitioners agreed they would apply StArch, in particular the strategy map and scorecards, in new projects again. In addition, they would recommend it to their colleagues. Finally, the success of StArch was also confirmed, as the Philips Healthcare officially confirmed transfer of StArch to their business.

7.5 Discussion and Conclusions

In this chapter, we proposed a new Strategy-focused Architecture (StArch) method, and then applied and evaluated it to a real-world project. StArch is a four-step method that incorporates best practices and the findings from our previous studies to guide a decision on architecture investments. The first StArch step guides practitioners to map business goals and related measures to architecture using strategy maps and balanced scorecards. It also helps them decide on evaluation criteria. The second step aims to create business-distinct scenarios, which have different impacts on scorecard values. The third step guides practitioners to assess scorecards used to estimate architecture value. The fourth step aims to evaluate proposed architecture scenarios based on the evaluation criteria and provide recommendations.

When StArch was applied on a long-pending decision for an architecture project at Philips Healthcare, the team reached a consensus on a recommendation within 40 person hours. At the end of the process, the team evaluated each step of StArch to provide insights on potential improvements. The experts involved in the study were satisfied, particularly with the strategy map tool in the first step.

Here we would like to discuss how well we met the requirements of the method stated earlier (section 7.1). First, we thought the method should fit within the existing process with small incremental changes (chapter 3) to accelerate adoption in industry. Compared to the existing process (section 3.3), StArch proposes architects and managers should work together, extending their scope of responsibilities. In the existing process, the architect makes the proof-of-concept and the manager makes a business case analysis. With StArch, architecture project evaluation is mostly conducted in team meetings with a few individual activities, which fosters communication and information sharing. In addition, StArch extends the business case analysis using a strategy map and balanced scorecards

to focus the team's discussion on relevant sources of architecture value and business information. Using StArch helped directly document the decision rationales that are often intangible, and therefore forgotten in the evaluation (such as a sales release trend). We can say that we succeeded in adding small incremental changes to best practices to accelerate StArch's adoption. Our confidence in StArch's adoption is high because Philips Healthcare confirmed they would begin to use our StArch method. In addition, the lead architect involved in the study stated that he would continue promoting and using StArch, in particular strategy maps and balanced scorecards.

Second, we thought architecture value should be identified and quantified (chapters 2, 3 and 6). Compared to existing economic methods, the main advantages of using StArch is in extending economic scorecards with others that can be used to assess architecture value. Despite the fact that economic goals are the ultimate goals of every organization, we observed that the economic criterion did not provide a definite decision. For instance, a net present value greater than zero does not determine investment decisions (although it should), but having one that is less than zero will stop it. In StArch, by using balanced scorecards from different perspectives, we end up broadening scorecards so that they also assess architecture value, which are eventual criteria for making decisions. For example, in the project illustrated in this chapter, the sales scorecard was used to optimize sales by maximizing architecture utilization not directly related to economic value. This support simulated a more real-world environment: a decision is a complex process of problem solving, based on how to maximize architecture value over its lifetime within business boundaries (Clements and Shaw 2009).

Third, we thought information selection should be driven by business objectives accommodating the architects' and managers' needs (chapters 4 and 5). As we have seen, StArch helped architects and managers work closely as a team to select relevant information in consensus, to avoid missing crucial decision drivers and to focus the discussion. However, practitioners with different roles were satisfied in different ways with the completeness of information offered by StArch. Their satisfaction depended on how the information generated by StArch matched the expert's own information needs in daily practice. For example the main information type used in the method was sales. Since the architect did not use sales in his practice, he was the most satisfied, while the business manager, who required large amounts of sales information, was the least satisfied. The fact that experts appreciated their own types of information is consistent with the findings of previous chapters (chapters 3 to 6). We believe that an organization with better infrastructure might be more satisfied with the completeness of information as the information would be readily available for use.

Finally, the new decision-making process should be more efficient than the existing methods.

We can definitely say that StArch was more efficient than the existing method. One way to look at it is that the decision was made in a consensus after several unsuccessful attempts over the past years. According to practitioners' time spent trying to evaluate ISR over the past years, the effort is significantly larger than time spent by the expert team when StArch was applied. Another way is to look at the additional effort of experts that would still be investigating whether this would be a good decision or not in the future.

Although StArch was used in one organization, we can say that StArch helped the process, and therefore improved decision-making. StArch guided a team to reach a consensus on a decision which has been pending for some time, within a reasonable period. However, we cannot be sure whether the decision was good. The “goodness” of a decision is difficult to define. The reason is that what we cannot directly measure the business indicators of the decision goodness. For example, if we try to correlate market share as a known indicator with the decision, this might be inadequate. There might be other external factors, like market uncertainty (for instance, new offerings of competition) that were unknown at the moment of the decision. The issue of defining “architecture goodness” is recognized and explained by the immaturity of the architecture field (Falessi, Kruchten et al. 2007). We think that more of these kinds of studies can provide empirical evidence to help define “good architecture decisions”. Thus, future work should explore how to apply StArch in different business contexts and organizations.

Conducting this study in a single organization, then, is just a first step to proving that StArch helps improve architecture investment decisions. More studies using StArch would provide greater insight and allow generalization of the method. Furthermore, we are aware that we did not directly compare or test our StArch method with other methods. This is a common issue in decision-making in real-world environments, especially in a business setting, and remains an open issue (Schmitt 1997) that we have to accept.

We conclude that we tried and succeeded to demonstrate that by addressing challenges explicitly and by exploiting best practices, we can improve the current state-of-the-practice with relatively little effort.

PART IV: Conclusion and appendices

8 Conclusion

8.1 Focus and approach

The thesis considers whether and how a systematic method for evaluating architecture investments can lead to decisions that are driven by business preferences rather than by personal incentives.

Architecture investment decisions in practice do not call for an entirely new method for evaluation. Moreover, typical organizations expect, and more easily accept, small improvements on their existing procedures, for instance considering best practices within the boundaries of the existing evaluation process. The “new” evaluation calls for architects and managers to work together to identify important design decisions and their consequences on business (Nord, Clements et al. 2009), while being aligned with the business strategy (Malan and Bredemeyer 2002).

A key point of supporting architecture evaluation in practice is to understand the theoretical and practical challenges and to propose meaningful improvements. The literature suggests that supporting architecture evaluation is not straightforward. A decision to invest in software architecture requires systematic evaluation of the trade-off between strategic long-term benefits of architecture for the business and investment. It typically is a decision that is difficult to explain and quantify. The theoretical challenges can be viewed from three perspectives: process, business and individual. The *process* perspective highlights a need for a close involvement of architects and managers to evaluate the consequences of architecture design decisions on business value. Such a process should adequately consider accommodating an architect’s and a manager’s information needs, aligning them with business goals in a systematic manner. This would help prevent decisions being based on information biased by individual incentives. Next, the *business* perspective involves the challenge of applying methods because of difficulties in identifying and quantifying the architecture value. Given the small amount of evidence on the use of such methods in practice, it is not surprising that an architecture decision is often driven by *individual* incentives or strong leadership of decision-makers, leading to suboptimal decision-making in the organization.

Built upon these challenges, we aimed to propose a method based on best practices that accommodate architects’ and managers’ information needs, aligned with business goals to guide investment decisions. To reach this goal, we applied a hybrid research strategy (Yin 2003) that combines the strong points of case studies, interview data, and experimenting.

Several case studies (observational and participatory) were conducted in naturalistic settings (Schmitt 1997) at the Magnetic Resonance Imaging (MRI) business at Philips Healthcare in The Netherlands. We expected that the system and organizational complexity of the MRI business would be helpful for both similar and less complex environments. While case studies were adequate to investigate architecture evaluation and possible improvements in practice, the understanding of architects’ and managers’

information needs required quantified techniques. We used structured interviews to elicit information needs and a conjoint study to empirically investigate information predictors of architecture investment decisions by managers and architects. We now briefly reiterate the main questions of the study.

The first research question was *what are the practical challenges of architecture investment decision making and how do they relate to general trends and theoretical challenges?* The main aim was to better understand architecture evaluation in practice and draw boundaries for its improvements in subsequent studies. We conducted two case studies. In the first study, we analyzed a previously made decision on architecture investment by an expert team. The findings were used as a reference to the official decision-making process throughout the thesis. In the second study, we adapted the real options way of thinking as a promising guideline to support a decision in this same case. Practitioners reviewed the study results on decision-making by the expert team and applied “real options”. This brought forward a set of practical challenges as a base to propose improvements on architecture evaluation in the following studies.

The second research question was *what kind of information do architects and managers (say they) need for architecture evaluation?* The aim of this study was to understand architects’ and managers’ information needs so that we could (1) define a relevant information set and (2) examine the applicability of the existing methods and define possible improvements. We interviewed ten architects and nine managers at Philips Healthcare in semi-structured interviews. Then we quantitatively analyzed and compared their information needs.

The third research question was *do professionals use the information they ask for (in the interviews) and how do individual characteristics (experience and roles) determine the use of information.* The aim of this study was to examine to what extent the alleged necessary information is indeed used and to define (if possible) the main determinants of architecture decisions. We conducted an experiment with 114 practitioners. The participant was asked to decide on investing in one out of two architecture scenarios based on a given architecture description and information inputs. Analyzing the answers, we study how the information and individual characteristics of the respondents affect their decisions. Then we compared findings from the experiment and the interviews to get a better understanding of relevant information in architecture evaluation.

The fourth research question was *how to identify and quantify the customer-centric value?* The aim of this study was to explore best practices in attaching quantified values in several parts of the decision-making process. In two case studies we exploited management tools—strategy maps and balanced scorecards—to identify customer value by mapping architecture decisions to customer-centric objectives and measures. Furthermore, for each study, we adopted a marketing concept, customer value-in-use and customer segments to quantify the value of architecture changes for a single and for multiple customers. To assess potential adoption of the customer-value concept, we compared existing and proposed customer-value indicators on the same real-world case and let them be evaluated by decision-makers in the organization.

The last research question we tackled refers to the main aim or goal of this thesis: *to design guidelines for supporting a decision on architecture investments*, given the answers to our

previous questions. The aim of this study was to build upon findings throughout the previous studies to propose a new method for architecture evaluation decisions. First, acknowledging a need for the method to fit into the existing process, we decided to use scenario analysis and business cases that are identified “best practices” in architecture. We decided to exploit the strategy map concept used in the previous study to map architecture decisions to business goals, as this concept allowed the kind of decision-making we envisage and resonated well with practitioners. Given the controversial findings on information needs, we proposed to guide information selection based on business goals rather than on individual preferences by using the balanced scorecard tool. This led to a structured approach integrating established management techniques (strategy maps and balanced scorecards), scenario methods, and business case analysis to support decisions on architecture investments. For ease of reference, we have labeled this four-step method “Strategy-focused Architecture” (StArch). The first step maps architecture to diverse business goals and related scorecards, and facilitates reaching a consensus on evaluation criteria. The second step creates business-distinct scenarios that have different impacts on scorecard values. The third step assesses scorecards that are used to estimate the architecture value. The fourth step evaluates proposed architecture scenarios based on the evaluation criteria and guides the documenting of recommendation on investment decision. As a first real-world test, StArch was applied to support practitioners in evaluating a real-world project investment which had been on hold for several years because of the difficulty to properly assess the architecture value. The practitioners involved in the project evaluated StArch by comparing it to the existing decision-making process to provide recommendations on architecture investments.

8.2 Summary of main findings

We group the main findings to reflect the thematic parts of this thesis, challenges (part I), information (part II), and best practices (part III).

The first main finding was that practical challenges in making architecture investment decisions are mostly of the process, individual or business type described above. However, we also identified the additional challenges that architecture evaluation must follow the established process in the organization and improvements should be based on best practices to increase the adoption rate.

From a process perspective, architecture evaluations in practice do not entirely support the strategic nature of architecture investments. The main architect’s responsibility is often to make a “proof-of-concept” and the manager’s responsibility is to make a business case analysis and project planning, and both tasks are largely unrelated or separated. This can lead to a decision without having identified the sources of architecture value and without aiming to maximize the utilization of architecture over its entire lifecycle. Given this, the challenge was to incorporate architecture “proof-of-concept”, project planning, and business case analysis tightly into the joint activities of architects and managers.

The interviews with practitioners revealed that architects and managers are somewhat biased by their expertise in the sense that they emphasize or overuse their own kind information to make decisions. This implies that we would want the information set that

practitioners use to concentrate on the most relevant management and architectural information, being broad enough to cover all the key information, but limited to prevent information overload. Thus, the challenge is to provide guidance in selecting a set of relevant business information, accommodating the information needs of architects and managers.

When considering the business perspective, we were able to highlight advantages and pitfalls in applying the real options way of thinking in a business case analysis. Consistent with the literature, a lack of guidance in quantifying customer value in the decision-making process is seen as one of the main complications. The difficulty in adequately quantifying customer value can lead to a general feeling among decision-makers that, by definition, the decision must be based on gut feeling or intuition, thereby being at odds with a structural approach to decision-making. We also identified two additional challenges that were not apparent in the literature. First, we found that architecture evaluation must follow the established process in the organization. This is because any process change in a complex organization requires large cultural changes, necessitating a management effort going far beyond the scope of a single research project. There are decision-making procedures in place already, both good and less good, and there is a general reluctance to move too far away from these processes. Second, we found that improvements that we might propose are most easily adopted in the organization when based on or inspired by best practices. A set of practical challenges provided guidance for further improvements on architecture evaluation.

Our second main finding was that architects' and managers' information needs and uses are not the same, which might significantly affect architecture evaluation (chapters 4 and 5). In the interviews (chapter 4), architects and managers reported having large information needs in making decisions on architecture investments. A comparative analysis suggested that architects' and managers' information needs differ among themselves, but also in a comparison with other experts. Architects reported using system-specific information and managers financial information to support architecture investments. For each group, the reported information set was larger than the one used by other experts in general. Despite the differences, architects and managers agreed on the need to use information that measured strategy-centric goals in the organization (for the customer-centric strategy at Philips Healthcare that was time-to-market and upside potential for customers). We were then interested in whether and how the information is actually being used (chapter 5). The results showed that the identified information needs were much richer than the information set used to decide on architecture investments. Whereas previous research on expert decision making tends to find that a handful of cues (typically four to eight) are the main determinants of decisions, our results showed much less consistency among practitioners. Apparently there is hardly any consensus about which kinds of cues to use. One can see that this is a real danger, also because architects are more likely to use information about quality and managers prefer information about sales in making decisions. This implies that without a structured decision-making process, the decision might be based on the right information but the interpretation and use of that information might be driven by personal characteristics, such as development experience or the resilience to time pressure of individuals rather than by business incentives. Thus, our results show a real need to identify relevant information and to

determine how this information should be combined (for instance, through predefining decision rules).

The third main finding was that it is possible to improve architecture evaluation by applying best practices in management and architecting within an industry-accepted time frame. To substantiate this finding, we elaborated on the results of two studies, one on modeling customer value (chapter 6) and a second one that proposed a method to support the new architecture evaluation process (chapter 7).

Customer-centric value modeling in two real-world architecture projects demonstrated that although not trivial, it is possible to identify and quantify customer value in practice (chapter 6). The use of customer-centric value is feasible when customer value is closely aligned with an organization's business strategy and the time spent on data collection is acceptable. Throughout both our case studies, our practitioners agreed that customer-value modeling was more advantageous than the existing value indicators in use to support architecture investment decisions. The main reason was that the existing value indicators were not tailored for architecture investment decisions, but were rather used because of their availability in the organization.

Furthermore, the techniques used to assess the value indicators were biased by the stakeholders' expertise. In contrast to this, management tools such as strategy maps and balanced scorecards provided guidance in identifying the business measures (scorecards) independent of the expertise of the stakeholders. In this process, design decisions (for instance on quality improvements) were mapped explicitly to customer-centric goals, which was one of the main theoretical and practical challenges. Customer modeling satisfied the information needs of both architects (quality attributes) and managers (customer value).

Unlike the management tools, the acceptance of the marketing tools varied. Customer value-in-use was regarded as helpful only when the architecture design was optimized to create value for a single customer. This is typically seen in organizations with a small customer base (for instance, with customers buying wafer steppers in the semiconductor industry). Differently to this, a customer segment concept was appreciated for two reasons. First, segmentation had already been used in practice to identify product market segments for a business case analysis, so practitioners were familiar with the idea. Second, customer segment concepts in our studies tended to provide more accurate data.

Considering the effort spent in the process, assessing the customer value of a single customer was found to be too costly in evaluating the architecture design if an organization has more than dozens of customers (and for each of them, a separate estimate needed be made). In this case, a huge effort may be required to collect data. Again, in this case, customer segmentation proved acceptable because it was closely aligned with existing processes of business case modeling. It also meant that effort spent on data collection processes would change little compared to the existing data collection procedure.

A four-step StArch method was applied by the expert team on a project that had been pending for several years, bringing consensus among the experts. StArch enabled joint activities of architects and business managers to agree on business goals, scorecards, and assumptions, proposing scenarios used to estimate the value and make a recommenda-

tion. Evaluation of each step of StArch by the expert team brought about interesting findings. The first step, to map the architecture to business goals, was the most appreciated step. In this step, strategy maps and balanced scorecards were used with high satisfaction, as it had been in customer value modeling. Similar to the first study, satisfaction about the completeness of the information use in StArch was biased by people's roles. Even when people agreed on business-driven information, they tended to ask for additional data from their own perspective that would be inconsistent with the information needs of other experts. One main advantage of StArch is that it did not interfere much with the existing business process, requiring about 40 hours of effort (for investments of the size of 10 person years). Practitioners recommended using StArch within a week for projects with relatively large investments and a reasonably predictable impact of design decisions on the value.

Supporting strategy-focused architecture investment decisions is not a straightforward process in practice. On the contrary, it requires addressing a complex landscape of challenges including issues at the process, business, and individual level. In this thesis, we have tried to show that by addressing the challenges explicitly and by exploiting best practices, it is possible to improve the current state-of-the-practice with relatively small effort. In this sense, the findings in this thesis are stepping stones towards building a safer road to informed strategy-focused architecture investment decisions.

8.3 Discussion

8.3.1 *Some positive aspects of the study...*

In this thesis we used a hybrid research strategy that combines the strong points of multiple case studies, interview data, and experimenting. We elaborate on three advantages.

First, five case studies helped us investigate decision-making in real-world projects as opposed to decision-making in theoretical examples. In each study, we proposed improvements based on best practices and directly applied them in a real-world project. Investigators and practitioners reviewed the study findings and suggested improvements for the follow-up study. This iterative process made it easier to understand practical challenges, provided direct tests of our suggestions, and forced us to meet the practitioners' needs after each completed study. After a few iterations, we proposed the StArch method, which was officially transferred to the MRI business at Philips Healthcare.

Second, we reviewed the problem from a multidisciplinary perspective (economic, management, individual decision-making), which is not that common in decision-making. As can be seen from the existing methods, research on decision-making has most often been linked to economic theories. When applied to well-specified problems, such theories lead to unique solutions (for instance cost models in product lines). However, in real-world decisions, when experts work on problems that are less well-defined (for instance, a question on a source of architecture value), the relevance and applicability of economic theories can be questioned. In our proposal, we extended economic theories by best practices in strategic management and marketing and theories on experts' decision-making.

Third, we investigated the information needs of experts (architects and managers) by combining interview and empirical data. Usually the interview data are taken for granted in the sense that one tends to believe what people say, especially when they are experts in their field. We challenged information needs reported by architects and managers in the experimental study. To the best of our knowledge, this is the first of this kind of study in the architecting domain. We think that the multidisciplinary approach on architecture investment decisions was one of the key drivers of the success of the method in practice.

Next to a research strategy, we think that understanding the psychology of experts in making architecture investment decisions was crucial in proposing improvements. For example, the fact that people are biased in valuing their own-kind information when making decisions meant that explicit support was required in eliciting business-relevant information. This suggests that architects and managers should work closely as a team to share information and make a decision in consensus to avoid missing crucial decision drivers. In addition, we found that architects and managers hardly show any consistency with respect to information use. We could not find many strong cues that the practitioners agreed on. This shows the need for a consistent process of dealing with information. It also highlights the fact that even when aspects that were hard to quantify have been quantified, there is still ample room to make mistakes in using that information.

Our StArch method tries to overcome such people-biased decisions by guiding a team (of architects and managers) to identify their own-kind of information and align it with strategic business goals. Furthermore, using best practices in strategic management and marketing, we succeeded in broadening the economic scope of architecture evaluation. In StArch, next to economic decision rules, other business constraints can be explicitly added that provide a boarder context for making a decisions, not only economic.

This support simulates a more real-world-alike environment: a decision is a complex process of problem solving, based on how to maximize architecture value over the lifetime within business boundaries.

Compared to the archetypical management books that provide generic guidance that is often difficult to follow without a management background, we proposed a tailored solution for architecture evaluation. In a couple of cases, we demonstrated the use of individual methods in architecting practice. Given our experience, we think that our StArch method is applicable more broadly. In principle, we would argue that StArch can be applied in strategic investments in which the impact of intangible changes (like quality improvements) is reasonably predictable. In practice, this means that an organization must have previous experience on estimating the impact of changes on the relevant scorecards. One could think of investments in any kind of quality improvements (for instance in hospital businesses) or infrastructure (for instance investments in highways) as examples in which the method could also be used. Our approach would be less likely to be applicable in making investments in, for instance, pharmaceutical clinical trials in which outcomes are highly unpredictable.

8.3.2 ... and some aspects in need of improvement and extension

Next to the positive sides of this thesis, we would also like to elaborate on a few aspects of the study that warrant some extra attention.

First, we conducted our studies within a single organization. This poses an obvious question about the generalization of our results. Given the fact that Philips Healthcare deals with rather complex architecture evaluations, an advantage is that we do cover a broad range of theoretical and practical challenges that encompass the kinds of challenges one can expect in similar but less complex software-intensive system organizations. Nevertheless, we agree that cross-organizational studies would be useful. On the other hand, our choice of reiterating (parts of) the method in several real examples, almost by necessity, confines the study to a single company, given the necessity to learn the domain and organization to understand practical challenges in architecture evaluation.

We also acknowledge that we did not directly compare or test our StArch method with other methods. This is a common issue in decision-making in real-world environments, especially in a business setting and remains an open issue (Schmitt 1997). We might learn from the large experiments in the military domain where, in training, two teams make a strategic decisions in parallel, one with decision support and another based on gut feelings (Gladwell 2005). It is, however, difficult for organizations to find support for such experiments. Nevertheless, we might have improved on StArch by applying it in another case with a different context (organization, business goal). More studies using StArch would provide more insights about the generalization of the method.

We also observed that our presence in the case study may have influenced the decision-making. This was, however, unavoidable, as we needed to introduce the actual methods or “best practices” and observe possible improvements. One open question is to what extent the method can be applied without actual involvement of at least one or two people who are knowledgeable about it (although this issue obviously gets less important after the method has been used a couple of times). Furthermore, there is a risk that the evaluation of the method by practitioners directly involved in our studies might be subjective, or biased by our presence in the project. To at least partially address this issue, questionnaires were followed by open-ended questions in the review meeting. Interview findings were then cross-checked by two investigators who were at the meeting.

Finally, we should remark that we proposed improvements on architecture evaluation that are expected to improve the process, and in the end, also the decision. For lack of a proper control and given the complex context in which decisions are made, it is hard to definitively argue that decisions will necessarily get better. We can argue in rebuttal that we have at least shown that our method led an expert team to uncover business information that allowed them to make a decision in a case that had been “pending decision” for years because of the lack of adequate decision information. In this way, the decision was finally made in a relatively short time and the business team could eliminate the awaiting architecture project. However, that still does not show that our method leads to the right or better business decisions, although it is hard to believe that proper and systematic use of information could deteriorate the decision. Of this we can be sure: StArch provides systematic guidance to help a decision to be made in a consistent way among the members of the expert team. We believe that with StArch, we succeeded in improving

the process by providing sufficient information and guidance for a consensus of different experts in making a decision within a reasonable timeframe (chapter 7). Future lines of research should build up evidence on StArch's adequacy, although as we mentioned before, controlled trials in a business setting are rare.

8.4 Future lines of research

Following the structure of this thesis, we suggest two main future lines of research: the first one on information needs of experts in architecture investment decisions and the second one on best practices to support investment decisions.

In the empirical part of this thesis, we analyzed architects' and managers' information use. Our findings were somewhat surprising. First, we recognized that they use few information types inconsistently: apparently there is not that much consensus about the factors that should drive architectural decisions. A better understanding of what is happening here is crucial. Do experts indeed find a couple of cues important (as we had expected based on the literature) but each expert uses different cues? Or, shouldn't our participants be seen as experts, and should one focus on finding the ones who are experts in these kinds of decisions? In any case, our findings bring to light new lines of research to better understand information needs and decision rules of experts in architecture investment decisions. A natural step would be to repeat the same study by improving on weaker points of the study. One improvement might be to address different domains with a larger sample. However, we envision two other research lines and possible challenges along the lines of our findings might be more interesting.

One more specific line of research could identify "successful" experts (architects and manager) in architecture investment decisions. A better understanding on how successful experts make decisions can set a 'golden' standard in information use. A golden standard would provide a first step in making an informed decision. The next step would then be to tailor the golden set to different contexts (business goals) and domains. There are several theoretical and practical challenges in conducting such research. The first is that it might not be easy to find the real "successful experts" in architecture investment decisions, given that these persons are supposed to be those whose actions resulted in projects with high business performance over years. Companies are sensitive to share their business performance indicators (except for financial reports) and to point to people responsible for them, especially if the companies do not directly benefit from such research. However, we can observe that this barrier is weakening. In a highly competitive environment such as the healthcare business in the US, research along these lines is already happening. Hospitals and their clinical specialists (experts) are ranked with the same publically available key quality indicators (for instance morality or readmission rate). This might explain a large literature corpus on expert's decisions and success of expert's systems in the medical domain. We are not there yet in architecture investment decisions, but we could learn from other domains in conducting the future studies.

Furthermore, we think that our understanding can be advanced by analyzing how and when teams of experts share and use information to make the decision. This appears to be a logical step given that architecture evaluation is conducted as a joint effort of architects and business managers who typically each have their own reasons and roles. We

expect that in the team, other factors than strictly economic ones may play a role in the deliberation phase, such as the personality of the professionals (e.g. introverted vs. extroverted) or the existence of a higher hierarchical level of experts in the organization.

The literature suggests two possibilities in investigating such phenomena in the context of architecture knowledge management. The first one is the use of a research community in sharing architecture knowledge (SHARK 2011). SHARK aims to understand how to share, use and re-use architectural knowledge. This is attested by numerous workshops (SHARK 2011) and empirical studies (Clerc, Lago et al. 2008; Farenhorst, Hoorn et al. 2009). The current body of knowledge in SHARK is primarily concerned with codification, storage, and retrieval of information on architecture knowledge. Given that, it makes sense to conduct empirical studies on architecture investments to code documented business rationales that lead to a decision. This might bring more insights into how information is shared and used in architecture evaluation. Another literature stream proposes to look at architecture knowledge management as rather socialization-heavy. In this respect, not documentation but face-to-face communication is the state-of-the-practice of architecture knowledge management. The concept of the lead architect as “walking architecture” refers to the constant knowledge building in the architect’s practice that is often not documented (Unphon and Dittrich 2010). The question would be how one can tap knowledge from “walking architecture” in a way that is useful to others. Adapting this concept to the business managers in the expert team, we would then follow “walking architecture” and “walking business” to understand the evaluation process. Given the StArch method, leading to investments in the order of magnitude of a week per evaluation, this is probably possible. Such an observational study, in which one follows architects and managers during their evaluation process and collects information on evolving knowledge to support a decision on architecture investments, seems a promising idea to us. Ultimately, this would deliver a comprehensive overview of information and rationales used in architecture evaluation.

The second line of research we suggest has to do with extending the StArch method to investment decisions. As we have argued, we feel the method is more broadly applicable and an obvious first step would be to try it in both similar and less similar contexts. This would help us determine the scope of the method and would identify new points of improvement. Furthermore, if this proved to be successful, we would argue for a how-to guide on StArch in more detail so that practitioners can apply the method themselves.

Also, a more specific line of research would be to improve the individual steps of the StArch method. One improvement would be to explicitly assess *willingness to buy* of customers in particular segments. This insight would improve the estimates of the number of customers who would be more likely to buy the new improved product. Willingness to buy estimation would then require adopting the marketing literature to the architecture context. Succeeding in this line of research would provide more concrete and predictive modeling of the impact of architecture changes on the monetary value of the organization. This would imply justifiable economic rules to make design decisions, instead of a hazardous process in which the person with the biggest intuition gets his or her way. Such a rational comparison of costs and benefits of architecture investments still lies beyond the horizon to some extent, but we do feel we are getting closer to such an ultimate goal.

Appendix A: Interview format

The interviews were designed to gather general opinion about architecture evaluation and more-specific impressions on information needs. The interview was supposed to take approximately 45 to 60 minutes.

The interview questions refer to two or three topics, depending on whether interviewees participated in the pilot (Step 1) or other interviews (Step 2), respectively, as shown in Table 22 below.

Table 22. Interview structure with its elements, purpose, and exemplary questions

Interview elements	Purpose																																																																																				
Step 1 & 2 Introduction	<p>Get interviewees familiar with the study and set expectations Understand an interviewee's profile</p> <ul style="list-style-type: none"> • Domain of expertise (architecting/management) • Responsibilities in architecture evaluation activities 																																																																																				
Step 1 & 2 Case description	<p>Understand how the architecture evaluation process (preceding a decision on architecture investments) is done in a typical case based on the interviewee's experience.</p> <ul style="list-style-type: none"> • A process: who does what, how, and when • Information needs to support such a process <p>If necessary, to avoid ambiguity, ask for another case description and follow the same open-ended questions.</p>																																																																																				
Step 2 Information selection	<p>Elicit a use of information types or gut feeling in supporting a decision on architecture investments by using the structured matrix.</p> <p>Question A: Select information types (Table 8 on page 57) from the list below, which you use to support a decision on architecture investments.</p> <table border="1"> <thead> <tr> <th rowspan="2">Information types</th> <th colspan="4">Interviewees</th> </tr> <tr> <th>Jan</th> <th>Baas</th> <th>Nico</th> <th>Sven</th> </tr> </thead> <tbody> <tr> <td>Gut feeling</td> <td>x</td> <td>x</td> <td></td> <td></td> </tr> <tr> <td>Investment</td> <td></td> <td>x</td> <td>x</td> <td>x</td> </tr> <tr> <td>Cash flow, NPV, IRR</td> <td>x</td> <td></td> <td>x</td> <td></td> </tr> <tr> <td>Sales</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Market uncertainty</td> <td></td> <td></td> <td></td> <td>x</td> </tr> <tr> <td>Customer segment benefits</td> <td>x</td> <td></td> <td></td> <td></td> </tr> <tr> <td>Time-to-market</td> <td></td> <td>x</td> <td></td> <td></td> </tr> <tr> <td>Upside potential</td> <td></td> <td>x</td> <td></td> <td></td> </tr> <tr> <td>Customer satisfaction</td> <td></td> <td>x</td> <td></td> <td></td> </tr> <tr> <td>Quality attribute trade-off</td> <td>x</td> <td>x</td> <td></td> <td></td> </tr> <tr> <td>Future proof</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Downside effect</td> <td></td> <td></td> <td></td> <td></td> </tr> <tr> <td>Resources</td> <td></td> <td></td> <td></td> <td>x</td> </tr> <tr> <td>Technology risk</td> <td></td> <td></td> <td></td> <td>x</td> </tr> <tr> <td>Cost savings</td> <td></td> <td></td> <td></td> <td>x</td> </tr> </tbody> </table> <p>Question B: What is possible missing information? Which information? Where do you use such information? Example.</p>	Information types	Interviewees				Jan	Baas	Nico	Sven	Gut feeling	x	x			Investment		x	x	x	Cash flow, NPV, IRR	x		x		Sales					Market uncertainty				x	Customer segment benefits	x				Time-to-market		x			Upside potential		x			Customer satisfaction		x			Quality attribute trade-off	x	x			Future proof					Downside effect					Resources				x	Technology risk				x	Cost savings				x
Information types	Interviewees																																																																																				
	Jan	Baas	Nico	Sven																																																																																	
Gut feeling	x	x																																																																																			
Investment		x	x	x																																																																																	
Cash flow, NPV, IRR	x		x																																																																																		
Sales																																																																																					
Market uncertainty				x																																																																																	
Customer segment benefits	x																																																																																				
Time-to-market		x																																																																																			
Upside potential		x																																																																																			
Customer satisfaction		x																																																																																			
Quality attribute trade-off	x	x																																																																																			
Future proof																																																																																					
Downside effect																																																																																					
Resources				x																																																																																	
Technology risk				x																																																																																	
Cost savings				x																																																																																	

Appendix B: Case descriptions: automotive and consumer electronics

Automotive case

BigTruck develops premium quality busses and trucks worldwide accounting total sales of SALES vehicles the last year. The main business strategy of *BigTruck* is to offer highly customized vehicles.

To offer highly customized vehicles it is important to make a flexible system design to enable easy integration of external 2nd party devices such as garbage collectors, fire-fighting equipment, or tippers. With the fact that the 2nd party integrates external devices with vehicles, there is also a high requirement on designing the system to minimize the integration cost.

Recently *BigTruck* decided to invest in the new feature, a body builder manager. To integrate this feature, there are two scenarios taken into consideration, Scenario *Keep* the existing architecture and Scenario *FlexNet* to invest in architecture flexibility.

Scenario 1: Keep

Connect an external device to the communication link directly to the current cabin gateway ECU through an existing but unused bus interface, see Scenario *Keep* in Figure 2.

- Starting investment is INVESTMENT IN SCENARIO 1 with RISK IN SCENARIO 1 technology risk with MARKET UNCERTAINTY IN SCENARIO 1 uncertainty of market acceptance of new vehicles on the market.
- UPSIDE POTENTIAL 2 IN SCENARIO 2
- DOWNSIDE EFFECT IN SCENARIO 1
- It is expected that the existing component cost will UPSIDE POTENTIAL 1 IN SCENARIO 1
- This implementation will end TTM (TIME) months earlier than in the scenario *FlexNet*.
- The 2nd party integrator will need QUALITY ATTRIBUTE IN SCENARIO 1 months for integrating the vehicles with such a solution.

Scenario 2: FlexNet

Embed a new ECU to create the external communication with more flexibility, see Scenario *FlexNet* in Figure 2.

- The investment is INVESTMENT IN SCENARIO 2 with RISK IN SCENARIO 2 technology risk with MARKET UNCERTAINTY IN SCENARIO 2 uncertainty of market acceptance of new vehicles on the market.
- The architecture changes with the feature integration will last for 12 months.
- QUALITY ATTRIBUTE IN SCENARIO 2
- FUTURE PROOF IN SCENARIO 2
- Component costs are higher than in scenario *Keep*.

Experienced marketers estimated that approximately 80% of all customer needs for external devices are already met with the existing E/E architecture. A rough forecast of met customer needs over time in scenarios Keep and FlexNet is shown in the graph below. CUSTOMER NEEDS. Total cost savings in scenarios Keep and FlexNet is presented in the graph below. COST SAVINGS.

Consumer electronic case

SimpleMore develops low- to high-end TVs for the global consumer market. An annual report shows total sales of SALES million TVs and the following financial figures:

Price, volume, and margins of catalogued products for consumer market

Product category	Price range (Euro)	Volume (% unit sales)	Margins (% of the price)
High-end TV	1000-4000	15	10
Mid-range TV	500-1000	35	3
Low-end TV	200-500	50	1

The new business strategy is to expand to the business-to-business (B2B) markets. B2B TV markets characterize a high demand for low-end TVs and an insignificant demand for mid-range and high-end TVs. SimpleMore decided to enter the hotel market first and then to address hotel, school, and hospital markets.

The hotel market imposes new requirements as following. Consumer TVs will be adapted to switch between a TV and a hotel terminal-information mode. New features such as fixed channel programming, volume control to prevent disturbance to other guests, video on demand systems (pay-TV), or WiFi access will be included. Hotel service engineers explicitly ask for hotel mode TVs which they can easily install in a hotel's audio-video (AV) environment.

Currently, all consumer TVs are developed on three architectures: low-end, mid-range, and high-end. SimpleMore needs to invest in architecture changes to better manage margins across consumer and B2B TVs and enable entrance to the new B2B markets. There are two architecture scenarios into consideration.

First, to develop the new architecture with hard integration of low-end consumer and B2B TVs and at the same time to keep the existing mid-range and high-end architectures for consumer TVs, called *Low scenario*. Second, to develop a B2B-TV-box as an interface of B2B TVs to existing low-end, mid-range, and high-end architectures, called *Full scenario*. In this scenario, there will be minor changes in the existing architectures to interface to a B2B-TV-box.

The scenarios in more details are presented below.

Scenario 1: Low

- Investment is INVESTMENT IN SCENARIO 1 million euro with RISK IN SCENARIO 1 technology risk and MAR-KET UNCERTAINTY IN SCENARIO 1 market acceptance uncertainty.
- After half a year of architecture implementation, QUALITY ATTRIBUTE FOR SCENARIO 1 low-end TVs will be released for B2B market and all low-end TVs will be available for the B2B market in a year.

- It is expected that hard integration will increase UPSIDE POTENTIAL 1 IN SCENARIO 1 margins across low-end products.
- UPSIDE POTENTIAL 2 IN SCENARIO 1
- DOWNSIDE EFFECT IN SCENARIO 1
- Development time of this architecture will be TIME-TO-MARKET in the Full scenario.

Scenario 2: Full

- Investment is INVESTMENT IN SCENARIO 2 million euro with RISK IN SCENARIO 2 technology risk and MAR-KET UNCERTAINTY IN SCENARIO 2 market acceptance uncertainty.
- The architecture implementation for full range product will be in phases. The low-end TVs for B2B market will be available in 9 months, mid-range in a year and high-end in 15 months)
- QUALITY ATTRIBUTE IN SCENARIO 2
- FUTURE PROOF IN SCENARIO 2

Experienced marketers estimated that 90% of customers need low-end hotel TVs and forecasted roughly how much customer needs in the hotel market will be met in Low and Full scenario, see the graph below CUSTOMER NEEDS.

Currently the low-end market contributes approximately 23% of the total revenue. If SimpleMore keeps the existing prices, a margin impact on the revenue in Low and Full scenario is estimated as in a graph below. COST SAVINGS

Appendix C: Data and analyses

Table 23. A profile of participants in the study (personal measurements)

Profile of participants		% (n=114)
Role	Managers	30.7
	Architects	43.9
	Designers	4.4
	Others	21.0
Domain	Healthcare	43.0
	Automotive	17.5
	Consumer electronics	28.1
	Other	76.3
Experience	Development	100
	Management	80
Average year of experience	Development	14.7
	Management	9

Table 24. Distribution of decision measurements across the three cases

Decision measurements		Distribution per case (%)		
		Healthcare (n= 114)	Automotive (n=113)	Consumer elec- tronics (n=114)
Decision	Scenario 1	64.9	53.5	57.0
	Scenario 2	22.8	33.3	31.6
	Not completed	12.3	12.3	11.4
Confidence	(1) It's just a guess	4.4	1.8	4.4
	(2)	5.3	4.4	6.1
	(3)	11.4	12.3	7.0
	(4)	19.3	18.4	17.5
	(5)	24.6	28.1	28.1
	(6)	14.9	17.5	16.7
	(7) Virtually certain	7.9	5.3	8.8
	No answer	12.3	12.3	11.4
Realism of the case	(1) Not at all	3.5	2.6	5.3
	(2)	2.6	4.4	4.4
	(3)	6.1	11.4	12.3
	(4)	20.2	15.8	15.8
	(5)	28.1	29.8	35.1
	(6)	21.1	14.9	18.4
	(7) Absolutely	9.6	10.5	4.4
No answer	8.8	10.5	4.4	

Decision measurements		Distribution per case (%)		
		Healthcare (n= 114)	Automotive (n=113)	Consumer elec- tronics (n=114)
Previous expe- rience with the decision	No	40.4	36.8	51.8
	Yes	50.9	52.6	43.9
	No answer	8.8	10.5	4.4

Table 25. Predictors of the decision confidence in 315 cases, R-squared = 0.2399

	Coef.	Std. Err.	t	P> t	95% Conf.	Interval
Role						
- Manager	.2827735	.1786361	1.58	0.115	-.0688191	.6343662
- Designer	1.185764	.3987769	2.97	0.003	.4008884	1.970639
- Other	-.5389567	.2137888	-2.52	0.012	-.9597373	-.1181762
Case						
- Healthcare	-.3166596	.186183	-1.70	0.090	-.6831061	.049787
- Automotive	-.1890786	.1864198	-1.01	0.311	-.5559914	.1778341
Experience	.0065507	.0107455	0.61	0.543	-.0145987	.0277001
Realism	.3788098	.0540391	7.01	0.000	.2724497	.4851699
Have experience	.3097748	.1588071	1.95	0.052	-.0027904	.6223399
Timer used	.3379403	.1531908	2.21	0.028	.6394515	.0364291

Table 26. Predictors of the participant's' decision on scenario 2 with confidence level greater than 3 in the healthcare case (Number of cases = 76, Pseudo = 0.4679)

	Coef.	Std. Err.	t	P> t	95% Conf.	Interval
Personal Characteristics						
Development experience	.1856259	.0640671	2.90	0.004	.0600567	.3111952
Management experience	-.0002635	.0704819	-0.00	0.997	-.1384055	.1378785
Manager	-.1104041	1.112997	-0.10	0.921	-2.291837	2.071029
Other roles	-.9765272	1.129479	-0.86	0.387	-3.190265	1.237211
Business information						
Investment in s1	-0.3737212	0.9401012	-0.40	0.691	-2.216286	1.468843
Investment in s2	1.899071	1.152957	1.65	0.100	-.3606827	4.158824
Sales	-.2484458	0.583799	-0.43	0.670	-1.392671	0.8957792
Time-to-market	1.677066	0.9995165	1.68	0.093	-0.28195	3.636083
Customer needs	0.6765234	0.8080288	0.84	0.402	-0.9071839	2.260231
Cost savings	0.6036815	0.768023	0.79	0.432	-0.901616	2.108979
Downside effect in s1	2.997381	1.086839	2.76	0.006	0.08672156	5.127547
Upside potential 1 in s1	-0.4430842	0.7970776	-0.56	0.578	-2.005328	1.119159
Upside potential 2 in s1	-0.4430842	0.7970776	-0.56	0.578	-2.005328	1.119159
Quality attribute in s1	-0.6624145	0.8199153	-0.81	0.419	-2.269419	0.94459
Quality attribute in s2	0.0405588	0.7973673	0.05	0.959	-1.522252	1.60337

	Coef.	Std. Err.	t	P> t	95% Conf.	Interval
Future proof in s2	0.0405588	0.7973673	0.05	0.959	-1.522252	1.60337
diffR1R2	0.5268453	0.2854707	1.85	0.065	-0.0326669	1.086358
diffMU1MU2	0.5309927	0.3229287	1.64	0.100	-0.1019359	1.163921
Time						
Timer used	.6958122	1.022831	0.68	0.496	-1.3089	2.700525

Table 27. Predictors of the participant's' decision to select the scenario 2 with the confidence level greater than 3 in the automotive case: (Number of cases = 77, Pseudo = 0.2782)

	Coef.	Std. Err.	t	P> t	95% Conf.	Interval
Personal Characteristics						
Development experience	.0291713	.0430452	0.68	0.498	-.0551957	.1135383
Management experience	-.0406196	.0547608	-0.74	0.458	-.1479489	.0667096
Manager	-.0977169	.8112662	-0.12	0.904	-1.687769	1.492336
Other roles	-1.376733	.8416074	-1.64	0.102	-3.026253	.2727869
Business information						
Investment in s1	.4933809	.7786814	0.63	0.526	-1.032807	2.019568
Investment in s2	.0941978	.8228647	0.11	0.909	-1.518587	1.706983
Sales	-.4296144	.4108536	-1.05	0.296	-1.234873	.3756439
Time-to-market	.3016023	.6428457	0.47	0.639	-.9583521	1.561557
Customer needs	-.2816118	.5746785	-0.49	0.624	-1.407961	.8447373
Cost savings	.8673696	.6143267	1.41	0.158	-.3366885	2.071428
Downside effect in s1	1.411336	.6592723	2.14	0.032	.1191864	2.703486
Upside potential 1 in s1	-.4617549	.669362	-0.69	0.490	-1.77368	.8501704
Upside potential 2 in s1	-.6573579	.6666422	-0.99	0.324	-1.963953	.6492368
Quality attribute in s1	-.8226852	.6012513	-1.37	0.171	-2.001116	.3557457
Quality attribute in s2	-.0572545	.5680002	-0.10	0.920	-1.170514	1.056005
Future proof in s2	.6867743	.5788973	1.19	0.235	-.4478435	1.821392
diffR1R2	.0094522	.2001511	0.05	0.962	-.3828366	.4017411
diffMU1MU2	.1456069	.2122291	0.69	0.493	-.2703545	.5615684
Time						
Timer used	.5733268	.6061472	0.95	0.344	-.6146999	1.761353

Reference list

- (2010). "Clarity tool ", from www.claritytools.com.
- (2010). "Philips Healthcare." Retrieved March 9, 2010, from <http://www.philips.com/about/company/businesses/healthcarehighlights>.
- (2011). "SHARK workshop." from <http://www.shark-workshop.org/>.
- Amram, M. and N. Kulatilaka (1999). Real Options, Managing Strategic Investment in an Uncertain World. Boston, Harvard Business School Press.
- Anderson, J. C., D. C. Jain, et al. (1993). Customer Value Assessment in Business Markets: A State-of-Practice Study, Institute for the Study of Business Markets.
- Bahsoon, R. and W. Emmerich (2003). ArchOptions: A Real Options-Based Model for Predicting the Stability of Software Architectures. Fifth Workshop on Economics-Driven Software Research (EDSER-5), affiliated with the 25th International Conference on Software Engineering. Portland, USA.
- Bahsoon, R. and W. Emmerich (2004). Applying ArchOptions to Value the Payoff of Refactoring. Sixth International Workshop on Economics-Driven Software Engineering Research. Edinburgh, Scotland, UK.
- Baldwin, C. Y. (2006). The Option Value of Software Product Lines. 10th International Software Product Lines Conference. Baltimore, Maryland.
- Barney, J. B. (1986). "Strategic Factor Markets: Expectations, Luck, and Business Strategy." Management Science **32**: 36.
- Bass, L. and B. Berenbach (2008). Leadership and Management in Software Architecture (LMSA'08) - A Report on an ICSE Workshop.
- Bass, L., R. Kazman, et al. (2003). Software Architecture in Practice, Addison Wesley.
- Berry, M. and A. Aurum (2006). Measurement and Decision Making. Value-Based Software Engineering. S. Biffel, A. Aurum, B. Boehm, H. Erdogmus and P. Grünbacher, Springer.
- Bevan, N. and M. Macleod (1994). "Usability measurement in context." Behaviour and Information Technology **13**: 132-145.
- Black, F. and M. Scholes (1973). "The Pricing of Options and Corporate Liabilities." Journal of Political Economy **81**.
- Blocker, C. P. and D. J. Flint (2007). "Customer segments as moving targets: Integrating customer value dynamism into segment instability logic." Industrial Marketing Management **36** 810-822.

- Böckle, G., P. Clements, et al. (2003). A Cost Model for Software Product Lines. Fifth International Workshop on Product Family Engineering (PFE-5). Siena, Italy, Springer. **3014**: 310-316.
- Böckle, G., P. Clements, et al. (2004). "Calculating ROI for Software Product Lines." IEEE Software **21**(3): 23-31.
- Boehm, B. W. (2006). Value-Based Software Engineering: Seven Key Elements and Ethical Considerations. Value-Based Software Engineering. S. Biffel, A. Aurum, B. Boehm, H. Erdogmus and P. Grünbacher, Springer.
- Boehm, B. W., E. Horowitz, et al. (2000). Software Cost Estimation with Cocomo II, Prentice Hall.
- Borison, A. (2003). Real Options Analysis: Where are the Emperor's Clothes? Real Options Conference. Washington, DC.
- Brandenburger, A. M. and B. J. Nalebuff (1995). "The Right Game: Use Game Theory to Shape Strategy." Harvard Business Review **73**(4): 14.
- Breeuwer, M., G. Hautvast, et al. (2008). "Simplifying cardiac MR analysis." MedicaMundi **52**(2): 68-76.
- Carroll, J. S. and E. J. Johnson (1990). Decision Research: A Field Guide, SAGE Publications.
- Chi, M. T. H. (2006). Two Approaches to the Study of Expert's Characteristics The Cambridge Handbook of Expertise and Expert Performance. A. Ericsson, N. Charness, P. Feltovich and R. Hoffman, Cambridge University Press.
- Christensen, C. M. and M. E. Raynor (2003). The innovator's solution Harvard Business School Press.
- Clements, P. (2007). An Economic Model for Software Architecture Decisions. First International Workshop on the Economics of Software and Computation. Minneapolis, Minnesota, USA, IEEE.
- Clements, P., R. Kazman, et al. (2001). Evaluating Software Architectures: Methods and Case, Addison-Wesley Professional.
- Clements, P., R. Kazman, et al. (2007). The Duties, Skills, and Knowledge of Software Architects. Sixth Working IEEE/IFIP Conference on Software Architecture (WICSA'07)
- Clements, P., J. D. McGregor, et al. (2005). The Structured Intuitive Model for Product Line Economics (SIMPLE), Carnegie Mellon University
- Clements, P. and M. Shaw (2009). "'The Golden Age of Software Architecture' Revisited." IEEE Software **26**(4): 70-72.
- Clerc, V., P. Lago, et al. (2008). The Architect's Mindset. 3rd International Conference on the Quality of Software (QoSA 2007), Springer LNCS.

- Copeland, T. and V. Antikarov (2003). Real Options, A Practitioner's Guide. New York, TEXERE.
- Cox, J. C., S. A. Ross, et al. (1979). "Option Pricing: A simplified Approach." Journal of Financial Economics **7**: 87-106.
- Day, G. S. (1990). Market Driven Strategy. New York, NY Free Press.
- Dibb, S. and L. Simkin (2001). "Market Segmentation: Diagnosing and Treating the Barriers." Industrial Marketing Management **30**: 609-625
- Dixit, A. K. and R. S. Pindyck (1995). "The Options Approach to Capital Investment." Harvard Business Review: 105-115.
- Doherty, M. E., C. R. Mynatt, et al. (1979). "Pseudodiagnosticity." Acta Psychologica(43): 111-121.
- Dul, J. and T. Hak (2008). Case Study Methodology in Business Research, Elsevier.
- Einhorn, H. (1974). "Expert judgment: Some necessary conditions and an example " Journal of Applied Psychology **59**(5): 562-571.
- Erdogmus, H. (2000). Aligning Software Investment Decisions with the Markets. Second International Workshop on Economics-Driven Software Engineering. Limerick, Ireland.
- Erdogmus, H. (2002). "Valuation of Learning Options in Software Development Under Private and Market Risk." The Engineering Economist **47**(3): 308-353.
- Erdogmus, H. (2006). Valuation of Software Initiatives Under Uncertainty: Concepts, Issues, and Techniques. Value-Based Software Engineering S. Biffi, A. Aurum, B. Boehm, H. Erdogmus and P. Grünbacher, Springer.
- Erdogmus, H. and J. Favaro (2002). Keep Your Options Open: Extreme Programming and the Economics of Flexibility. Extreme Programming Perspective. G. Succi, M. Marchesi, L. Williams and D. Wells, Addison Wesley
- Ettenson, R., J. Shanteau, et al. (1987). "Expert judgment: Is more information better?" Psychological Reports(60): 227-238.
- Falessi, D., P. Kruchten, et al. (2007). Issues in Applying Empirical Software engineering to Software Architecture. 1st European Conference on Software Architecture (ECSA2010). Madrid, Spain
- Farenhorst, R., J. F. Hoorn, et al. (2009). The Lonesome Architect. Joint Working IEEE/IFIP Conference on Software Architecture & European Conference on Software Architecture (WICSA/ECSA 2009). Cambridge, UK.
- Gaeth, G. J. and J. Shanteau (1981). "A bibliography of research on the effects of irrelevance in psychology." Applied Psychology Report (81-13).

- Gladwell, M. (2005). Blink: The Power of Thinking Without Thinking Little, Brown and Company.
- Gupta, S. and V. Zeithaml (2006). "Customer Metrics and Their Impact on Financial Performance." Marketing Science **25**(6): 718-739.
- Hammond, K. R., E. Frederick, et al. (1989). Application of cognitive theory to the student-teach dialogue. . Cognitive science in medicine: Biomedical modeling. D. A. Evans and V. L. Ptel. Cambridge, MA, The MIT Press.
- Hoffman, P., P. Slovic, et al. (1968). "An analysis-of-variance model for the assessment of configural cue utilization in clinical judgment." Psychological Bulletin **69**(5): 338-349.
- Hofmeister, C., P. Kruchten, et al. (2007). "A general model of software architecture design derived from five industrial approaches." Journal of Systems and Software **80**(1): 106-126.
- Hooley, G. J. and J. Saunders (1993). Competitive Positioning: The Key to Marketing Strategy. New York, NY, Prentice Hall.
- Ionita, M. T., P. America, et al. (2005). Method for Strategic Scenario-Based Architecting. 38th Hawaii International Conference on System Sciences.
- Ionita, M. T., P. America, et al. (2004). A Scenario-Driven Approach for Value, Risk, and Cost Analysis in System Architecting for Innovation. WICSA 2004.
- Jansen, A. and J. Bosch (2005). Software Architecture as a Set of Architectural Design Decisions. Fifth Working IEEE/IFIP Conference on Software Architecture (WICSA'05): 109-120.
- Kaplan, R. S. and D. P. Norton (1992). "The Balanced Scorecard: Measures That Drive Performance." Harvard Business Review **70**(1): 71-79.
- Kaplan, R. S. and D. P. Norton (2001). The Strategy-Focused Organization: How Balanced Scorecard Companies Thrive in the New Business Environment, Harvard Business School.
- Kaplan, R. S. and D. P. Norton (2004). Strategy Maps: Converting Intangible Assets into Tangible Outcomes, Harvard Business School.
- Kaplan, R. S. and D. P. Norton (2008). "Mastering the Management System." Harvard Business Review.
- Kazman, R., J. Asundi, et al. (2001). Quantifying the costs and benefits of architectural decisions. 23rd International Conference on Software Engineering. Toronto, Canada.
- Kazman, R., J. Asundi, et al. (2002). Making Architecture Design Decisions: An Economic Approach, Carnegie Mellon University

- Kazman, R. and L. Bass (2005). *Categorizing Business Goals for Software Architectures*, Carnegie Mellon University
- Keiningham, T. L., B. Cooil, et al. (2007). "A Longitudinal Examination of Net Promoter and Firm Revenue Growth." *Journal of Marketing* **71**: 39–51.
- Khurum, M., T. Gorschek, et al. (2008). *Systematic Review of Solutions Proposed for Product Line Economics. 2nd International Workshop on Measurement and Economics of Software Product Lines*. 2008. Limerick, Ireland.
- Kim, W. C. and R. Mauborgne (2005). *Blue Ocean Strategy: How to Create Uncontested Market Space and Make Competition Irrelevant* Harvard Business School Press.
- Kotler, P. and K. Keller (2008). *Marketing Management*, Prentice Hall.
- Kreuter, R., C. Lescher, et al. (2008). *Applying a Cost Model for Product Lines: Experience Report. 2nd International Workshop on Measurement and Economics of Software Product Lines*. Limerick, Ireland.
- Kruchten, P. (1999). *The Rational Unified Process, an Introduction*, Addison-Wesley.
- Laar, P. v. d., A. U. Douglas, et al. (2010). *Researching Evolvability. Views on Evolvability of Embedded Systems*. P. V. d. Laar and T. Punter, Springer.
- Lipshitz, R. and O. Strauss (1997). "Coping with Uncertainty: A Naturalistic Decision-Making Analysis." *Organizational Behavior and Human Decision Processes* **69**(2): 149-163.
- Luehrman, T. A. (1997). "What's It Worth?" *Harvard Business Review*.
- Malan, R. and D. Bredemeyer (2002). Chapter 1. *Software Architecture: Central Concerns, Key Decisions. Visual Architecture Action Guide Book*.
- Mintzberg, H. (1994). "The Fall and Rise of Strategic Planning." *Harvard Business Review*.
- Moore, M., R. Kazman, et al. (2003). *Quantifying the Value of Architecture Design Decisions: Lessons from the Field. 25th International Conference on Software Engineering*. Portland, Oregon, IEEE: 557-562.
- Muller, G. (2003). "Gaudi System Architecting Homepage." from <http://www.extra.research.philips.com/natlab/sysarch/>
- Nord, R. L., P. C. Clements, et al. (2009). *A Structured Approach for Reviewing Architecture Documentation*, Carnegie Mellon University
- Normann, R. and R. Ramirez (1993). "From Value Chain to Value Constellation: Designing Interactive Strategy." *Harvard Business Review* **71**.
- Ondategui-Parra, S., J. G. Bhagwat, et al. (2005). "Use of Productivity and Financial Indicators for Monitoring Performance in Academic Radiology Departments: U.S. Nationwide Survey." *Radiology* **236**(1).

- Ozkaya, I., L. Bass, et al. (2008). "Making Practical Use of Quality Attribute Information." IEEE Software.
- Ozkaya, I., R. Kazman, et al. (2007). Quality-Attribute Based Economic Valuation of Architectural Patterns. First International Workshop on the Economics of Software and Computation. Minneapolis, Minnesota, USA, IEEE.
- Ozkaya, I., R. Kazman, et al. (2007). Quality-Attribute-Based Economic Valuation of Architectural Patterns, Software Engineering Institute.
- Parnas, D. L., P. C. Clements, et al. (1984). The modular structure of complex systems. 7th International Conference on Software Engineering Orlando, Florida, United States.
- Pohl, K., G. Böckle, et al. (2005). Software Product Line Engineering: Foundations, Principles, and Techniques, Springer.
- Porter, M. (1980). Competitive Strategy. London, Macmillan.
- Rogers, E. M. (2003). Diffusion of Innovation, Free Press.
- Rommes, E. and P. America (2006). A Scenario-Based Method For Software Product Line Architecting. Software Product Lines - Research Issues in Engineering and Management. T. Käkölä and J. C. Dueñas, Springer: 3-52.
- Rommes, E., A. Postma, et al. (2005). A Framework for Measuring Architecting Effort and Its Application in Medical Imaging Systems Development. Fifth Working IEEE/IFIP Conference on Software Architecture (WICSA'05). Pittsburgh, PA.
- Schelling, T. (1980). The Strategy of Conflict, Harvard University Press.
- Schmid, K. (2003). A Quantitative Model of the Value of Architecture in Product Line Adoption. Fifth International Workshop on Product Family Engineering (PFE-5). Siena, Italy, Springer. **3014**: 32-43.
- Schmitt, N. (1997). Naturalistic Decision Making in Business and Industrial Organizations. Naturalistic Decision Making. C. E. Zsombok and G. Klein. Mahwah, New Jersey, Lawrence Erlbaum Associates.
- Schulz, A. P., E. Fricke, et al. (2000). Enabling Changes in Systems throughout the Entire Life-Cycle - Key to Success? . 10th annual INCOSE conference. Minneapolis, USA
- Shanteau, J. (1992). "How much information does an expert use? Is it relevant?" Acta Psychologica **81**(1): 75-86.
- Shanteau, J. (2000). Why Do Experts Disagree? Risk behaviour and risk management in business life. B. Green, R. Cressy, F. Delmaret al. Dordrecht, The Netherlands, Kluwer Academic Press: 186-196.
- Shapiro, A. C. (1989). "The Theory of Business Strategy." Rand Journal of Economics **20**: 12.

- SHARK. (2011). "SHARK workshop." from <http://www.shark-workshop.org/>.
- Slovic, P. (1969). "Analyzing the expert judge: A descriptive study of a stockbroker's decision process." *Journal of Applied Psychology* **53**(4): 255-263.
- Smit, H. T. J. and L. Trigeorgis (2004). *Strategic Investment: Real Options and Games*. New Jersey, Princeton University Press.
- Sullivan, K., P. Chalasani, et al. (1998). Software Design as an Investment Activity: A Real Options Perspective. *Real Options and Business Strategy: Applications to Decision Making*. L. Trigeorgis.
- Taleb, N. N. (2007). *The Black Swan: The Impact of the Highly Improbable*, Random House.
- Taudes, A. (1998). "Software Growth Options." *Journal of Management Information systems* **15**(1): 165-189.
- Tennent, J. and G. Friend (2005). *Guide to Business Modeling*, Bloomberg Press.
- Trigeorgis, L. (1996). *Real Options, Managerial Flexibility and Strategy in Resource Allocation*. London, The MIT Press.
- Tversky, A. and D. Kahneman (1974). "Judgment under Uncertainty: Heuristics and Biases." *Science* **185** (4157): 1124-1131.
- Tyree, J. and A. Akerman (2005). "Architecture decisions: demystifying architecture." *IEEE Software* **22**(2): 19-27.
- Unphon, H. and Y. Dittrich (2010). "Software architecture awareness in long-term software product evolution." *The Journal of Systems and Software*(83): 2211-2226.
- van der Linden, F., K. Schmid, et al. (2007). *Software Product Lines in Action*, Springer.
- Wang, T. and R. d. Neufville (2005). Real Options "in" Projects. *9th Real Options Annual International Conference*. Paris, France.
- Wernerfelt, B. (1984). "A Resource-Based view of the firm." *Strategic Management Journal* **5**: 9.
- Wesselius, J. H. (2005). Modeling Architectural Value: Cash Flow, Time and Uncertainty. *9th International Software Product Lines Conference*. Rennes, France.
- Yin, R. K. (2003). *Case study research: design and methods*, SAGE Publications.

Summary

Strategy-focused architecture investment decisions

Organizations have been investing the development of software-intensive systems, such as medical devices, airplanes, or satellite systems, for decades. Continuous quality improvements of these systems are critically important for a company's competitive advantage on the market and for business success. Investments in these system-quality improvements are called architecture investments. A decision to invest in system architecture requires a systematic evaluation of the trade-off between the strategic long-term benefits of architecture on the business and the required investments. It typically is a decision that is difficult to explain and quantify. In this sense, it is not surprising that such a decision is often driven by personal biases or the strong leadership of decision-makers, which leads to suboptimal decision-making processes in an organization. This doctoral dissertation, therefore, examines the following central research question: *Whether and how a systematic method for evaluating architecture investments can lead to decisions that are driven by business preferences rather than by personal biases in practice.*

This PhD thesis proposes a way in which to support the decision to invest in architecture by linking architecture improvements to the business strategy and by considering human factors.

The literature in chapter 2 reveals the theoretical challenges for decision-making in architecture investments. Supporting architecture evaluation is not straightforward because of the multidisciplinary perspectives for architecture investments: process, business, and individual. The *process* perspective highlights the need for the close involvement of architects and managers to evaluate the consequences of architecture design decisions on business value. Such a process should adequately accommodate the architect's and manager's information needs, aligning them both with business goals in a systematic manner. This would help prevent decisions from being based on information biased by individual motivations. Next, the *business* perspective involves the challenge of applying methods because of difficulties in identifying and quantifying the architecture value. However, little evidence on the use of such methods in practice would indicate a need to improve the support of architecture investment decisions by accommodating *individual* information needs and aligning them with business goals.

Built upon these challenges, we aimed to propose a method, based on best practices that would accommodate architects' and managers' information needs, aligning them with business goals to guide investment decisions. To reach this goal, we applied a hybrid research strategy (Yin 2003) that combined the strong points of case studies, interview data, and experimenting.

In the first study in chapter 4, we investigated *the practical challenges of architecture investment decision-making at Philips Healthcare and their relation to theoretical challenges* to draw boundaries for improvements in subsequent studies. The results of the two case studies revealed that practical challenges are similar to the theoretical ones described above. From a process perspective, the main challenge was to tightly incorporate architecture

“proof-of-concept”, project planning, and business case analysis into the joint activities of architects and managers. Currently, they are largely unrelated or separated, which was a threat to identifying the sources of architecture value. The study highlighted that architects and managers are somewhat biased by their expertise in the sense that they emphasize or overuse their own kind information to make decisions. When considering the business perspective, we were able to highlight advantages and pitfalls in applying the real options way of thinking. Consistent with results found in other studies, it was seen that a lack of guidance in quantifying customer value in the decision-making process is one of the main complications. Ultimately, we also identified an additional practical challenge: architecture evaluation has to follow the established processes in an organization, so improvements should be based on best practices to increase the adoption rate.

Individual perspectives on architecture investment decisions are addressed in a quantitative study to identify (1) *what kind of information architects and managers (say they) ask for in an architecture evaluation* (chapter 4) and (2) *whether professionals use the information they asked for and how individual characteristics (experience and roles) determine the use of information* (chapter 5).

In chapter 4, a quantitative analysis of ten interviews with architects and nine with managers at *Philips Healthcare* highlighted that architects and managers need large and different types of information to support a decision on architecture investments. To examine the extent to which the alleged necessary information is used and to define (if possible) the main determinants of architecture decisions, we conducted an experiment (chapter 5). In total, 114 practitioners worldwide were asked to decide on investing in one of two architecture scenarios based on a given architecture description and information inputs. The results showed that the identified information needs (in the interviews) were much richer than the information set used. Apparently, there was hardly any consensus about which kinds of information to use. One can see that this causes real danger, especially because architects are more likely to use information about quality and managers prefer information about sales. This implies that without a structured decision-making process, a decision might be based on the right information but the interpretation and use of that information might be driven by personal biases, such as development experience and the resilience to time pressure of individuals rather than by business needs. Thus, our results show a real need to identify relevant information and to determine how this information should be combined (for instance, through predefining decision rules).

Finally, based on the challenges and previous study findings, we propose to apply best practices in management and architecting to improve architecture evaluation within an industry-accepted time frame. To attach quantified values to architecture investments, we propose modeling customer value (chapter 6). Then we propose a method to support this new architecture evaluation process (chapter 7).

Customer-centric value modeling in chapter 6 exploited management tools—strategy maps and balanced scorecards—and adopted a marketing concept, customer value-in-use and customer segments to quantify the value of architecture changes. In two real-world architecture projects at *Philips Healthcare*, we demonstrated that although not trivial, it is possible to identify and quantify customer value. The use of customer-centric value is feasible when customer value is closely aligned with an organization’s business strategy

and the time spent on data collection is acceptable. Throughout both our case studies, our practitioners agreed that customer-value modeling was better than the existing value indicators to support architecture investment decisions. The main reason was that the existing value indicators were not tailored for architecture investment decisions, but were rather used because of their availability in the organization. Furthermore, the techniques used to assess the value indicators were biased by the stakeholders' expertise. In contrast to this, management tools such as strategy maps and balanced scorecards provided guidance in identifying the business measures (scorecards) independent of the expertise of the stakeholders. Unlike the management tools, acceptance of the marketing tools varied. Customer value-in-use was regarded as helpful only when the architecture design was optimized to create value for a single customer. In contrast, a customer segment concept was appreciated for two reasons. First, segmentation had already been used in practice to identify product market segments for a business case analysis, so practitioners were familiar with the idea. Second, customer segment concepts in our studies tended to provide more accurate data.

We tackled the main goal of this thesis: *to design guidelines for supporting a decision on architecture investments*, building on the findings of the previous studies, in chapter 7. First, acknowledging a need for the method to fit into existing processes, we used scenario analysis and business cases that were identified as “best practices” in architecture. We exploited the strategy map concept used in the previous study to map architecture decisions to business goals, as this concept allowed the kind of decision-making we envisaged and resonated well with practitioners. Given the controversial findings on information needs, we proposed to guide information selection based on business goals rather than on individual preferences by using a balanced scorecard tool. This led to a structured approach, integrating established management techniques (strategy maps and balanced scorecards), scenario methods, and business case analysis to support decisions on architecture investments. For ease of reference, we labeled this four-step method “Strategy-focused Architecture” (StArch). The StArch method was applied by an expert team on a project at *Philips Healthcare* that had been pending for several years, bringing consensus amongst the experts. StArch enabled architects and business managers to work jointly and agree on business goals, scorecards, and assumptions to estimate architecture value and make a recommendation. Strategy maps and balanced scorecard tools were the most appreciated, as it had been in customer value modeling. Satisfaction with the completeness of the information used in StArch was biased by people's roles. Even when people agreed on business-driven information, they tended to ask for additional data from their own perspective that would be inconsistent with the information needs of other experts. One main advantage of StArch is that it did not interfere much with existing business processes, requiring about 40 hours of effort (for investments of a size of 10 person years). Practitioners recommended using StArch for a week for projects with relatively large investments and a reasonably predictable impact of design decisions on the value.

Supporting strategy-focused architecture investment decisions is not a straightforward process in practice. On the contrary, it requires addressing a complex landscape of challenges including issues at the process, business, and individual level. In this thesis, we have tried to show that by addressing the challenges explicitly and by exploiting best practices, it is possible to improve the current state-of-the-practice with relatively small effort.

Acknowledgements

I lie in disbelief that my PhD journey is nearing its end. This is such a rewarding moment to think of and thank people who were part of this expedition professionally and privately.

Professional support

First, I thank Chris Snijders, my promoter and the main person responsible for shaping my empirical work to reach an even higher academic level. Undoubtedly, my journey would last much longer without Chris's sharp comments, excellent teaching skills, and calm demeanor, all of which helped tie my PhD together. Chris was open to my concerns and complaints, and despite his packed agenda, my emails would be answered promptly. His ability to synthesize a complex idea into a few short sketches always astounded me, and I remain indebted to him.

I must also thank Pierre America, my co-promoter. Pierre introduced me to Philips, the world of system architecture and the peculiarities of detail. He was willing to give me the freedom to explore my ideas without imposing his own views on me. I am also thankful for our amusing, yet meaningful, talks.

Beyond my official supervisors, I would like to thank the Embedded Systems Institute (ESI) for funding my PhD research and providing the support to conduct the survey. Under the watchful management of ESI, I became a part of the Darwin team, to whom I thank for a place to share our hopes and fears about the scientific and practical contributions of PhD assignments.

My research would not be possible without the case studies conducted at MRI business of Philips Healthcare, in Best, Netherlands, which was my primary PhD residence. Joland Rutgers, Nico van Rooijen, William van der Sterren, Frank Benschop, and Erik Meijer were my "buddies", patient to teach me about MRI system architecture, organization, and business. They helped me collect data, understand political issues, and shape my empirical results into a consistent story. I am also thankful to all my Philips colleagues and the survey participants worldwide for providing input to unveil the mysterious pieces of architecture investment decisions.

The analytical part of my PhD journey was spent at Phillips Research. My great gratitude goes to my group leaders, Jaap van der Heijden, who offered me a chance to do the PhD work, and Sybo Dijkstra, who supported my attendance at conferences and set targets to finalize this thesis. I also appreciated the crisp reviews of my work and informal chats at the coffee corner with my colleagues, which made me feel part of the group. I would especially like to thank the witnesses to my last PhD year, Rob van Ommering and the CDS4HF team. They showed great empathy for my PhD challenges and active support by reviewing and editing my papers, which became chapters of this book. My warmest thanks go to my secretary, Jet van Happen, who generously offered her ears for sour PhD stories and helped me navigate through a maze of complex organizational issues.

Finally, for the arty part of my work, I send my gratitude to Henny Herps and Lotta Partanen who were thinking with me to design a confident manager, who heads a maze of architecture investments (see the front cover), and to David Regeczi who spent sleepless nights to edit and give the final touch with amusing remarks to my thesis under tight deadlines.

Private support

My journey could not have been completed without people who shared my outside-the-office life on the cobblestone PhD road.

Above all, I would like to thank my parents for their support to finance my study in turbulent times in Serbia and their patience for my research career.

Vedran, my partner, also earned my deepest gratitude for his daily support in the last PhD year. I thank VedranKo for his warm words, warm food, and the warm nights of dancing and singing, and cool my brain down by getting me out for fresh air after long writing hours. It would be hard to imagine my PhD getting finished without such support.

My highest appreciation goes to my long-trusted girls who resisted my moody phases and remained my friends: Jelena, Natasa, Aleksandra and my sister Ivana. Many thanks to Jelena's diplomacy, Natasa's empathy, Aleksandra's can-do attitude and Ivana's different-points-of-views that helped me greatly navigate my PhD. I would also like to thank Mile for the 20 years of unequivocal belief in me (and in my PhD, more than myself) and cheering me up with endless talks about sailing boats.

During my PhD, I also met great people that enlightened my journey with new insights and emotions. I would like to thank Bjorn for our exciting talks and feeding my addiction for museum visits. My appreciation goes to Jan, who helped me understand the importance of people versus performance for my well-being. I am also thankful to Britt who introduced me to the Diversity and Inclusion (D&I) philosophy. My appreciation goes to the Philips Global I's network for the inspirational gatherings and offering me the possibility to drive D&I initiatives.

It is difficult not to mention my gratitude for time spent with dear friends, Dule, Lotta, Michael, Carla, Megumi, Andrew, Agnieszka, Justyna, Julia, Stefan and Isa, and Natasa and her family. My unforgettable moments of tango dancing I owe to the Eindhoven tango community (Scala). Finally, many thanks to other friends all around the world who are not listed by name.

Once I read from Orson Welles, "We're born alone, we live alone, we die alone. Only through our love and friendship can we create the illusion for the moment that we're not alone." Thank you all for sharing these illusions with me on my PhD journey!

Curriculum vitae

Ana Ivanovic was born in 1974 in Kragujevac, Serbia. She studied at the Faculty of Electrical Engineering at the University of Belgrade in Serbia. In 2000 she graduated within the Medical and Nuclear Techniques group on 2D reconstruction of medical computer tomography images. After that, she worked as a research assistant for a year at the Faculty of Technology and Metallurgy, Belgrade, Serbia.

In March 2001 she started her international career as a research scientist. First, she spent three years at the Department of Virtual Reality at the Fraunhofer Institute for Media Communication in Sankt Augustin, Germany, where she worked as a researcher on image-guided surgery using augmented reality and as a project leader. After that, she moved to The Netherlands to spend one and a half year at the Information Systems group at the University of Twente in Enschede. There, she studied how to gather customer requirements on ambient intelligent systems in highly uncertain environments, such as stress management systems in nomadic-office settings.

For the past five years she has worked on a PhD project at Philips Research at Eindhoven, The Netherlands. The project was a collaboration between Philips Research, Philips Healthcare, and Eindhoven University of Technology (TU/e). Her thesis (“Strategy-focused system-architecture investment decisions”) addresses improvements on system-architecture investment decisions in practice. Her research interests include system-architecture economics, expert’s decisions, and strategic decision-making. Part of the thesis is a paper, “Customer value in architecture decision making” that was awarded best paper at the 4th European Conference on Software Architecture (ECSA2010), Copenhagen, Denmark, 2010 and selected for a submission to the Journal of Software and Systems. Her primary interest these days is to drive healthcare innovation with a focus on clinical decision support and healthcare service consultancy at Philips Healthcare.