

Identifying Architectural Technical Debt in Embedded Systems: A Case Study

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Abstract

Who needs an abstract?

Sammendrag

Hvem trenger et sammendrag?

Preface

Here is the preface

Acknowledgements

I would like to thank Ingar Kulbranstad from Autronica for giving me this great opportunity.

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CHAPTER 1

INTRODUCTION

This chapter provides an introduction to this masters thesis. We begin with outlining the motivation and context for the research. Then a brief description of the research questions is presented. Thesis outline is presented in the last section.

1.1 Motivation and Background

Successful embedded systems continuously evolve in response to external demands for new functionality and big fixes [1]. One consequence of such evolution is an increase of issues in design, development, and maintainability("SITER COMPOSE: A composite embedded software approach"). Software code often ends up not contributing to the mission of the original intended software architecture. The main challenge with software evolution is the technical debt that is not paid by the organization during software development and maintenance. Technical debt addresses the debt that software developers accumulate by taking shortcuts in development in order to meet the organizations business goals. For example, a deadline may lead developers to create "non-optimal" solutions in order to deliver on time. When technical debt keeps accumulating, systems can become unmanageable and eventually unusable. More resources during software maintenance have to be spent on paying off the interest (the cost of having the debt). According to Gartner [2], the cost of dealing with technical debt threatens to grow to \$1 trillion globally by 2015. That is the double of the amount of technical debt in 2010. Furthermore, many embedded systems are getting interconnected within existing Internet infrastructure. This is known as Internet of Things. This has led to embedded systems threatened by security issues. Matthew Garret recently

revealed that he had access to the electronic equipment connected to a network in every hotel room in a hotel located in London.

Several studies has classified the metaphor of technical debt into different types of debt that are associated with the different phases of software development("siter noen artikler her"). Architectural technical debt is an example of a type of TD, which accumulates when compromises are made in software architecture level. Architecture plays a significant role in the development of large systems [3], and unlike code-level debt, architectural debt usually has more significant consequences [4].

This thesis builds upon our previous study "Managing Technical Debt in Embedded Systems" [5]. In our previous research, we wish to look deeper into a more narrow field by conducting a deeper case study with companies.

1.2 Research Design

The relevant research methods in software engineering can be survey, design and creation, case study, experimentation, action research, and ethnography [6]. In this study, literature review and case study have been used. Literature review was a part of the pre-study and has been used to get familiar with the term architectural technical debt and to define the research questions. Case studies are empirical methods used to investigate a single entity or phenomenon within a specific time space [7]. It can be both qualitative and quantitative [6,8].

The main research questions investigated in this thesis are:

1. **RQ1:** How can architectural technical debt be identified?
2. **RQ2:** Why does architectural technical debt accumulate?
3. **RQ3:** What are the effects of architectural technical debt?

1.3 Contrubution

Contribution: New knowledge about architectural technical debt in embedded software. How it differs from existing research.

1.4 Thesis Structure

The thesis is structured into several chapters with sections and subsections. The outline of the thesis is as follows:

- **Chapter 1:** Introduction contains a brief and general introduction to the study and the motivation behind it.
- **Chapter 2:** State-of-the-Art looks at important aspects of the research question.
- **Chapter 3:** Research Method describes how the literature review was carried out throughout the research, as well as a description of the case study to be performed.
- **Chapter 4:** Results presents the results from the case study, and takes a closer look at the findings from the case study.
- **Chapter 5:** Discussion contains a summarized look at the findings from the case study, and connects it with the literature review and to the research questions. An evaluation of the research is also given in this chapter.
- **Chapter 6:** Conclusion concludes the research by providing a summary of the most important points of the results and discussion chapter. Additionally, it outlines possible routes to take in the research field.

CHAPTER 2

STATE-OF-THE-ART

This chapter presents the state-of-the-art topics which are relevant to this thesis. Section 2.1 presents the metaphor of technical debt.

2.1 Technical Debt

The metaphor of technical debt was first introduced by Ward Cunningham in 1992 to communicate technical problems with non-technical stakeholders [9]. To deliver business functionality as quick as possible, *'quick and dirty'* decisions are often made. These decisions may have short-term value, but it could affect future development and maintenance activities negatively. Cunningham was the first one who drew the comparison between technical complexity and financial debt in a 1992 experience report [9]:

“Shipping first time code is like going into debt. A little debt speeds up the development as long as it is paid back promptly with a rewrite... The danger occurs when the debt is not repaid. Every minute spent on not-quite-right code counts as interest on that debt. Entire engineering organizations can be brought to a stand-still under the debt load of an unconsolidated implementation, object-oriented or otherwise.” - Ward Cunningham, 1992.

The concept refers to the financial world where going into debt means repaying the loan with interest [10]. Like financial debt, technical debt accrues interest over time. Interest is defined as the extra effort that has to be dedicated in the future development in order to modify the part of the software that contains technical debt [11–13]. Unmanaged technical debt can cause projects to face

significant technical and financial problems, which ultimately leads to increased maintenance and evolution costs [14].

2.1.1 Definitions of Technical Debt

Several researchers have attempted to give us a clear picture of what technical debt is [3, 15, 16]. Fowler [15] presents a technical debt quadrant which consists of two dimensions: *reckless/prudent* and *deliberate/inadvertent* [15]. Technical debt quadrant in Figure 2.1 indicates four types of technical debt: *reckless/deliberate*, *reckless/inadvertent*, *prudent/deliberate*, and *prudent/inadvertent*. Reckless/Deliberate debt is usually incurred when technical decisions are taken intentionally without any plans on how to address the problem in the future. A team may know about good design practices, but still implements ‘*quick and dirty*’ solutions because they think they cannot afford the time required to write clean code. The second type is reckless/inadvertent. It is incurred when best practices for code and design are being ignored, ultimately leading to a big mess of spaghetti code. Prudent/Deliberate debt occurs when the value of implementing a ‘quick and dirty’ solution is worth the cost of incurring the debt to meet a short-term goal. The team is fully aware of the consequences, and have a plan on how to address the problem in the future. At last, we have prudent/inadvertent debt. This type of debt occurs when a team realizes that the design of a valuable software could have been better after delivering it. A software development process is much as learning as it is coding.

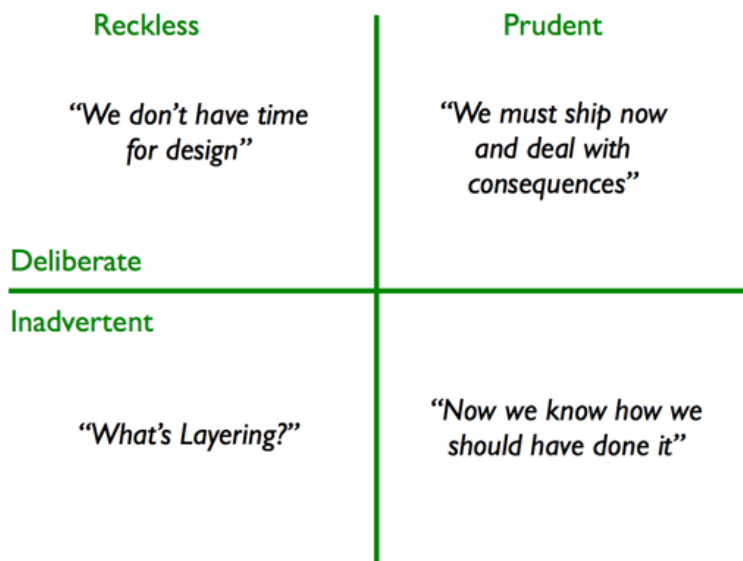


Figure 2.1: Fowler’s Technical Debt Quadrant

McConnell [16] classified technical debt as intentional and unintentional debt.

Intentional debt is described as debt that is incurred deliberately. For example, an organization makes a strategic decision that aims to reach a certain objective by taking a shortcut they are fully aware of. Intentional debt can further be viewed as short-term and long-term debt [17, 18]. Short-term debt is usually incurred reactively, for tactical reasons. Long-term debt is usually incurred proactively, for strategic reasons. Unintentional debt is described as debt that is incurred inadvertently due to lack of knowledge or experience. For example, a junior software developer may write low quality code that does not conform with standard coding standard due to low experience.

Krutchén et al. [3] presented a technical debt landscape for organizing technical debt. They distinguished visible elements such as new functionality to add or defects to fix, and the invisible elements that are only visible to software developers. On the left side of Figure 2.2, technical debt affects evolvability of the system, while on the right side, technical debt mainly affects software maintainability.

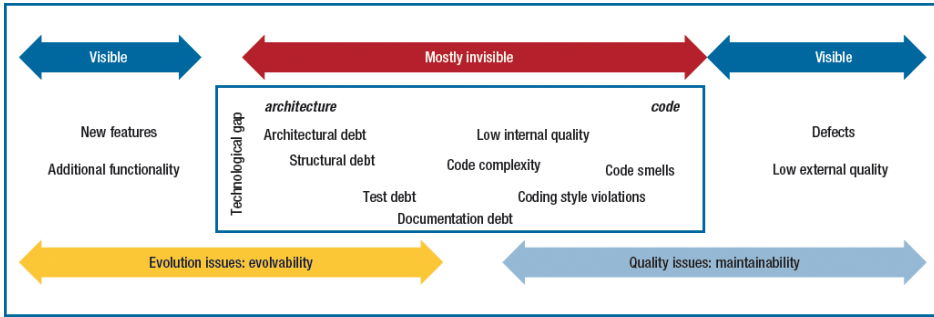


Figure 2.2: Technical Debt Landscape

2.1.2 Classification of Technical Debt

Technical debt can accumulate in many different ways, and therefore it is important to distinguish the various types of technical debt. Multiple studies [13, 17, 19–22] have pointed out several subcategories of technical debt based on its association with traditional software life-cycle phases; architectural debt, code debt, defect debt, design debt, documentation debt, infrastructure debt, requirements debt, and test debt. Table 2.1 lists the different subcategories of technical debt.

2.1.3 Causes and Effects of Technical Debt

Several researchers have investigated the reasons to incur technical debt. Klinger et al. [12] conducted an industrial case study at IBM where four technical architects with different backgrounds were interviewed. The goal was to examine how decisions to incur debt were taken, and the extent to which the debt provided

Table 2.1: Types of Technical Debt

Subcategory	Definition
Architectural debt [13, 17, 19]	Architectural decisions that make compromises in some of the quality attributes, such as modifiability.
Code debt [13, 19, 20]	Poorly written code that violates best coding practices and guidelines, such as code duplication.
Defect debt [13, 20]	Defect, failures, or bugs in the software.
Design debt [13, 19, 21]	Technical shortcuts that are taken in design.
Documentation debt [13, 19, 22]	Refers to insufficient, incomplete, or outdated documentation in any aspect of software development.
Infrastructure debt [13, 17, 20]	Refers to sub-optimal configuration of development-related processes, technologies, and supporting tools. An example is lack of continuous integration.
Requirements debt [13, 22]	Refers to the requirements that are not fully implemented, or the distance between actual requirements and implemented requirements.
Test debt [13, 19, 22]	Refers to shortcuts taken in testing. An example is lack of unit tests, and integration tests.

leverage [12]. The study revealed that the company failed to assess the impact of intentionally incurring debt on projects. Decisions regarding technical debt were rarely quantified. The study also revealed big organizational gaps among the business, operational, and technical stakeholders. When the project team felt pressure from the different stakeholders, technical debt decisions were made without quantifications of possible impacts.

Lim et al. [23] pointed out that technical debt is not always the result of poor developer disciplines, or sloppy programming. It can also include intentional decisions to trade off competing concerns during business pressure. Furthermore, Li et al. explains that technical debt can be used in short term to capture market share and to collect customers feedback early. In the long term, technical debt tended to be negative. These trade-offs included increased complexity, reduced performance, low maintainability, and fragile code. This led to bad customer satisfaction and extra working hours. In many cases, the short term benefits of technical debt outweighed the future costs.

Guo et al. [24] studied the effects of technical debt by tracking a single delayed maintenance task in a real software project throughout its life-cycle, and simulated how managing technical debt can impact the project result. The results indicated that delaying the maintenance task would have almost tripled the costs, if it had been done later.

Siebra et al. [25] carried out an industrial case study where they analyzed documents, emails, and code files. Additionally, they interviewed multiple developers and project managers. The case study revealed that technical debt were mainly

taken by strategic decisions. Furthermore, they commented out that using a unique specialist could lead the development team to solutions that the specialist wanted and believe were correct, leading the team to incur debt. The study also identified that technical debt can both increase and decrease the amount of working hours.

Zazworka et al. [26] studied the effects of god classes and technical debt on software quality. God classes are examples on bad coding, and therefore includes a possibility for refactoring [21]. The results indicated that god classes require more maintenance effort including bug fixing and changes to software that are considered as a cost to software project. In other words, if developers desire higher software quality, then technical debt needs to be addressed closely in the development process.

Buschmann [27] explained three different stories of technical debt effects. In the first case, technical debt accumulated in a platform started had growth to a point where development, testing, and maintenance costs started to increase dramatically. Additionally, the components were hardly usable. In the second case, developers started to use shortcuts to increase the development speed. This resulted in significant performance issues because an improper software modularization reflected organizational structures instead of the system domains. It ended up turning in to economic consequences. In the last case, an existing software product experienced increased maintenance cost due to architectural erosion. However, management analyzed that re-engineering the whole software would cost more than doing nothing. Management decided not to do anything to technical debt, because it was cheaper from a business point-of-view.

Codabux et al. [17] carried out an industrial case study where the topic was agile development focusing on technical debt. They observed and interviewed developers to understand how technical debt is characterized, addressed, prioritized, and how decisions led to technical debt. Two subcategories of technical debt were commonly described in this case study; infrastructure and automation debt.

These studies indicates that the causes and effects of technical debt are not always caused by technical reasons. Technical debt can be the result of intentional decisions made by the different stakeholders. Incurring technical debt may have short-term positive effects such as time-to-market benefits. Not paying down technical debt can result economic consequences, or quality issues in the long-run. The allowance of technical debt can facilitate product development for a period, but decreases the product maintainability in the long-term. However, there are some times where short-term benefits overweight long-term costs [24].

2.1.4 Identification of Technical Debt

Technical debt accumulation may cause increased maintenance and evolution costs. At worst, it may even cancel out projects. The first step towards managing technical debt is to properly identify and visualize technical debt items.

According to Zazworka et al. [28], there are four main techniques for identifying technical debt in source code: modularity violations, design patterns and grime buildup, code smells, and automatic static analysis issues.

Modularity Violation

Software modularity determines software quality in terms of evolveability, changeability, and maintainability [29], and the essence is to allow modules to evolve independently. However, in reality, two software components may change together though belonging to distinct modules, due to unwanted side effects caused by *'quick and dirty'* solutions [28, 30]. This causes a violation in the software designed modular structure, which is called a modularity violation. Wong et al. [30] identified 231 modularity violations from 490 modification requests in their experiment using Hadoop. 152 of the 490 identified violations were confirmed by the fact that they were either addressed in later versions of Hadoop, or recognized as problems by the developers. In addition, they identified 399 modularity violation from 3458 modification request of Eclipse JDT [30]. Among these violations, 161 were confirmed. Zazworka et al. [28] revealed that the average number of modularity violations per class in release 0.2.0 to release 0.14.0 of Hadoop ranged from 0.04 to 0.11. They identified 8 modularity violations in the first release of Hadoop and 37 in the last one. In addition, they revealed that modularity violations are strongly related to classes with high defect- and change-proneness.

Design Pattern and Grime Buildup

Patterns are known to be general solutions to recurrent design problems. They are commonly used to improve maintainability and architecture design of software systems. 23 design patterns are widely used in software development and is classified into three types: creational, behavioural, and structural. What each include.

nevn noen fordeler med bruk av design patterns.

However, software continuously evolve in response to external demands for new functionality. One consequence of such evolution is software design decay. Izurieta et al. [31] defines decay the deterioration of the internal structure of system designs. Furthermore, they define Design pattern decay as deterioration of the structural integrity of a design pattern realization. That is, as a pattern realization evolves, its structure and behavior tend to deviate from its original intent. Design pattern grime is a specific type of design pattern decay [31].

However, changes in the code base could lead to code ending up outside the pattern. This is known as design grime.

Code Smell

Some forms of technical debt accumulate over time in the form of source code [28]. Fowler et al. [32] describes the concept of code smells as choices in object-oriented systems that does not comply with the principles of good object-oriented design and programming practices. They are an indication of that some parts of the design is inappropriate and that it can be improved. Code smells are usually removed by performing one or more refactoring [32]. For instance, one such smell is "Long Method", a method with too many lines of code. This type of code smell can be refactored by 'Extract Method', by reducing the length of the method body [32].

Mäntylä et al. [33] proposes a taxonomy based on the criteria on code smells defined by Fowler et al. [32]. The taxonomy categories code smells into seven groups of problems: bloaters, object-oriented abusers, change preventers, dispensables, encapsulators, couplers, and others. The first class, Bloaters, represents large pieces of code that cannot be effectively handled. Object-oriented abusers is related to cases where the solution does not exploit the the possibilities of object-oriented design. Change preventers refers to code structure that considerably hinder the modification of software. Dispensables represent code structure with no value. Encapsulators deal with data communication mechanism or encapsulation. Couplers refers to classes with high coupling. The last group of problem is Other, which refers to code smells that does not fit into any of the other categories. This includes *Incomplete Library Class* and *Comments*. Table 2.2 lists all the code smells that are presented by Fowler et al. [32].

Several studies has been conducted to investigate the relationship between code smell and change-proneness of classes in object-oriented source code. A study by Olbrich et al. [34] revealed that different phases during evolution of code smells could be identified, and classes infected with code smells have a higher change frequency; such classes seem to need more maintenance than non-infected classes. Khomh et al. [35] investigate if classes with code smells are more change-prone than classes without smells. After studying 9 releases of Azureus and 13 releases of Eclipse, their findings show that classes with code smells are more change-prone than others.

Multiple approaches have been proposed for identifying code smells, ranging from manual approaches to automatic. Manual detection of code smells can be done by code inspections [36]. Travassos et al. [36] present a set of reading techniques that gives specific and practical guidance for identifying defects in Object-Oriented design. However, Marinescu [37] argue that manual code inspection can be time expensive, unrepeatable, and non-scalable. In addition, it is often unclear what exactly to search for when inspecting code [38]. Moreover, a study by Mäntylä revealed more issues regarding manual inspection of code. He states that manual code inspection is hard due to conflicting perceptions of code smells among the developers, causing a lack of uniformity in the smell evaluation.

Table 2.2: Code Smell Taxonomy

Code Smell	Group
Long Method	Bloaters
Large Class	Bloaters
Primitive Obsession	Bloaters
Long Parameter List	Bloaters
Data Clumps	Bloaters
Switch Statements	O-O Abusers
Temporary Field	O-O Abusers
Refused Bequest	O-O Abusers
Alternative Classes with Different Interfaces	O-O Abusers
Parallel Inheritance Hierarchies	O-O Abusers
Divergent Change	Change Preventers
Shotgun Surgery	Change Preventers
Lazy Class	Dispensables
Data Class	Dispensables
Duplicated Code	Dispensables
Speculative Generality	Dispensables
Message Chains	Encapsulators
Middle Man	Encapsulators
Feature Envy	Couplers
Inappropriate Intimacy	Couplers
Comments	Other
Incomplete Library Class	Other

Automatic approaches for identifying code smells reduce the effort of browsing through large amounts of code during code inspection process. Ciupke [38] propose an approach for detecting code smells in object-oriented systems. In this approach, code smells to be identified are specified as queries. The result of a queries is a piece of design specifying the location of the code smell in the source code. This approach was applied to several case studies, both in academical and industrial context. Their findings revealed that code smell detection can be automated to a large degree, and that the technique can be effectively applied to real-world code.

Another method for automatic detection of code smells is done by using metrics. Marinescu [37] propose a general metric-based approach to identify code smells. Instead of a purely manual approach, the use code metrics were proposed for detecting design flaws in object-oriented systems. This approach were later refined, with the introduction of detection strategies [39]. Based on their case study, the precision of automatic detection of code smells is reported to be 70%. Furthermore, a study by Schumacher et al. [40] investigated how human elicitation of technical debt by detecting god class code smells compares to automatic approaches by using a detection strategy for god classes. Their findings show that humans are able to detect code smells in an effective way if provided with a suitable process. Moreover, the the findings revealed that the automatic approach yield high recall and precision in this context.

Automatic Static Analysis Issues

Software tools play a critical role in the process of identifying technical debt. The identification of software design and code issues has been done with automatic static analysis code tools, by looking for violations of recommended programming practices that might cause faults or degrade some parts of software quality.

Mention the tools here, and its case study context.

Static analysis tools are able to alert software developers of potential problems in the source code.

SOFTWARE METRICS Proposed as quality indicator for software systems. Rien defined 61 object-oriented design heuristics characterizing

2.1.5 Strategies and Practices for Managing Technical Debt

Increasing awareness of technical debt

Detecting and repaying technical debt

Prevent accumulation of technical debt

2.2 Architectural Technical Debt

Bass et al. [41] defines software architecture as following:

The software architecture of a system is the set of structures needed to reason about the system, which compromise software elements, relations among them, and properties of both.

The architecture of a software is one of the most important artifacts within the systems life cycle [41,42]. Architectural design decisions that are made during the design phase, affect the systems ability to accept changes and to adapt to changing market requirements in the future. As the design decisions are made early, it will directly affect the evolution and maintenance phase [43], activities that consumes a big part of the systems lifespan [44]. Design changes are specifically related to the adaptive and corrective categories. The issues of software architecture has long been a concern for those building and evolving large software systems [45].

Architectural technical debt is regarded as implemented solutions that are sub-optimal with respect to the quality attributes defined in the desired architecture.

Architecture plays a significant role in the development of large systems [3].

Examples

2.2.1 Dependencies

2.3 Software Quality

2.4 Patterns

2.5 Software Evolution and Maintenance

Increasingly, more and more software developers are employed to maintain and evolve existing systems instead of developing new systems from scratch [46]. Lehman [47] introduced the study of software evolution. Software evolution is a process that usually takes place when the initial development of a software project is done and was successful [48]. The goal of software evolution is to incorporate new user requirements in the application, and adapt it to the existing application. Software evolution is important because it takes up to 85-90% of organizational software costs [46]. In addition, software evolution is important because technology tend to change rapidly.

Software maintenance is defined as *modifications of a software after delivery to correct faults, ti improve performance or other attributes, or to adapt the product*

Quality Attributes	Criteria	Description
Functionality	Suitability	
	Accuracy	
	Interoperability	
	Security	
Reliability	Maturity	
	Fault Tolerance	
	Recoverability	
Usability	Understandability	
	Learnability	
	Operability	
	Attractiveness	
Efficiency	Time behaviour	
	Resource utilization	
Maintainability	Analyzeability	
	Changeability	
	Stability	
	Testability	
Portability	Adaptability	
	Installability	
	Co-existence	
	Replaceability	
All		
	Compliance	

to a *modified environment* [49]. Maintenance can be classified into four types [48, 49]:

- Adaptive: Modification of a software product performed after delivery to keep a computer program usable in a changed or changing environment.
- Perfective: Modification of a software product after delivery to improve performance or maintainability.
- Corrective: Reactive modification of a software product performed after delivery to correct discovered faults.
- Preventive: Maintenance performed for the purpose of preventing problems before they occur.

Van Vliet [44] states that the real maintenance activity is corrective maintenance. 50% of the total software maintenance is spent on perfective, 25% on adaptive maintenance, and 4% on preventive maintenance. This leads to that 21% of the total maintenance activity is corrective maintenance, the 'real' maintenance [44]. This has not changed since the 1980s when Lientz and Swanson conducted a study on software maintenance [50]. The study points out that most severe maintenance problems were caused by poor documentation, demands from users for changes, poor meeting scheduled, and problems training new hires.

2.6 Software Reuse

2.7 Refactoring

2.8 Embedded Systems

2.8.1 Component Software

CHAPTER 3

RESEARCH METHODOLOGY

This chapter provides a brief introduction to research methods in software engineering, and describes the research conducted in the thesis. Section 3.1 describes the relevant research methods in software engineering. Section 3.2 describes the term research design. Section 3.3 presents the research questions that are to be answered, as well as the research design that are used to acquire the research data.

3.1 Research Methods in Software Engineering

Research is believed to be the most effective way of coming to know what is happening in the world [8]. Empirical software engineering is a field of research based on empirical studies to derive knowledge from an actual experience rather than from theory or belief [51]. Empirical studies can be explanatory, descriptive, or exploratory [7].

There are two types of research paradigms that have different approaches to empirical studies [7]; the qualitative, and the quantitative paradigm. Qualitative research is concerned with studying objects in their natural setting [7]. It is based on non-numeric data found in sources as interview tapes, documents, or developers' model. Quantitative research is concerned with quantifying a relationship or to compare two or more groups [7]. It is based on collecting numerical data.

To perform research in software, it is useful to understand the different research strategies that are available in software engineering. Oates [6] presents six different research strategies; survey, design and creation, case study, experimentation,

action research, and ethnography.

Survey focuses on collection data from a sample of individuals through their responses to questions. The primary means of gathering qualitative or quantitative data are interviews or questionnaires. The results are then analyzed using patterns to derive descriptive, exploratory, and explanatory conclusions.

Design and creation focuses on developing new IT products, or artifacts. It can be a computer-based system, new model, or a new method.

Case study focuses on monitoring one single 'thing'; an organization, a project, an information system, or a software developer. The goal is to obtain rich, and detailed data.

Experimentation are normally done in laboratory environment, which provides a high level of control. The goal is to investigate cause and effect relationships, testing hypotheses, and to prove or disprove the link between a factor and an observed outcome.

Action research focuses on solving a real-world problem while reflecting on the learning outcomes.

Ethnography is used to understand culture and ways of seeing of a particular group of people. The researcher spends time in the field by participating rather than observing.

3.2 Choice of Research Method

The main purpose of this research project is to gain an understanding about the nature of technical debt in software design and architecture, and its potential sources in embedded systems in order to improve the management of software evolution. Based on the research questions stated in Chapter 1, and our previous research, we wanted to conduct an exploratory case study to get deeper insight about the problem.

3.2.1 Case Study Method

Case study is an empirical method to investigate a single phenomenon within a specific time space in real-life context [7]. Case studies excels at bringing an understanding of why or how certain phenomena occur or to add strength to what is already known through previous research [7, 52]. Moreover, Runeson et al. [53] suggests case study as the most appropriate research method to use when exploring how a problem behaves in a real life context. In addition, they conclude that case study is suitable for software engineering research. There has been suggested systematic approaches for organizing and conducting a research successfully [52, 53]. According to Yin [54], a research design is an action plan

from getting here to there, where here is defined as the initial set of questions answered, and there is some set of conclusions about these questions. Moreover, a research design can be seen as a blueprint of research, dealing with at least four problems: what questions to study, what data are relevant, what data to collect, and how to analyze the results [54]. Soy [52] proposes six steps that can be used when carrying out a case study:

1. *Determine and Define the Research Questions:* The first step involves establishing a research focus by forming questions about the problem to the studied. The researcher can refer to the research focus and questions over the course of study.
2. *Select the Cases and Determine Data Gathering and Analysis Techniques:* The second step involves determining what approaches to use in selecting single or multiple real-life cases to examine, and which instruments and data gathering approaches to use. (whom we want to study, the case, cases, sample. and how we want to study it, design).
3. *Prepare to Collect Data:* The third step involves a systematic organization of the data to be analyzed. This is to prevent the researcher from being overwhelmed by the amount of data and to prevent the researcher from losing sight of the research focus and questions.
4. *Collect Data in the Field:* This step involves collecting, categorizing, and storing multiple sources of data systematically so it can be referenced and sorted. This makes the data readily available for subsequent reinterpretation.
5. *Evaluate and Analyze the Data:* The fifth step involves examining the raw data in order to find any connections between the research object and the outcomes with reference to the original research questions.
6. *Prepare the Report:* In the final step, the researcher report the data by transforming the problem into one that can be understood. The goal of the written report is to allow the reader to understand, question, and examine the study.

3.3 Case Context

We had the opportunity to work with Autronica.

AutroSafe is a high-end distributed fire alarm system. It was first released around year 2000. The software that is used in AutroSafe is written in C/C++. Project "Firmus" is the project name for the next generation AutroSafe. Firmus is a Latin word, which in English means: solid, firm, strong, steadfast, steady, stable, reliable, and powerful. The goal with "Firmus" is to replace the existing software

by using newer technologies. It is developed by Autronica Fire and Security. Their main office is located in Trondheim, Norway.

In this research, we have studied one system. This is a pilot project by the company with the purpose on replacing an existing system. The goal is to identify the technical debt before it gets worse. System description, language, commercial, usage, context. How it was selected.

To study the consequences of technical debt, we have chosen to study a commercial system. One of the disadvantages using commercial is the constraints associated with obtaining permission to mine and publish findings. This system is developed using C/C++, which makes data mining a challenge due to most tools available for data mining in this context operate on Java systems.

Summary of system: Written in C/C++ and has been in development since late 1990s. It is used widely on their products. We have studied a pilot project which goal is to use better design, technologies etc. This is a pilot project so it has not entered the evolution. Our goal is to identify technical debt that has accumulated recently, and we'd like to discover them before they get messy.

Tools that we have used: Various tools are used to mine data and understand the structure of the system studied. Eclipse plugins, Doxygen, etc. AltovaUML? A commercial suite of tools. UML design tool with the added functionality to produce UML diagrams from code.

How big the system is etc.

Lines: 88546 Lines of Code: 49287 Files: 461 Number of Packages Number of Classes Number of Interfaces Number of Methods Average Lines of Code per Class Developers on this project

3.4 Research Process

A research process provides a systematic approach on how to fulfill the goal of a research. In this study, we have chosen to follow the principles of the six steps defined by Soy [52], combined with the research process suggested by Oates [6].

Figure X illustrates the research process that has been used through this thesis.

3.4.1 Determine and Define the Research Questions

First, we need to set up the goals of this research by defining the research questions. In prior to our previous research [5], we are interested in getting deeper insight into the field of technical debt. As mentioned in Section 2.1.2, many subcategories of technical debt exists. With regards to that, we have chosen to investigate design debt in embedded systems.

Table 3.1: Research Questions

RQ1	How can design debt be identified?
RQ2	Why does design debt accumulate?
RQ3	What are the effects of design debt?
RQ4	What kind of design debt can be found in embedded systems?
RQ5	How to pay design debt?

In order to determine and define the research questions, we begin with an analysis of the state-of-the-art to determine what prior studies have determined about this topic, along with our experiences from our previous research. These research questions will be out primarily driving force through this research. We have defined three research questions RQ1-3 which are summarized in Table 3.1.

Literature Review

To define the research questions, and to design the case study, it was necessary to conduct a literature review.

3.4.2 Select the Cases and Determine Data Gathering and Analysis Techniques

To investigate the research questions, a representative context has to be chosen. With regards to that, we have chosen to conduct an exploratory and descriptive case study in real-life context to obtain knowledge about the problem to be studied. We had the opportunity to wok with Autronica Fire and Security in this study. "Firmus" is the project name for the next generation of AutoSafe. The main goal of this project is to replace the existing software that is used by AutoSafe today by adopting todays standards.

A company located in Trondheim were interested in this case study and collaborated with us by offering us a system to study. The case study was conducted on a system developed in C/C++., which we have briefly described in Section XX. Furthermore, the company provided us a workspace and multiple data sources. We had access to their source code, issue lists in Stash, system requirements, design and code documentation. Our data were mainly extracted from these sources using various tools. The system consists of multiple components. Due to our time limit, we focused on three of the biggest components in the system.

A part of the literature review was to get familiar with existing tools that has been used to address similar problems. In Section XX, we have listed each tool that has been used to extract relevant data in this case study. Doxygen is used by the company to generate and keep the documentation up-to-date. In order to

understand the system and how the different components interact, we spent some time analyzing the system documentation. Moreover, Doxygen can generate various diagrams such as inheritance diagrams, and dependency graphs. However, a downside with Doxygen is that it lacks a feature for interacting with the diagrams and graphs. Doxygen allows us to specify depth of the graphs that are generated, but they can become very large, which makes the graphs difficult to understand. Moreover, Doxygen does not provide full diagrams for internal dependencies in each component, it can generate dependencies for a chosen file. There are many tools that offers reverse engineering of C/C++ source code, so we decided to try out a few of them, including ArgoUML, Enterprise Architect, and Understand.

Some static analysis tools has been used to extract design problems at code level. These includes Understand, SonarQube, CppClean, CppDepend, CppCheck, and Sonargraph.

Data is collected from issue lists, and has been mapped to their corresponding components and source files in order to find which component we should look more at. This data will be compared to the data we have extracted using static analysis tools mentioned above.

3.4.3 Prepare To Collect Data

The third step in this case study is about preparing for data collection. Firstly, we need to review the system documentation in order to get familiar with the system and its components. Due to the time limit, we have chosen to collect data from three critical components using the tools listed in Section XX. We prioritize the components using the issue lists, and break down the components to identify bad design. Bad design includes god classes, dependency cycles, complex interfaces, and unused code in the components. A Word document is created to keep track of the extracted data so we can review it later for analysis. If any interviews would be needed, they would be set up and planned on this stage.

Selection of Tools

Various tools have been used to mine for data and understand the structure of the system studied. The following sections will describe the tools that has been used in this research.

Doxygen is a free software for generating documentation from annotated C++ sources. Doxygen has the ability to generate documentation in HTML or in Latex. Since the documentation is extracted from the source code, it is easier to keep the documentation up to date. In addition, Doxygen can be configured to extract the code structure from undocumented sources files, which makes it possible to visualize the relations between various elements in the software. Doxygen is used

by the company to keep the documentation up-to-date, and was therefore used in this project to learn about the system and to visualize the system.

ArgoUML is an open source UML modeling tool that includes support for all standard UML 1.4 diagrams [55]. ArgoUML features reverse engineering of C++ projects by reading C++ source files and generate and UML model and diagrams.

Enterprise Architect is a commercial UML modeling tool. It has the ability to produce UML diagrams from code. This tool was used to create class diagrams for each component, allowing us to identify possible class hotspots and design pattern realizations.

SonarQube is an open source platform for quality management of code. It has the ability to monitor different types of technical debt. It supports multiple languages through plugins, including Java, C/C++, JavaScript, and PHP. A downside with SonarQube is that some of the plugins requires a commercial license, and that some features included are not applicable for C++.

Understand is a commercial code static analysis tool. It supports dozen of languages, including Java, C/C++, Fortran and Python. Understand can help developers analyze, measure, visualize, and maintain source code. It includes many features, including dependency graph visualization of code, and various metrics about the code (e.g. coupling between object classes),.

CppDepend is a commercial static analysis tool for C/C++ code.

CppClean is an open source static analysis tool for C/C++ code. It attempts to detect problems in C++ that slow development in large code bases. Among many features, CppClean supports finding unnecessary `'#includes'` in header files, global/static data that are potential problems when using threads, and unnecessary function declarations.

CppCheck is another open source static analysis tool for C/C++ code. Unlike CppClean, CppCheck detects various kinds of bugs that the compilers normally do not detect, such as memory leaks, out of bounds, and uninitialized variables.

CCCC

SourceMonitor

Metrics

3.4.4 Data Collection

The fourth step of the research process is to execute the plan that was created in step three. During the case study, data is collected from multiple sources by using different tools to improve the reliability of the study. The first source of design flaws it to look for code smells. The second source is to analyze the various software and object-oriented metrics. The third source of evidence are interviews

to validate the results from first and second source, done at the end of the case study. The developers are interviewed using a semi-structured interview. This type of interview allow us to improvise and explore the course of the interview. The interview

Since Doxygen was not able to provide class diagrams for each component, or full dependency graphs for each component, we had to look for other tools. ArgoUML is an open source alternative to generate UML diagrams by reverse engineering C/C++ code. After comparing the results with Doxygen diagrams, we noticed that ArgoUML failed to generate some classes and relations between classes. This led us to the use of commercial software. Using Understand, we have extracted internal dependencies in components, and dependencies between components by reverse engineering C/C++ source code. There was two types of dependencies, direct and circular. We updated our word template with the circular dependencies. Moreover, Understand was able to generate full UML class diagrams. The class diagrams were used to identify complex interfaces, class hotspots etc.

Additionally, we conduct the necessary interviews.

3.4.5 Evaluate and Analyze the Data

In the fifth step of the case study, we will examine the data collected in fourth step. Validations and confirmations of the data needs to be done in a systematic way, and confirmations is needed to draw some valuable and conclusions about them.

We analyze the data by looking at the extracted data from the tools manually. Furthermore, we plot the findings into a word document. This was done to make the findings more accessible, and to interpret the data afterwards. The results are then compared with our findings from the literature review.

3.4.6 Prepare the Report

At last, the methods conducted will be reported through this thesis. This involves all the steps that we have gone through this thesis, including stating the problem, performing a literature review, listing the research questions, explaining data gathering and analysis techniques used, and a conclusion where research questions are answered and suggestions are made for further research. The report also includes findings from the literature review, and how they are related to our findings from the case study. At last, the report conclusion makes suggestions for further research, so that other researchers may apply these techniques in some other context to determine whether findings are similar to our research or not.

3.5 Summary of the Research Design

The research questions described in Section XX were answered using the case study methodology and a literature review. The literature review helped us getting familiar with the topic and to identify the tools needed to mine data. Furthermore, the case study was conducted in collaboration with a company located in Trondheim.

CHAPTER 4

RESULTS

This chapter presents the results of this study. The first section presents the participants. The main findings are presented in Section X.. Section X focuses the term technical debt. Finally, Section X reveals the way technical debt is managed.

4.1 Overview

In this study, we evaluated the design and software quality of the system. This study also addresses all of the research questions.

4.2 Issue List Resultsts

The first step was to examine the issue list in order to determine which of the components to look out for.

4.3 Tool Analysis

4.4 Code Smell Detection

As we explained in Chapter 2, one of the ways to identify design debt is to look at the number of code smells in the source code. Table [4.1](#) describes the number

Table 4.1: Number of Code Smells detected

Code Smell	Detected
Long Method	10
Large Class	8
Long Parameter List	15
Data Clumps	Bloaters
Switch Statements	O-O Abusers
Temporary Field	O-O Abusers
Refused Bequest	O-O Abusers
Alternative Classes with Different Interfaces	O-O Abusers
Parallel Inheritance Hierarchies	O-O Abusers
Divergent Change	Change Preventers
Shotgun Surgery	Change Preventers
Lazy Class	Dispensables
Data Class	Dispensables
Duplicated Code	Approximately 5% of the source code. 39 files affected
Speculative Generality	Dispensables
Message Chains	Encapsulators
Middle Man	Encapsulators
Feature Envy	Couplers
Inappropriate Intimacy	Couplers

of code smells that were identified using automatic and manual approaches.

4.4.1 Duplicated Code

Duplicated code is found by looking for a block of code that appears at multiple places in the source code, both internally in a file or in another file. Our results revealed that 39 files contains duplicated code. This determines 5% of the source code, roughly 4400 lines of code is duplicated. Table XX summarizes the

4.4.2 Large Class

4.4.3 Long Method

Looks for LOC of the method. A long method code smell is considered to be 200 LOC. Another tool using the rules: 30 LOC and 150+ lines reported 47 hits.

4.4.4 Long Parameter List

The minimum number of parameters is 6. 3 of them were considered as critical, one with 9 parameters and two with 12.

4.4.5 Speculative Generality

In addition, we record the number of false positive to further reflect the accuracy of the results. "False positive definition."

4.4.6 Dead Code

Dead Code is a code smell that is not mentioned by Fowler.

Unused variables, unused functions.

How did we study the different code smells, the approach and the results. The results from Table XX

As we see, there are many code smells detected. We take a closer look at some of the classes; presented in UML diagrams here:

4.5 Software Quality Metrics Results

The metrics used to measure the quality of the code is mostly based on the work of "AUTHOR NAME". They have proposed a set of static metrics that are designed to measure the quality of object-oriented software. These metrics are widely known, and the measurements we have are the following:

Table 4.2 summarizes the measurements over the project as a whole from the different tools. The results from the different tools reveals some differences in the measurements. For example, CCCC did not identify number of files in the project, but instead it identified number of non-trivial modules in the project. Non-trivial modules include all classes, and any other module for which member functions are identified. Furthermore, SonarQube identified 851 classes in the project. We can see that the difference between the results of amount of classes from SourceMonitor/Understand and SonarQube is big. In addition, SonarQube identified a total of 45153 statements in the source code, while Understand identified 35254 statements, which is pretty close to what SourceMonitor identified.

Using CCCC, we were able to measure information flow between the different modules. This is done by identifying and counting inter-module couplings in the module interfaces.

Table 4.2: Project Summary

	CCCC	SonarQube	Understand
Lines		88404	88546
Lines of Code (LOC)	46220	48693	49287
Number of Files (NOM)		461	461
Number of Modules (NOF)	459		
Classes		851	339
Functions		3111	2637
Statements		45153	22115 (executable)
McCabe's Cyclomatic Complexity (MVG)	3572	15266	
Comments (COM)	19705	15962	23017
LOC/COM (L_C)	2.346	3.05	2.141
MVG/COM (M_C)	0.181		
Information Flow Measure (inclusive) (IF4)	171493		
Information Flow Measure (visible) (IF4v)	166589		
Information Flow Measure (concrete) (IF4c)	3789		

Moreover, we gathered two types of metrics: Class metrics and file metrics. File metrics returns software quality metrics for the specific file, while class metrics contains metrics for each class. A file can contain multiple classes. We wish to look at the different metrics on each file to indicate if there is any weaknesses in that particular file and what classes the file contains. The metrics we measured are lines of code, complexity of file, average complexity per function, amount of functions, and max depth.

SonarQube class metric includes nested classes, enums, interfaces, and annotations. Understand and SourceMonitor class metric includes classes and struct keyword.

SonarQube has more accurate data on classes and functions, while SourceMonitor has more accurate data about statements.

Metrics for files: - Component / Filename - Lines of Code - Complexity - Complexity per function - Structure (classes, methods, statements) - Functions - Max depth

Object-Oriented Design Metrics

Several metrics have been proposed for OO systems by researchers. The best known suites of OO metrics was proposed by Chindabmer and Kemerer. The metrics proposed are Weighted Method per Class (WMC), Depth of Inheritance Tree, Response For a Class, Number Of Children, Lack of Cohesion of Methods, and Coupling Between Objects.

While size metrics are important for identifying large classes, size metrics alone

may not tell us why the classes are big. In addition to the file metrics, we also gathered data using other classes of metrics: WMC, DIT, NOC, CBO, LCOM, and CCN. Since the software contains a large number of classes, we chose to identify classes with abnormal values in their corresponding metrics.

Table XX lists the classes and their metrics we thought were interesting.

- LOC (Lines of Code) - WMC (Weighted Methods Per Class) - DIT (Depth of Inheritance Tree) - NOC (Number of Children) - Coupling (Various coupling metrics, such as afferent and efferent) - LCOM (lack of cohesion) - CCN (McCabe Cyclomatic Complexity) - CBO (Coupling between Objects)

Table X shows a sample of metrics for some of the classes.

A description of Software Metrics can be found in Section 2 in Chapter 2.

Table X shows the value of each software metric captured. For some of the metrics, the lower value, the better. Values that are presented in the table are average. The metrics calculation are from several static code analyzers, both open source and commercial: CppDepend, SourceMonitor, CCCC, Understand. All these software provides extensive numbers of software quality metrics. We will show the metrics that are related to the code smells; hence we do not show all the metrics here.

Our results show that (whats good and wrong with these metrics, what can be done).

4.6 Threats To Validity

4.6.1 Internal Validity

4.6.2 External Validity

4.6.3 Construct Validity

CHAPTER 5

DISCUSSION

CHAPTER 6

CONCLUSION

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