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Avoiding Software Decay in Military Software Development

by

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List of Abbreviations

BSI	Federal Office for Information Security
CI	Continuous Integration
CI/CD	Continuous Integration/Continuous Delivery
CD	Continuous Delivery
CPM	Customer Product Management
DOD	Department of Defense
EVB-IT	Ergänzende Vertragsbedingung für die Beschaffung von IT-Leistungen
NRC	National Research Council
QA	Quality Assurance
SASPF	Integrated Standard-Application-Software-Product Family
TDD	Test Driven Development
UI	User Interface
VS-NFD	Verschlusssache - Nur für den Dienstgebrauch
XP	Extreme Programming

List of Symbols

1 Introduction

Software Decay describes the gradual deterioration in software quality and maintainability, which creates significant challenges across various software domains. The challenges become even more pronounced in environments where the systems are expected to operate for decades, such as in military software context. The motivation for this thesis stems from observations of the difficulties of managing aging software projects, particularly in the military domain. Over time the systems become increasingly problematic to maintain and modify, which highlights the importance of proactively maintaining the software quality and thereby ensuring long-term viability.

The long system lifecycle is very common in military software projects, which need to be robust and dependable, while also having regulatory requirements, high security standards and complex stakeholder demands. With these unique factors in mind, usual software engineering practices to mitigate software decay could face limitations and require certain adaptions. Therefore this thesis specifically investigates how software decay can be prevented or slowed down with the specific requirements of the German military sector.

The main research question of this thesis is:

How can software decay in military systems be prevented or slowed down?

To answer this overarching question, the following sub-questions have been formulated:

- What are the main causes and symptoms of software decay specific to the military software domain?
- Which mitigation strategies are currently in use at T-Systems IFS, Chapter Defense Systems, and how effective are they?

The main goal of this thesis is to identify the specific constraints influencing software decay within military software projects and to evaluate existing practices that could effectively mitigate the decay. Through a literature review and a semi-structured expert interview conducted with three practitioners form T-Systems IFS, Chapter Defense Systems, the thesis uses both theoretical and practical insights to answer the research questions.

The thesis is structured as follows: Initially a literature review is conducted to establish the theoretical foundation. This includes general information about software decay and technical debt, as well as common mitigation strategies and unique constraints in the military domain. The second part of the thesis presents the methodology and explains the research design and analysis of the expert interviews. In the third part, the findings of the interviews are presented in key themes derived from the data. These findings are further interpreted and discussed in the fourth part of the thesis, which integrates the theoretical insights with the practical findings. Concluding, the final chapter synthesizes the key findings of the research, highlighting the implications for practitioners, as well as limitations and future research opportunities.

The primary audiences for this thesis include industry practitioners in the military software domain, as well as stakeholders from military institutions seeking to understand and improve their long-term software management practices.

2 Literature Review

2.1 Problems of Software Engineering

Software has become an integral part of our daily lives. Certain expectations exist regarding the quality of software in terms of reliability, security and efficiency. These expectations come with challenges for the software developers across all industries. For decades, software engineers have tried to develop methods and guides to overcome these issues. However, in 1986 Frederick Brooks published his paper 'No Silver Bullet' in which he argues that: '...building software will always be hard. There is inherently no silver bullet.'[1]. He based this statement on the fact that there two types of difficulties in software development: the essential and the accidental. The essential difficulties he names are complexity, conformity, changeability and invisibility.

With complexity, Brooks wants to describe the inherit intricacy of software systems: 'Software entities are more complex for their size than perhaps any other human construct, because no two parts are alike'.[2] This complexity makes 'conceiving, describing and testing them hard'[3].

The second essential difficulty Brooks names is conformity. To explain this, he compares software development to physics. Even though they are similarly complex, physics has the advantage of relying on a single set of laws or 'creator'. The same cannot be said for software engineers. Brooks claims that the complexity is 'arbitrary [...], forced without rhyme or reason by the many human institutions and systems to which his interfaces must

[1] *Brooks, F.*, No Silver Bullet, 1987, p. 3.
[2] Ibid., p. 3.
[3] Ibid., p. 3.

conform'[4]. This is due to software being perceived as 'the most comfortable'[5] element to change in a system.
Brooks explains the third issue, changeability, by comparing software to other products like cars or computers. With these types of products, changes are difficult to make once the product is released. Software however is just 'pure thought-stuff, infinitely malleable.'[6] Another major issue regarding changeability is the fact that software often 'survives beyond the normal life of the machine vehicle for which it is first written'[7]. This means that software has to be adapted to new machines causing an extended life time of the software.
Invisibility is the last essential difficulty Brooks names. With this he means the difficulty to visualize software compared to other products. This not only makes the creation difficult but also 'severely hinders communication among minds'[8]. According to Brooks, these issues are in 'the very nature of software'[9]. These difficulties are unlikely to be solved, in comparison with the accidental difficulties.

In contrast, the accidental difficulties arise from limitations of current languages, tools and methodologies. According to Brooks, this involves issues such as inefficient programming environments, suboptimal development processes and integration challenges which can be overcome as the industry improves its practices and technologies.[10] For example, the adaptation of agile methodologies, integrated development environments and continuous integration have helped to overcome some of these accidental difficulties.

The persistent nature of these challenges presented by Brooks have since been substantiated by further empirical research. For instance, Lehman and Ramil (2003) discussed in their paper 'Software evolution—Background, theory, practice' that software systems which are left unchecked will experience a decline in quality over time.[11] This phenomenon is encapsulated in Lehman's laws of software evolution, which he formulated in multiple papers. Lehman and Ramil present empirical observations supporting the notion that software quality tends to deteriorate over time[12] - a phenomenon often described as software decay.

[4] *Brooks*, *F.*, No Silver Bullet, 1987, p. 4.
[5] Ibid., p. 4.
[6] Ibid., p. 4.
[7] Ibid., p. 4.
[8] Ibid., p. 4.
[9] Ibid., p. 2.
[10] Ibid., pp. 5–6.
[11] *Lehman*, *M. M.*, *Ramil*, *J. F.*, Software Evolution, 2003, p. 34.
[12] Ibid., p. 42.

2.1.1 Software Decay

The term software decay or erosion was empirically studied and statistically validated by Eick et al. in their influential paper 'Does Code Decay? Assessing the Evidence from Change Management Data'(2001). They begin by stating that 'software does not age or "wear out" in the conventional sense.'[13] If nothing in the environment changes, the software could run forever. However, this is almost never the case as there is a constant change in several areas, predominantly with respect to the two areas of the hard- and software environments and the requirements of the software.[14]

The previous statement is in accordance with the first two laws of Program Evolution Dynamics formulated by Belady and Lehman (1976). The first law states: 'A system that is used undergoes continuing change until it is judged more cost effective to freeze and recreate it.'[15] Building on this, their second law declares: 'The entropy of a system (its unstructuredness) increases with time, unless specific work is executed to maintain or reduce it.'[16]

The analysis of Eick et al. provide empirical validation for these theoretical laws, offering 'very strong evidence that code does decay.'[17] This conclusion is based on their findings that 'the span of changes increases over time'[18] meaning that modifications to the software tend to effect increasingly larger parts of the system as the software evolves. This growth in the span of changes indicates and potentially leads to a breakdown in the software's modularity. Consequently the software becomes 'more difficult to change than it should be,'[19] measured specifically by three criteria: cost of change, time to implement change and the resulting quality of the software.[20] Therefore, the combination of theoretical insights from Lehman and Belday and empirical data from Eick et al. paints a clear picture: software decay is an inevitable consequence of ongoing evolution unless consciously and proactively managed through structured efforts such as continuous refactoring and architectural vigilance.

[13] *Eick*, *S. G.* et al., Does Code Decay?, 2001, p. 1.
[14] Ibid., p. 1.
[15] *Belady*, *L.*, *Lehman*, *M.*, Large Program Development, 1976, p. 228.
[16] Ibid., p. 228.
[17] *Eick*, *S. G.* et al., Does Code Decay?, 2001, p. 7.
[18] Ibid., p. 7.
[19] Ibid., p. 3.
[20] Ibid., p. 3.

The concept of software decay aligns closely with earlier theoretical discussions by David Parnas (1994). In his influential paper 'Software Aging', Parnas describes software aging as a progressive deterioration of a program's internal quality primarily due to frequent, inadequately documented modifications which he termed 'Ignorant surgery'[21], as well as the failure to continuously adapt the architecture to evolving needs which he called 'Lack of movement'[22]. Without this proactive maintenance and refactoring effort, Parnas argues that software inevitably reaches a state where changes become more risky, costly and error-prone[23].

2.1.2 Technical Debt

The term 'Technical Debt' was first coined by Ward Cunningham in his paper 'The WyCash Portfolio Management System' (1992). This metaphor was used to describe the trade-off between a quickly implemented solution and a thought-out process. Using the quick solution 'is like going into debt.'[24] Cunningham argues that this debt accumulates interest if not repaid or rewritten. If this does not happen, Cunningham warns that 'Entire engineering organizations can be brought to a stand-still under the debt load of an unconsolidated implementation'[25].

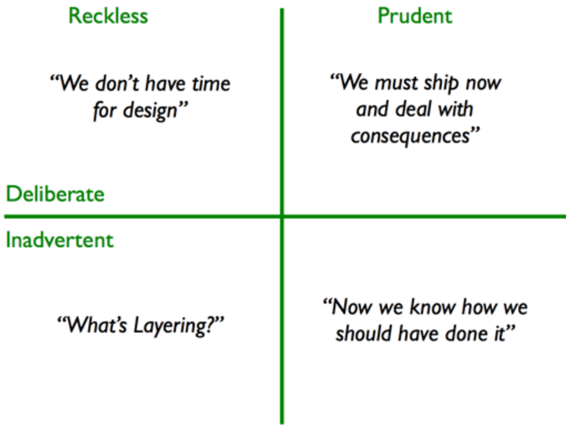
This term was further built upon and refined by the industry through white papers like 'Technical Debt' by Steve McConnell (2008) or the 'Technical Debt Quadrant' by Martin Fowler (2009). McConnell differentiates between two types of technical debt: Unintentional and Intentional[26]. The first results from bad code, inexperience or unknowingly taking over a project with technical debt. The second type is taken on purpose 'to optimize for the present rather than for the future.'[27] As the first is not planned, it is difficult to avoid. The second type, however, can be managed and controlled.

Additionally, McConnell differentiates between different types of intentional debt. According to him, debt can be taken on a short-term or long-term basis. The short-term debt is taken on to meet a deadline or to deliver a feature. Therefore it is 'taken on tactically or reactively'[28]. The long-term debt on the other hand is more strategic and is taken on to help the team in a larger context. The difference between those two is that short-term

[21] *Parnas*, *D. L.*, Software Aging, 1994, p. 280.
[22] Ibid., p. 280.
[23] Ibid., pp. 280–281.
[24] *Cunningham*, *W.*, WyCash Portfolio, 1992, p. 2.
[25] Ibid., p. 2.
[26] *McConnell*, *S.*, Managing Technical Debt, 2017, p. 3.
[27] Ibid., p. 3.
[28] Ibid., p. 3.

debt 'should be paid off quickly, perhaps as the first part of the next release cycle'[29], while long-term debt can be carried by companies for years.

Figure 1: Fowler's Technical Debt Quadrant


Reckless
Prudent
"We don't have time for design"
"We must ship now and deal with consequences"
Deliberate
Inadvertent
"What's Layering?"
"Now we know how we should have done it"

Martin Fowler, on the other hand, warned against taking on too much deliberate debt. He argues that 'Even the best teams will have debt to deal with as a project goes on - even more reason not to overload it with crummy code.'[30] He created a quadrant between reckless and prudent and deliberate and inadvertent debt. For Fowler, the difference between reckless and prudent is the way the debt is taken on. Reckless debt happens without an appropriate evaluation of the consequences, risking difficulties in the future. Alternatively, prudent debt is taken on with the trade-offs in mind and the knowledge of the future costs. Fowler differentiates between deliberate and inadvertent in a similar way to McConnell's differentiation between intentional and unintentional debt. The various combinations of these four elements in the quadrant results in four different approaches. Reckless and deliberate would mean quick solutions without considering the long-term impact. Reckless and inadvertent results in flawed design or implementation, either carelessly or unknowingly. Prudent and deliberate is purposefully taking on debt to gain a short-term advantage with plans of repayment and finally prudent and inadvertent means taking on debt due to lack of knowledge or experience.[31]

In their article 'Technical Debt: From Metaphor to Theory and Practice' (2012) Kruchten et al. criticize the concept of technical debt to be 'somewhat diluted lately'[32], stating that every issue in software development was called some form of debt. Therefore they set out to

[29] *McConnell*, *S.*, Managing Technical Debt, 2017, p. 4.
[30] *Fowler*, *M.*, 2009.
[31] Ibid.
[32] *Kruchten*, *P.*, *Nord*, *R. L.*, *Ozkaya*, *I.*, Technical Debt, 2012, p. 18.

define ‘a theoretical foundation’[33] for technical debt.
Kruchten et al. state that technical debt has become more than the initial coding shortcuts and rather encompasses all kinds of internal software quality comprises.[34] According to them, this includes architectural debt, ‘documentation and testing’[35] as well as requirements and infrastructure debt. All these debt types allow engineers to better discuss the trade-offs with stakeholders and to make better decisions.

TODO: IMPORTANT add Kruchten and theory of compliace driven environemnts

There have been many studies providing empirical evidence for the theoretical concepts of technical debt. Highly influential studies were undertaken by Potdar and Shihab (2014) as well as by Li et al. (2015).
In their study Potdar and Shihab analyzed four large open source projects to find self-admitted technical debt as well as the likelihood of debt being removed. They found that ‘self-admitted technical debt exists in 2.4% to 31% of the files.’[36] Additionally, they found that ‘developers with higher experience tend to introduce most of the self-admitted technical debt and that time pressures and complexity of the code do not correlate with the amount of the self-admitted technical debt.’[37] They also discovered that ‘only between 26.3% and 63.5% of the self-admitted technical debt gets removed’[38]. This relatively low removal rate of self-admitted technical debt indicates a wider challenge: developers recognize the issues of their implementation, but defer remediation potentially leading to a major impact on long-term maintainability.
Another approach to provide empirical evidence towards technical debt was taken by Li et al. . They conducted a systematic mapping study to ‘get a comprehensive understanding of the concept of "technical debt"’[39], as well as obtaining an overview of the current research in the field. Areas of investigation included existing types of technical debt (TD), the effect of technical debt on software quality and quality attributes (QAs) as well as the limit of the technical debt metaphor.
They established that the ‘10 types of TD are requirements TD, architectural TD, design TD, code TD, test TD, build TD, documentation TD, infrastructure TD, versioning TD and defect TD.’[40] Additionally they found that ‘[m]ost studies argue that TD negatively affects the maintainability [. . .] while other QAs and sub-QAs are only mentioned in a handful of

[33] *Kruchten*, *P.*, *Nord*, *R. L.*, *Ozkaya*, *I.*, Technical Debt, 2012, p. 19.
[34] Ibid., p. 19.
[35] Ibid., p. 20.
[36] *Potdar*, *A.*, *Shihab*, *E.*, Self-Admitted Debt, 2014, p. 1.
[37] Ibid., p. 1.
[38] Ibid., p. 1.
[39] *Li*, *Z.*, *Avgeriou*, *P.*, *Liang*, *P.*, Mapping of Technical Debt, 2015, p. 194.
[40] Ibid., p. 215.

studies'[41].

During their studies, Li et al. observed that the inconsistent and arbitrary use of the term 'debt' among researchers and practitioners can cause confusion and hinder effective management of technical debt.[42] Additionally practitioners 'tend to connect any software quality issue to debt, such as code smells debt, dependency debt and usability debt.'[43] This indicates an inflationary use of the term, which is important to keep in mind when speaking about technical debt.

The implications these studies have for the software industry are significant. They show that software decay and technical debt are tangible and measurable in real world software projects. In their paper 'Software complexity and maintenance costs' (1993) Banker et al. empirically demonstrated that 'software maintenance costs are significantly affected by the levels of existing software complexity.'[44] This finding emphasizes the important of proactively managing the software quality and addressing debt early in the project lifecycle, to keep the complexity and therefore cost to a minimum.

To address these effects, practitioners strongly recommend refactoring. Fowler argued in his book 'Refactoring: Improving the Design of Existing Code' (2019) that '[w]ithout refactoring, the internal design - the architecture - of software tend to decay.'[45] To prevent this, he suggests '[r]egular refactoring [to] help[s] keep the code in shape'[46].

To prevent long-term issues, practitioners recommend actively managing technical debt through refactoring, tracking and other strategies that integrate debt management into the software development process.

2.1.3 Conclusion

This chapter has outlined the foundational challenges inherent to software engineering and introduced two critical concepts: software decay and technical debt. Drawing on Frederick Brooks' distinction between essential and accidental difficulties, it becomes evident that complexity, changeability and lack of uniformity are deeply rooted in the nature of software itself and cannot be fully resolved. These enduring challenges are the foundation of the

[41] *Li*, *Z.*, *Avgeriou*, *P.*, *Liang*, *P.*, Mapping of Technical Debt, 2015, p. 215.
[42] Ibid., p. 211.
[43] Ibid., p. 212.
[44] *Banker*, *R.* et al., Software Complexity, 1993, p. 12.
[45] *Fowler*, *M.*, Refactoring, 2019, p. 58.
[46] Ibid., p. 58.

concepts of software decay and technical debt.

Software Decay refers to the gradual degradation of a software system's internal quality, leading to reduced maintainability, increased complexity and higher change effort. This is a natural outcome of continuous system evolution in a response to changing requirements and environments. As shown through empirical work of Eick et al. and the theoretical contributions of Lehman and Parnas, software that is not actively maintained becomes harder to main, less modular and more fragile, making decay a systematic and long-term threat to software sustainability.

On the other hand, technical debt captures the intentional or unintentional compromises made during software development that create short-term advantages but lead to long-term costs. Originating as a metaphor, it has since evolved into a structured framework for describing, architectural design, code or process-related liabilities. While software decay can be seen as a developing property of ongoing change, technical debt often originates from conscious decisions. Whether this is due to deadlines, insufficient knowledge or lack of resources, it manifests through debt like code quality deterioration, architectural erosion or insufficient testing.

Importantly, technical debt and software decay are closely related: unmanaged technical debt accelerates software decay, while software decay can lead to the accumulation of technical debt. Empirical studies from Potdar, Li and Banker confirm the measurable impact of these phenomenon on maintenance costs, defect rates and overall system quality.

To effectively manage these issues, the software industry has developed strategies that go beyond reactive maintenance. Structured, proactive practices such as continuous refactoring, rigorous quality assurance, technical debt management and large scale testing are essential to prevent the accumulation of debt and decay. Based on these foundations, the next chapter will explore concrete mitigation strategies in commercial environments providing a comprehensive overview of the most common strategies, techniques and frameworks used in the industry to address technical debt and software decay.

2.2 Mitigation Strategies in Commercial Environments

As discussed in the previous section, technical debt and software decay have been recognized as significant challenges in the software industry. They can lead to increased maintenance costs, reduced software quality and decreased developer productivity, overall resulting in a more expensive and less competitive product. With these challenges in mind, practitioners and researchers have developed a variety of strategies which manage, prevent and mitigate technical debt. This section will provide an overview of the most common strategies, techniques and frameworks used in commercial environments to address technical debt. This will be viewed on different levels: high-level strategies, code-level practices, architectural level as well as process and organizational measures.

2.2.1 High-Level Mitigation Strategies

To efficiently mitigate software decay and technical debt, proactive management strategies are essential. These strategies aim to prevent the accumulation of debt and address software entropy and decay directly by integrating quality assurance into everyday development process. Such strategies include Agile methodologies like Scrum or Extreme Programming (XP) as well as technical practices such as Continuous Integration/Continuous Delivery (CI/CD). These practices are designed to embed ongoing maintenance and quality assurance into routine workflows, thus combating software entropy at its core.

Agile methods emphasize frequent iterations, close collaboration between developers and stakeholders as well as continuous refactoring to prevent the gradual degradation of software quality and mitigation of software decay.

Similarly, CI/CD introduces rigorous automation, rapid feedback loops and early detection of defects to proactively control both technical debt accumulation and broader software quality decay. Collectively, these methodologies create a culture of continuous improvement, adaptability and quality assurance, ensuring software maintainability and long-term project sustainability.

2.2.1.1 Agile Methodologies

In their paper ‘Technical Debt Management in Agile Software Development: A Systematic Mapping Study’ (2024)[47] Leite et al. investigated how agile methods can be used to

[47] *Leite*, *G. d. S.* et al., Technical Debt Management in Agile Software Development, 2024.

manage technical debt. They found that '…Scrum and Extreme Programming are the most utilized methodologies for managing technical debt.'[48] While this study focuses explicitly on technical debt, both Scrum and XP also inherently address the broader issue of software decay by encouraging proactive quality management and continuous improvement practices.

Scrum was first presented by Ken Schwaber in his paper 'SCRUM Development Process' (1997)[49]. It has since become one of the most popular agile frameworks in the software industry. Scrum explicitly manages software quality and technical debt through iterative cycles called sprints. After each sprint, the team reflects on their work, identifies quality issues, technical debt and potential decay indicators and plans improvements in retrospectives. Leite et al. found that the most used artifacts for identifying technical debt in Scrum are the Sprint and Product Backlog.[50] By explicitly managing these items with their workflow, teams effectively reduce both debt and software entropy, improving overall software maintainability.

XP was first introduced by Kent Beck in his influential book 'Extreme Programming Explained' (1999)[51]. It explicitly integrates practices to enhance software quality and directly prevent software decay. XP practices such as pair programming, Test Driven Development (TDD), Continuous Integration (CI) and continuous refactoring help maintain high software quality, thus preventing both debt accumulation and broader software entropy. Pair programming prevents decay by securing higher-quality code through collaborative review and knowledge sharing between developers. CI provides regular, frequent code integration, significantly reducing integration complexity and associated decay risks. TDD establishes robust test coverage, catching defects early and preventing quality erosion. The effectiveness of refactoring, a cornerstone XP practice, has been proven empirically. For example, in their case study (2008) Moser et al. demonstrated that refactoring explicitly 'prevents an explosion of complexity'[52] and promotes simpler, easier-to-maintain designs. They found it drove developers toward simpler designs, reducing complexity, coupling and long-term maintenance issues thereby directly counteracting software decay.[53] Beck argues that XP's incremental, continuous quality practices consistently maintain software quality and adaptability throughout development, directly addressing both debt and broader software decay.

[48] *Leite*, *G. d. S.* et al., Technical Debt Management in Agile Software Development, 2024, p. 318.

[49] *Schwaber*, *K.*, SCRUM Process, 1997.

[50] *Leite*, *G. d. S.* et al., Technical Debt Management in Agile Software Development, 2024, p. 315.

[51] *Beck*, *K.*, Extreme Programming Explained, 1999.

[52] *Moser*, *R.* et al., Case Study Refactoring, 2008, p. 262.

[53] Ibid., p. 262.

On the whole, agile methodologies, particularly Scrum and XP, systematically manage technical debt and proactively prevent software decay by fostering continuous improvement, structured quality management and adaptability. Complementing these Agile practices, the adoption of automated CI/CD pipelines further enhances the proactive management of both technical debt and broader software decay through rigorous quality control and systematic automation.

2.2.1.2 Continuous Integration/Continuous Deployment

CI was first introduced by Beck in the context of XP and later refined by Martin Fowler in his influential article ‘Continuous Integration’[54]. Fowler describes CI as not only the frequent, automated integration of code into the main repository but also the systematic automation of building and testing process. According to Fowler, ‘Self-testing code is so important to Continuous Integration that it is a necessary prerequisite.’[55]. Furthermore, another critical prerequisite is ‘that they can correctly build the code,’[56] thus guaranteeing that code changes consistently integrate without issues.

To further prevent technical debt and broader software decay by maintaining a specific code quality, quality analysis tools such as static code analyzers like SonarQube or DeepSource are frequently integrated into CI pipelines. These tools often provide a metric to evaluate technical debt which is calculated based on the effort in minutes to fix the found maintainability issues.[57] In their paper ‘Technical Debt Measurement during Software Development using Sonarqube: Literature Review and a Case Study’ (2021)[58] Murillo et al. found that SonarQube is a useful tool for early debt detection. The estimated remediation effort metric allows for a good debt management prioritization.[59] However during their research they noticed if they changed SonarQubes default rules by just 26 rules, the technical debt effort would increase from 1 hours and 50 minutes to 11 hours.[60] This issue, together with the fact that SonarQube can only detect code related debt if correctly configured as well as no other debt such as infrastructure or requirements debt, makes these tools useful but not a complete solution.

[54] *Fowler*, *M.*, 2006.
[55] Ibid.
[56] Ibid.
[57] *SonarQube*, 2025.
[58] *Murillo*, *M. I.*, *Jenkins*, *M.*, Technical Debt Measurement Sonarqube, 2021.
[59] Ibid., p. 5.
[60] Ibid., p. 4.

Continuous Delivery (CD), introduced by Jez Humble and David Farley in their foundational book ‘Continuous Delivery: Reliable Software Releases through Build, Test and Deployment Automation’ (2010) extends CI by automating the entire software release pipeline. CD ensures that the software is always in a releasable state. According to Humble and Farley, implementing a functional CD pipeline ‘creates a release process that is repeatable, reliable and predictable’[61]. Beyond predictability, additional significant benefits include team empowerment, deployment flexibility and substantial error reduction. Specially, CD effectively reduces errors, particularly those introduced by poor configuration management, including problematic areas such as ‘configuration files, scripts to create databases and their schemas, build scripts, test harnesses, even development environments and operating system configurations’[62].

2.2.2 Code-Level Practices for Preventing Decay

On the code level, a variety of practices can be used to prevent software decay and technical debt. The two major practices have been previously introduced: continuous refactoring and maintaining software quality.

The benefits of refactoring have been demonstrated in the previous section. However, deeper empirical research illustrates the impacts and challenges in a commercial environment. Kim et al. (2014) observe in their paper ‘An empirical study of refactoring challenges and benefits at Microsoft’ that ‘[d]evelopers perceive that refactoring involves substantial cost and risks’[63]. Additionally they describe the benefits refactoring brings as ‘multidimensional’[64]. Furthermore it is not consistent across different metrics, leading to their recommendation of a tool to monitor the impact of refactoring across these metrics[65]. Similarly, Tempero et al. (2017) established certain barriers to refactoring in their study ‘Barriers to refactoring’. They found that at least 40% of the developers in their study would not refactor classes, even though they thought it would be beneficial.[66]

Tempero et al. claims the reasons were ‘lack of resources, of information identifying consequences, of certainty regarding risk and of support from management’[67] even though developers did not state a lack of refactoring tools as a reason. To eliminate these barriers, Tempore et al. suggest refactoring should be goal-oriented instead of operations-oriented

[61] *Humble*, *J.*, *Farley*, *D.*, Continuous Delivery, 2010, p. 17.

[62] Ibid., p. 19.

[63] *Kim*, *M.*, *Zimmermann*, *T.*, *Nagappan*, *N.*, Refactoring Challenges, 2014, p. 17.

[64] Ibid., p. 17.

[65] Ibid., p. 17.

[66] *Tempero*, *E.*, *Gorschek*, *T.*, *Angelis*, *L.*, Barries to Refactoring, 2017, p. 60.

[67] Ibid., p. 60.

and a better quantification of the benefits refactoring should bring to better reach a decision.[68]

Both studies show that the theoretical benefits of refactoring are not always directly translated into the industry. Developers often perceive refactoring as risky and costly, even though they are aware of the benefits.

TDD is another code-level practice previously introduced. It was first formally described by Kent Beck in his book 'Test Driven Development: By Example' (2002) in which he argues that writing tests before the implementation encourages cleaner code and gives developers the confidence to tackle complex problems.[69] This practice promotes modularity, testability and clean design, key characteristics in preventing software decay. By focusing solely on code that fulfills predefined tests, developers are guided toward creating small and focused code, which is loosely coupled. These qualities make systems easier to maintain and refactor, directly counteracting long-term degradation. Multiple studies have confirmed the quality-enhancing effects of TDD. In an empirical study, Mäkinen and Münch (2014) found that TDD most commonly led to a reduction in defects and increased maintainability, although its effect on overall software quality was more limited.[70] Importantly, they note that TDD significantly improves test coverage, a key factor in preventing unintentional decay. These gains, however, were accompanied by higher development effort.[71]

This is consistent with the case study by Bhat and Nagappan (2006), who reported a 15-35% increase in development time when using TDD.[72] However they also observed that 'the resulting quality was higher than teams that adopted a non-TDD approach by an order of at least two times.'[73] Similarly, Bhadauria et al. (2020) confirm TDD's positive effect on code quality and defect reduction. Interestingly, their study found that for less experienced developers, TDD did not lead to increased development time and was associated with higher developer satisfaction.[74]

These findings indicate that TDD can significantly improve code quality and maintainability two critical factors in preventing software decay. However, the trade-off in development effort and time must be carefully considered, which may explain TDD's limited adoption in the industry.

[68] *Tempero*, *E.*, *Gorschek*, *T.*, *Angelis*, *L.*, Barries to Refactoring, 2017, p. 61.

[69] *Beck*, *K.*, Test-Driven Development, 2002, pp. 8-9.

[70] *Mäkinen*, *S.*, *Münch*, *J.*, Effects of TDD, 2014, p. 13.

[71] Ibid., p. 13.

[72] *Bhat*, *T.*, *Nagappan*, *N.*, Evaluating the Efficacy of Test-Driven Development, 2006, p. 361.

[73] Ibid., p. 361.

[74] *Bhadauria*, *V.*, *Mahapatra*, *R.*, *Nerur*, *S.*, Performance Outcomes of Test-Driven Development, 2020, p. 1058.

2.2.3 Architectural Strategies for Long-Term Quality

In addition to code-level practices, the maintenance of the software architecture is essential for preventing software decay and architectural-level technical debt. Architecture erosion, characterized by increasing divergence from the intended design due to continuous modifications and changing requirements, significantly impacts maintainability and introduces substantial technical debt.[75] One common strategy to mitigate these risks, is architecture conformance checking, a process ensuring code changes comply with predefined design rules. De Silva and Balasubramaniam (2012) emphasize that proper documentation, dependency analysis and compliance monitoring are critical prerequisites for effectively employing this strategy.[76]

Beyond mere conformance, teams must also embrace managed architectural evolution, adapting architectures systematically rather than reactively. Such evolution should actively balance new requirements with long-term sustainability to avoid uncontrolled erosion.[77] A key component in this proactive approach is managing the architectural technical debt. These structural design decisions could impact future adaptability if not carefully controlled. Besker et al. (2016) suggest a framework to systematically identify, analyze and address architectural debt to preserve structural integrity.[78]

Nevertheless, when architectural decay becomes substantial, teams face critical decisions between incremental refactoring and radical redesigns. Nord et al. (2012) highlight that systematic impact analysis, guided by explicit architectural metrics, is crucial for making informed decisions on when substantial redesign becomes necessary to substantially restore software quality.[79]

Practical tooling, such as automated architectural monitoring and recovery solutions, plays a significant supportive role in these efforts. The detailed application and empirical evidence of such tools issue discussed thoroughly in the subsequent section on Tool Support for Continuous Quality Assurance.

In summary, proactively maintaining software architecture is essential for mitigating long-term software decay. Architecture conformance checking prevents the inadvertent erosion by ensuring adherence to established design principles. Managed architectural evolution further ensures that the architecture can sustainably adapt to changing requirements without introducing uncontrolled structural degradation. Moreover, explicitly recognizing

[75] *De Silva*, *L. R.*, *Balasubramaniam*, *D.*, Controlling Software Architecture Erosion, 2012, p. 1.

[76] Ibid., p. 135.

[77] *Li*, *R.* et al., Understanding Software Architecture Erosion, 2022, p. 34.

[78] *Besker*, *T.*, *Martini*, *A.*, *Bosch*, *J.*, Managing Architectural Technical Debt, 2018, p. 11.

[79] *Nord*, *R. L.* et al., Managing Architectural Technical Debt, 2012, p. 99.

and managing architectural technical debt enables targeted interventions before significant decays occurs. Ultimately, strategic decisions on refactoring versus comprehensive redesign should be guided by systematic architectural analysis, metrics and empirical evaluations to ensure long-term maintainability and quality.

2.2.4 Process and Organizational Measures

Organizational and process-oriented practices form the third pillar in combating software decay. One crucial practice is the management of technical debt. Many companies track technical debt items like outdated modules, quick fixes or known architectural shortcomings. This can be done through issue trackers or backlogs to allow for structured approach and time allocation to address them regularly. An industry-wide survey conducted by Ramač et al. (2021) found that 47% ‘had some practical experience with TD identification and/or management’[80]. By visualizing and tracking technical debt, teams can prioritize and address debt items systematically, preventing their accumulation and broader software decay. Ramač et al. also found that the most common cause for technical debt was time pressure caused by deadlines[81] and the ‘single most cited effect of TD is delivery delay.’[82] This indicates that time pressure is not only a cause of technical debt but also a consequence, leading to a vicious cycle of debt accumulation and delivery delays. To break this cycle, a balance of new development and maintenance is crucial to prevent a border software decay.

Another important practice is conducting regular code reviews as part of the development workflow. This practice dates back to 1976 when Michael Fagan reviewed the benefits of peer code inspections.[83] He found that ‘inspections increase productivity and improve final program quality.’[84] Since then, code reviews have become more lightweight compared to the inspection proposed by Fagan, increasing participation. By removing in-person meetings and reviewer checklists, accelerating and simplifying the process, code reviews have become a standard practice in software development and usually occur before code is merged into the main repository. McIntosh et al. (2016) investigated the impact of code reviews on software quality by comparing the review coverage, participation and expertise of the reviewer against the post-release defects.[85] They found that coverage, while important,

[80] *Ramač*, *R.* et al., Prevalence, Common Causes and Effects of Technical Debt, 2021, p. 40.
[81] Ibid., p. 40.
[82] Ibid., p. 40.
[83] *Fagan*, *M. E.*, Code Inspections, 1976, p. 183.
[84] Ibid., p. 205.
[85] *Mcintosh*, *S.* et al., Impact Code Review, 2016, p. 6.

is not the only factor that influences the post-release defects.[86] They state that ‘review participation should be considered when making integration decisions.’[87] Additionally, they recommend that if an expert in the matter is not available for the original code, they should be included in the review process to prevent defects.[88]

In conclusion, structured approach to managing technical debt and preventing software decay is crucial to maintain software quality and long-term project sustainability. Process-integrated practices like code reviews, explicit technical debt control and a culture of continuous refactoring create an environment that proactively manages software decay and technical debt.

2.2.5 Tool Support for Continuous Quality Assurance

To further support the proactive management of software decay, technical debt and the overall code health over time, a variety of tools have established themselves in the industry. Automated quality assurance tools are often integrated into modern development processes. A common approach, as previously mentioned, is the use of CI pipelines. These can be used in combination with quality gates which use static code analysis to block additions to the code base that do not meet the quality standards e.g. a certain code coverage, complexity or maintainability threshold. This allows developers to catch issues early and rectify them before they are introduced into the code base . While the concept of quality gates is not new, the automation of these gates have recently been investigated by Uzunova et al. (2024). They found that these gates can serve as a check point to assess software metrics like code coverage, bug density or compliance with coding standards.[89] To allow for this kind of automation, they suggest tools like SonarQube, Sigrid or Maverix.ai. These tools provide real-time feedback allowing for an enforcement of quality criteria.[90] Utilizing this approach enables developers to catch issues early and prevent the introduction of technical debt and software decay into the codebase.

As discussed in a previous section, ensuring that changes do not divert from the original architecture design is crucial to prevent the erosion of the architecture. To support this, tools have been developed to automatically detect architecture violations. These tools are able to collect information about the architecture from the source code and compare it to

[86] *Mcintosh*, *S.* et al., Impact Code Review, 2016, p. 39.
[87] Ibid., p. 39.
[88] Ibid., p. 39.
[89] *Uzunova*, *N.*, *Pavlič*, *L.*, *Beranič*, *T.*, Quality Gates, 2024, p. 8.
[90] Ibid., p. 8.

the proposed architecture.[91] In their case study ‘Evaluating an Architecture Conformance Monitoring Solution’ (2016), Caracciolo et al. investigated three different tools to detect architecture violations: SonarQube, Sonargraph and TeamCity[92]. They concluded that their approach ‘can be applied in an industrial context.’[93] They furthermore argue that the tools can be conveniently added to a dashboard, allowing for a short feedback loop as well as proactive management of architectural violations.[94] These benefits can be seen in their case study, where they observed that the overall violations decreased from 606 to 600 in an 18 year old system with one million lines of code[95]. Based on these project parameters Caracciolo et al. ‘consider that to be a positive outcome.’[96]

Numerous empirical studies show the effectiveness of these tools. In their paper ‘Empirical investigation of the influence of continuous integration bad practices on software quality’ (2022), Silva and Bezerra found that ‘CI can improve software quality, especially about cohesion.’[97] However they also observed the impact of bad practices in the implementation of CI. They found that the quality levels were incorrectly set and the standard configuration tools were used instead of adjusting them to the project needs, which overall harmed the software quality indicators.[98] This indicates that, for the tools to be effective, they need to be correctly configured and adjusted to the project needs.

2.2.6 Synthesis of Commercial Mitigation Strategies

Effectively managing software decay and technical debt requires a balanced combination of technical, architectural and organizational strategies. At the highest level, Agile methodologies and CI/CD frameworks foster proactive maintenance cultures, reducing entropy through incremental improvement and automated quality assurance. On the code level, disciplined practices such as continuous refactoring and TDD have empirically demonstrated their effectiveness in maintaining modularity, testability and reducing technical debt - with the downside of a higher development effort. Architectural strategies complement these by ensuring structural integrity through systematic conformance checks, managed

[91] *Thomas*, *J.*, *Dragomir*, *A. M.*, *Lichter*, *H.*, Architecture Conformance Checking, 2017, p. 6.
[92] *Caracciolo*, *A.* et al., Evaluating Architecture Monitoring, 2016, p. 43.
[93] Ibid., p. 44.
[94] Ibid., p. 44.
[95] Ibid., p. 43.
[96] Ibid., p. 43.
[97] *Silva*, *R. B. T.*, *Bezerra*, *C.*, CI Bad Practices, 2022, p. 4.
[98] Ibid., p. 4.

evolution and explicit handling of architectural technical debt, especially as the scale or requirements of projects evolve.

Organizational measures such as technical debt tracking, dedicated maintenance cycles and structured code reviews provide essential process-level support, enabling teams to systematically prioritize and address decay risks before they escalate. Finally, the strategic use of modern quality-assurance tools, integrated into CI pipelines and architectural monitoring systems, ensures continuous, automated and actionable feedback, thereby enabling developers to maintain software quality proactively. Ultimately, integrating these diverse practices into a combined quality culture is vital for sustainable software development, reduced maintenance costs and the long-term viability of software products.

2.3 Unique Constraints in Military Software Development

2.3.1 Introduction to Military Software Context

Software development for military significantly differs from commercial software due to unique demands for high reliability, rigorous security and extended system lifecycles. The National Research Council (NRC) book ‘Reliability Growth: Enhancing Defense System Reliability’ (2015) highlights the differences between commercial and military software development.

According to the NRC there are three main distinctions. The first regards the ‘sheer size and complexity of defense systems’[99]. These systems often have a vast amount of individual elements which need to work together, and also evolve over time as the architecture between the different stages of the lifecycle changes.[100] In addition, the NRC highlights the fact that new systems have to interact with legacy systems, which can be a challenge due to the different technologies and architectures used.[101]

The second distinction is the different perspectives of the actors involved. Unlike in the commercial environment, where it is usually only the project manager who controls the vision and the goals of the project, in the military environment there are multiple stakeholders with different goals in mind.[102] Although the book specially focuses on the American military, the same can be said for the German military.

The third difference given by the NRC are the concerns risk. In the commercial environment,

[99] *National Research Council*, Comparison Defense Commerical, 2015, p. 31.

[100] Ibid., p. 32.

[101] Ibid., p. 32.

[102] Ibid., p. 32.

the manufacturer has a self-interest in the product being successful and reliable. In the military environment, however, the government is the customer and often holds most of the risk, as they will be using the product in the end. The NRC claims that this means 'the system developers do not have a strong incentive to address reliability goals early in the acquisition process'[103]. especially because the downstream benefits are not quantifiable for the developers.[104]
In her presentation on 'A perspective on military software needs', Heidi Shyu highlights additional challenges in military software development. She argues that, in addition to the complex setting, there are often a multitude of contractors working together, who must interoperate with each other in real time.[105] These projects often have a lifecycle of decades compared to the commercial software lifecycle of a few years.[106] Due to these long lifecycles, the software needs to be developed so it can be easily maintained and updated, while still working with legacy systems which often have very specific requirements.[107] Whereas the the architecture has to last for decades, soft- and hardware changes much faster, often resulting in a patchwork of quick fixes.[108] Heidi Shyu provides examples of necessary software solutions such as a flexible architecture which allows for easy updates and additions, self-testing modular code and intuitive, easy-to-use interfaces.[109]

In summary, these challenges in military software development are unique to the industry. The vast size and complexity of defense systems, their long lifecycles and the multitude of stakeholders involved all serve to create a complex environment that requires specialized strategies to manage software decay and technical debt effectively.

2.3.2 Regulatory and Procurement Constraints in the Bundeswehr

The procurement and regulatory environment significantly shapes military software development in the German Armed Forces (Bundeswehr). Unlike in commercial settings, Bundeswehr software projects are tightly governed by formalized frameworks, rigorous approval processes and comprehensive regulations designed primarily to ensure accountability, security and reliability. However, these structures can inadvertently limit agility, prolong software updates and contribute significantly to software decay and technical

[103] *National Research Council*, Comparison Defense Commerical, 2015, p. 33.
[104] Ibid., p. 33.
[105] *Shyu*, *H.*, Military Software Needs, 2017, p. 11.
[106] Ibid., p. 14.
[107] Ibid., p. 14.
[108] Ibid., p. 15.
[109] Ibid., p. 17.

debt over time.

Bundeswehr software utilizes the ‘V-Modell XT Bw’ as the project lifecycle model. It is a customized variant of the standard V-Modell XT, specifically tailored to Bundeswehr needs and closely integrated with the Bundeswehr’s overarching procurement framework, Customer Product Management (CPM). The V-Modell XT Bw is a comprehensive framework that encompasses the planning and execution of software projects in the Bundeswehr.[110] It includes detailed guidelines for all parts of the software development process, from roles and requirements engineering to Quality Assurance (QA) and product quality.[111] However, due to its rigid and sequential nature, the waterfall-based V-Modell XT Bw is known to limit flexibility, making iterative adjustments and agile methodologies not possible.

The procurement procedures of the Bundeswehr are outlined by the aforementioned CPM which was revised in 2012 after a commission in 2010 found that: ‘Die Streitkräfte erhalten ihre geforderte Ausrüstung zumeist weder im erforderlichen Zeit- noch im geplanten Kostenrahmen.’[112]. Due to these problems, the revised CPM has an increased focus on upfront requirement definition and comprehensive risk assessments. This creates long lead times for approval and makes quick technological changes difficult to realize. In addition, the Ergänzende Vertragsbedingung für die Beschaffung von IT-Leistungen (EVB-IT), the standardized contract for government IT solutions, hinders agile development. In his article from 2022, Holger Schröder claims that multiple different contract blueprints would have to be combined to allow for an agile development project.[113]

Collectively, all these requirements and procurement constraints strongly influence software development practices. Control and predictability are prioritized, making an iterative and agile framework difficult to use. While these procedures promote accountability and reduce risk, they can severely limit a system’s ability to evolve over time, thereby fostering conditions under which software decay and technical debt accumulate. Adding to this complexity are strong security and compliance requirements, which will be discussed in the following subsection.

[110] *Bundeswehr*, V-Modell Bw, 2013, p. 6.

[111] Ibid., pp. 20-21.

[112] *Strukturkommission der Bundeswehr*, Strukturkommissionsbericht Bundeswehr, 2010, p. 36.

[113] *Schröder*, *H.*, Agile Beschaffungsprojekte, 2022.

2.3.3 Security and Compliance Requirements

Military software is obliged to meet stringent security and compliance standards beyond the usual commercial requirements. Due to the sensitive nature of military operations and data, the software must adhere to both national and NATO standards. These strict requirements result in severe difficulties regarding the lifecycle of the product, the software architecture and maintenance practices. The resulting constraints accelerate the accumulation of technical debt and software decay.

Like all federal agencies in Germany, the Bundeswehr must adhere to the Federal Office for Information Security (BSI) guidelines for IT security, called IT-Grundschutz[114]. This defines a comprehensive security framework that includes technical, personnel and infrastructural security measures through the use of several standards. Eventhough these standards Compliance with these standards involves extensive documentation, risk management processes and regular audits. This leads to an increase in the complexity and effort required for ongoing software maintenance and updates.[115]

In addition to the national regulations, Bundeswehr software systems are obligated to comply with the NATO security standards. These guidelines establish requirements for the handling of classified data, encryption standards and security clearance of personnel. This is illustrated by the NATO Security Policy (C-M(2002)49) which dictates the handling of NATO-classified information, constraining software flexibility and maintenance practices[116]. Compliance with NATO standards mandates extensive security accreditation procedures, detailed documentation and comprehensive vetting of software and hardware systems. These processes slow down software development cycles and restrict flexibility due to the necessity of re-certifying software after significant changes.

Furthermore the Bundeswehr adheres to national classification rules, such as Verschlusssache - Nur für den Dienstgebrauch (VS-NFD). Systems classified under VS-NFD require access control, encrypted communications, dedicated network infrastructure and periodic security accreditation.[117] Developers and system administrators need to adhere to strict usage guidelines, which dictate the permissible software, hardware and methods of data handling.[118] Compliance significantly restricts the usage

[114] *Bundesamt für Sicherheit in der Informationstechnik*, Tasks of BSI, n. d.

[115] *Bundesamt für Sicherheit in der Informationstechnik*, BSI Standards, n. d.

[116] *North Atlantic Council*, 2002, Enclosure B, pp. 1–3, Enclosure F, pp. 1–2.

[117] *Bundesministerium für Wirtschaft und Klimaschutz (BMWK)*, VS-NFD, 2023, see Part 2, pp. 1–3, Part 3, pp. 1–6.

[118] Ibid., Part 3, No. 3.1–3.7, pp. 1–5.

of modern technologies such as cloud services or external software libraries, unless explicitly cleared[119]. This can be seen in the example of Genua's secure remote working solution, which complies with both VS-NfD and NATO security requirements while offering functionality typically restricted in classified environments.[120]

Although essential for operational security, these security and compliance requirements markedly constrain software adaptability and agility. Extensive documentation, mandatory security certifications and regular audits mandated by national and international regulations considerably increase the maintenance workload and complexity. Consequently, prolonged approval processes and heightened architectural complexity often accelerate software decay and technical debt accumulation, complicating extensive refactoring or proactive architectural evolution.

In summary, security and compliance requirements play a pivotal role in shaping Bundeswehr software development practices, significantly influencing architecture design, maintenance methodologies and lifecycle management. While crucial for safeguarding operational security and classified information, these rigorous standards often inhibit software adaptability and innovation, exacerbating the challenges of software decay and technical debt inherent in military software systems.

2.3.4 Legacy Systems and Extended Lifecycles

Legacy systems and extended lifecycles impose particularly significant constraints for military software projects, especially within the Bundeswehr. Unlike commercial software, which typically operates for a limited period, military systems frequently remain operational for decades due to high investment costs, complexity and risk aversion to adopting new technologies. Such prolonged operational lifespans inevitably contribute to technical debt accumulation and progressive software decay, significantly complicating maintenance and increasing lifecycle costs.

A prominent example of these challenges emerged within the Bundeswehr's logistics and support IT systems at the turn of the century. According to Sebastian Stein's 2011 blog entry, the Bundeswehr managed around 1,200 distinct outsourced IT systems, creating a highly fragmented and inefficient infrastructure.[121] To address this issue, the Bundeswehr initiated the Integrated Standard-Application-Software-Product Family (SASPF) program,

[119] *Bundesministerium für Wirtschaft und Klimaschutz (BMWK)*, VS-NFD, 2023, Part 3, No. 3.4.1–3.4.5, pp. 4–5.

[120] *genua GmbH*, Genua VS-NFD, 2024.

[121] *Stein, S.*, BPM in the Bundeswehr, 2011.

consolidating procurement, accounting, and logistics systems into a single, integrated SAP-based solution. However, standard SAP software met initially only around 70% of the Bundeswehr's unique operational requirements, necessitating extensive custom development and temporary workarounds.[122] These integrations were further complicated by stringent regulatory requirements, diverse stakeholder interests and interoperability challenges with outdated technologies. Consequently, significant technical debt and complexity accumulated, extending the modernization effort well over a decade and clearly demonstrating the severe maintenance implications of legacy systems.[123]

Another illustrative case within the Bundeswehr is the Luftwaffe's Tornado fighter jet program. Development began in 1981 and the aircraft entered operational service in 1992. Today, approximately 80 Tornado jets remain operational, with plans for replacement only by 2030 resulting in a lifecycle of nearly 50 years.[124] Continuous software updates have been crucial throughout this extensive period, including notable upgrades like the integration of the RecceLite reconnaissance system in 2009.[125] However, each update has progressively become more complex and costly due to aging hardware, software architecture limitations and stringent compliance demands. This incremental layering of software modifications directly contributes to accelerated software decay, increasing the difficulty and expense of maintaining operational effectiveness.

Comparable challenges are also prevalent among international NATO allies. A notable example was highlighted by Kynan Carver (2022), describing how the U.S. Department of Defense (DOD) continued operating critical strategic systems reliant on severely outdated technologies, including 8-inch floppy disks, until the late 2010s.[126] Carver emphasizes that maintaining these aging software infrastructures consumes significant financial and operational resources, limiting investment in innovation and proactive modernization strategies.[127]

In conclusion, effectively managing technical debt and mitigating software decay within military systems requires strategic, long-term investments, proactive modernization plans and an explicit focus on maintainability. Addressing the unique challenges posed by legacy systems and extended lifecycles is thus crucial for sustaining operational capability and flexibility within an increasingly dynamic military technology environment.

[122] *Stein*, *S.*, BPM in the Bundeswehr, 2011.
[123] Ibid.
[124] *Skiba*, *T.*, Der Tornado, 2024.
[125] bundeswehrTornado
[126] *Carver*, *K.*, Technical Debt, 2022.
[127] Ibid.

2.3.5 Conclusion

Military software development is fundamentally shaped by demands that are far beyond those of the commercial environments. The need for extremely reliable, long lasting systems which still meet strict classification regimes and multi-layered stakeholder requirements creates a highly regulated and risk-shy context. These characteristics collectively contribute to a development landscape where software decay and technical debt are not merely byproducts of poor practices but structural risks embedded within the system's lifecycle.

As shown throughout this section, four constraint areas amplify these challenges. Firstly, the inherit complexity of military systems, often designed to operate for decades, creates pressure to extend the viability of aging platforms. Secondly, the rigid procurement and development frameworks, such as the V-Modell XT Bw and the CPM process, prioritize upfront control and traceability over agility, hindering adaptive or incremental development practices. Thirdly, extensive national and NATO security requirements impose detailed compliance burdens, restricting the use of modern tools and leading to prolonged certification cycles. Finally, the heavy reliance on legacy systems and technologies, as illustrated by the Tornado jet or SASPF, reinforces technical inertia and raises the cost and difficulty of modernization efforts.

Together, these factors present a software ecosystem where continuous improvement, architectural evolution and proactive quality management are severely constrained. Consequently, technical debt tends to accumulate more rapidly and opportunities to refactor or modernize the system are limited due to procedural, regulatory and operational constraints.

Therefore it is crucial to understand how military software practitioners operate within this setting. The next section of this thesis will examine how experts working on Bundeswehr-related software systems experience and address these limitations in practice. The main focus will be their strategies in managing software decay, handling long-lived legacy systems and the impact of the regulatory environment on their work.

2.4 Summary of the Literature Review

Software development faces inherent challenges that have existed for decades. The previous chapters examined these problems from three key perspectives: the foundational problems of software engineering, the mitigation strategies used in commercial environments and the unique constraints faced in military projects. This summary will highlight the key insights to establish a foundation regarding software decay and technical debt, thereby laying the groundwork for the empirical investigation in the following chapters.

2.4.1 Problems of Software Engineering

The complexity of software systems, combined with their extended lifecycle and constant evolution, creates significant challenges. As presented by Brooks (1986), essential difficulties such as complexity, conformity, changeability and invisibility are inherent in software development. In contrast are the accidental difficulties which stem from the tooling and process problems of the current software development practices. These foundational matters create the two following common issues.

The first is software decay which refers to the gradual deterioration of software quality, due to evolving requirements and the constant need for updates and maintenance. This has been empirically validated by Eick et al and theoretically supported by Lehman, Belady and Parnas.
The second issue is Technical Debt, a metaphor introduced by Cunningham. Technical Debt represents the cost of implementation or design shortcuts taken to meet immediate needs, which can lead to long-term maintenance challenges. This concept has been further developed by McConnel, Fowler and Kruchten, highlighting the risks and management needs associated with both intentional and unintentional technical debt. Together, these two concepts create a complex environment where long-term degradation is inevitable unless proactively managed.

2.4.2 Mitigation Strategies in Commercial Environments

To combat software decay and manage technical debt, commercial software projects have developed a wide range of strategies. These include high-level practices such as agile methodologies like Scrum, XP or CI/CD pipelines which embed quality into the daily workflow. Such practices are complemented by code level-techniques like continuous refactoring, TDD or code reviews which help manage the complexity and ensure maintainability. Architectural strategies like conformance checking and managing architectural technical debt support long-term structural integrity. This is further supported by organizational practices such as backlog tracking of debt, balancing time pressure and cultivating a quality-focused culture. Finally, the use of modern tooling through automated analysis tools (e.g. SonarQube, TeamCity) allows enforcement of standards and early detection of issues.

These approaches aim to proactively manage quality and control the complexity, thereby reducing the long-term cost of maintenance.

2.4.3 Constraints in the Military Software Environments

While the challenges of decay and technical debt are universal, military software projects face the following unique constraints that complicate their management.

The project structure in the Bundeswehr is defined by the V-Modell XT Bw and the CPM processes, which emphasize documentation, predictability and rigid lifecycle phases, making agile practices difficult to implement. The procurement contracts like the EVB-IT further limit flexibility and iterative development. The security and compliance requirements from the BSI, NATO policies and VS-NfD create additional burdens through mandatory certifications, audits and limitations on tooling or external software. The extended lifecycles and legacy systems that exist in every military environment create decade long systems that need service and have to remain operational while also adapting to new requirements.

These conditions result in higher maintenance burdens and slower update cycles and also reduce the ability to refactor or modernize systems. This creates a software ecosystem where decay and technical debt accumulation are accelerated.

2.4.4 Conclusion

In conclusion, software decay and technical debt are persistent and measurable risks in all software systems. While commercial environments have developed effective mitigation strategies, their applicability in military projects is limited by structural, regulatory and operational constraints.

Understanding these differences is essential for designing effective strategies to manage decay and technical debt in military software projects. The next chapter will explore how professionals in military related software projects deal with these constraints in practice, offering real-world insights through expert interviews. They will provide a deeper understanding on how decay and debt are managed, despite the rigid frameworks and complex environments.

3 Methodology

3.1 Research Design

This thesis employs a qualitative, exploratory research design to investigate how software decay and technical debt are addressed in the context of military software development. Given the previously established challenges of complexity, extended lifecycles and high security requirements, these factors cannot be fully captured by quantitative methods.
Alternatively a qualitative approach was chosen to allow for a deep insight directly from the practitioners. The study is based on a semi-structured expert interview, conducted with software developers and project managers at T-Systems IFS, Chapter Defense Systems. The goal of the interviews is to identify core challenges, strategies and constraints related to managing long-lived software systems in the military domain.
The object is not to derive generalizable results for the entire industry, but rather to uncover key themes and practices specific to this organization and operational context. The interviews were designed based on the findings of the literature review and structured around topics like the management of legacy systems, use of CI/CD, architectural conformity, code quality and organizational or regulatory constraints.

3.2 Data Collection

To gather relevant and practice-based insights, this thesis employs a semi-structured interview approach as the primary data collection method. This approach allows for a balance between consistency across interviews and the flexibility to explore specific experiences or expertise of individual interviewees. The interview guidelines were developed based on the key topics identified in the literature review, with a focus on the following areas:

- Handling of legacy systems and long-term maintenance
- Use of Agile methodologies and CI/CD
- Architectural decision-making and conformance
- Code quality assurance practices
- Organizational and regulatory constraints in military projects

The participants were selected through purposeful sampling, all being practitioners currently working on military software systems within T-Systems IFS, Chapter Defense Systems. In total, three interviews were conducted. All participants hold several years of experience in software engineering, testing or project management in military software projects.

The interviews were conducted in person, recorded with consent and transcribed for analysis. The duration of each interview was between 20 and 40 minutes.

3.3 Data Analysis

The transcribed interview data was analyzed using Thematic Analysis, following the six-phase approach outlined by Braun and Clarke (2006). This method was chosen for its flexibility and suitability in identifying and interpreting patterns across qualitative datasets. According to Braun and Clarke, the first step is the familiarization with the data to become aware of potential patterns and themes.[128] The second step is the generation of the initial coding. Codes are defined by Braun and Clarke as 'a feature of the data (semantic content or latent) that appears interesting to the analyst'[129] and capture important features for the research question. The third step uses those codes to create broader themes. This is done by collecting all relevant codes and forming theme piles.[130] These themes are then reviewed and refined in the fourth step, as: 'it will become evident that some candidate themes are not really themes, while others might collapse into each other'[131]. In the fifth step, clear definitions and names for each theme are developed. This includes writing a detailed analysis of each theme and how it relates to the research questions.[132] Finally, the

[128] *Braun*, *V.*, *Clarke*, *V.*, 2006, p. 16.

[129] Ibid., p. 18.

[130] Ibid., pp. 19–20.

[131] Ibid., p. 20.

[132] Ibid., p. 22.

sixth step is the production of the report. This is created through the combination of the identified themes, supported by selected interview quotes to illustrate the findings.[133] The coding process followed a hybrid approach, combining both deductive elements based on the literature review as well as inductive elements to account for unexpected themes specific to the military software context. The analysis was conducted manually, using MAXQDA to support the coding process and facilitate the organization of themes and codes.

3.4 Limitations of the Methodology

While the qualitative approach chosen for this thesis provides valuable insights to uncover practical challenges and strategies, it is not without limitations.

Firstly, the study is based on a small number of expert interviews, conducted exclusively with practitioners from T-Systems IFS, Chapter Defense Systems. While the participants provided rich and relevant insights, the limited sample size means the findings cannot be generalized to the entire military software industry. Instead, the goal is to capture in-depth perspectives on key challenges and mitigation strategies in a specific organizational context.

Secondly, the semi-structured interview format, while allowing flexibility may introduce inconsistent coverage of topics between the interviews. Some participants may have focused on certain aspects, while others may have limited knowledge in specific areas. This may lead to uneven data quality across the thematic areas.

Thirdly, the subjective nature of qualitative analysis means that the findings are influenced by the researcher's interpretation of the data. While efforts were made to ensure rigor and transparency in the coding process, there is always a risk of bias or misinterpretation.

Finally, given the sensitive nature of military software projects, participants were limited in what they could disclose. This was either due to confidentiality agreements or the nature of the projects. This may lead to a partial representation of practices and challenges, especially in areas of security, architecture and procurement.

[133] *Braun, V.*, *Clarke, V.*, 2006, p. 23.

Despite these limitations, the methodology provides a valuable foundation that contributes to the understanding of how software decay and technical debt are managed in military software projects. The findings serve as a starting point for future, broader studies or as a reference point for practitioners in the field.

4 Results

4.1 Introduction

This chapter will present the findings of the qualitative content analysis of the three semi-structured expert interviews. The interviews were analyzed by the coding framework of Braun and Clarke as described in the methodology chapter. The results are structured into nine key themes, each containing several subthemes that emerged from recurring topics in the data.

4.2 Challenges in Managing Long-Lived Military Software

As established in the literature review, military software systems are typically designed for extended operational lifespans, sometimes for decades. This leads to significant challenges across technical, organizational and structural dimensions. From the expert interviews, the following subthemes emerged: System Complexity, Legacy Technologies and Compatibility Issues and Organizational Challenges.

4.2.1 System Complexity

One key challenge in maintaining long-lived military software lies within the complexity of the systems. This is not only due to the accumulation of new features but also the strict requirements regarding reliability, testability and compliance.

As one interviewee stated: ‘Je kritischer die Software, desto höher ist eben auch der Einfluss, den es auf unsere Arbeit hat, weil desto höher ist eben auch der Testaufwand [. . .] oder desto höher sind die Ansprüche an die Software.’

This highlights how the need for reliable and operationally safe systems leads to higher development and maintenance demands. Additionally, early architectural decisions which were often made decades ago, still constrain the current development process. For example, existing system architectures can no longer be easily modified: 'gewisse Entscheidungen [sind] vielleicht auch im Vorwege schon limitiert.'
Such constraints make implementing modern solutions or adapting to changing requirements difficult. This indicates a need for proactive simplicity and modularity in initial designs.

4.2.2 Legacy Technologies and Compatibility Issues

The continued reliance on outdated technologies represents another significant challenge in maintaining military systems. Many components are based on frameworks, languages and tools that are no longer widely used or supported. As one interviewee expressed, 'wir arbeiten noch mit sehr, sehr alten Versionen, [. . .] es ist alles sehr alt und es passt mit den Sachen nicht mehr zusammen.'

The problem not only exists in development but also in testing and tool integration. Test environments often rely on virtual machines and tools that require substantial manual effort, and are therefore prone for errors like misconfigurations or copy-paste mistakes. Moreover, forced tool usage from the customer side can lead to further complications: 'Wenn wir eine Vorgabe bekommen, dass wir mit bestimmten Tools testen müssen, dann ist das natürlich wieder mit extra Aufwand verbunden.'

These issues contribute to software decay. Several participants described how initial shortcuts like skipping broken automated tests because they passed locally led to accumulated technical debt and a decrease in test reliability.

4.2.3 Organizational Challenges

Finally, organizational factors significantly impact the long-term sustainability of software. Knowledge loss due to employee turnover and the lack of documentation were recurring themes in the interviews. As one interviewee noted: 'Wenn du selbst Quellcode geschrieben hast, ihn dann zehn Jahre später noch warten und verstehen zu müssen, ist eben eine Herausforderung.' This challenge is reinforced by the retirement of experienced employees and the onboarding of younger developers unfamiliar with the legacy systems.

The interviews revealed that documentation and review practices were inconsistent. Review processes only took place before major releases or were conducted informally. One participant stated: ‘Früher fast gar nicht. Also früher gab es quasi einen, der es gemacht hat und einen, der die offiziellen Tests dafür gemacht hat.’ Today, although formalized practices like mandatory reviews and issue tracking are in place, their absence in older project phases continues to impact the maintainability.

4.3 Impact of Procurement and Approval Processes

The procurement and approval processes in Bundeswehr software projects have a significant impact on the evolution and maintainability of long-lived systems. Multiple participants across the interviews highlighted that even though technical shortcomings are often recognized, procedural, financial or contractual constraints obstruct the implementation of fixes. As one participant observed, although issues are raised, ‘oft ist das dann für den Kunden attraktiver, ein neues Feature zu nehmen, statt irgendwas Bestehendes nochmal zu korrigieren.’ This indicates a systemic preference for visible new features over addressing underlying technical debt.

4.3.1 Financial Constraints

One central barrier is a limited budget flexibility. In several cases, technical debt was acknowledged and documented, yet not addressed due to financial constraints. As one project manager noted, ‘Wir hatten halt ein festes Budget, [. . .] aber da hat sich jetzt kein Folgeauftrag ergeben, deswegen liegen sie da jetzt erstmal.’ In this context, the willingness to fix issues exists, but funding remains a bottleneck: ‘Grundsätzlich ist der Wille da, es zu beheben, aber das Geld nicht.’ These conditions create an environment where known issues remain unsolved and accumulate over time.

4.3.2 Procurement Barriers

In addition to funding, rigid procurement processes restrict the ability of developers to act proactively. Retroactive code improvements or technical debt remediation often require formal authorization, as developers are not permitted to modify code already delivered without explicit approval: ‘Ohne dass wir einen Auftrag bekommen, dürfen wir halt auch nichts machen.’ Even when shortcomings are identified, requests may be stalled due to insufficient contractual flexibility. This is particularly problematic under traditional methodologies like the V-Model, where ‘ein Riesenwust an falschen Umsetzungen’ can emerge from misinterpreted or outdated requirements. As one interviewee pointed out, greater contractual agility could enable a more responsive development process: ‘Wenn man halt in den Verträgen schon leichte Spielräume schaffen würde, [. . .] wäre schon dem Problem viel geholfen.’

4.3.3 Slow Approval Processes

The formal structure of software certification further increases the lack of flexibility. Even minor adjustments are subject to lengthy testing and approval processes. One participant described how a simple removal of unreachable code is often not pursued: ‘Weil die Prozesse eben so aufwendig sind, wird das dann eben normalerweise nicht gemacht.’ This is not due to technical difficulty but to procedural formalities: ‘Die Softwareänderungen [dauern] manchmal 10 Minuten, aber der Prozess mit Testen und Nachweis und Lieferung und Freigabe dann durchaus mal eine Woche.’ These approval processes are not only time-consuming but also discourage iterative improvement and create a cautious approach to change.

4.4 Technical Debt and Software Decay Practices

The interviews revealed that technical debt and software decay are recognized challenges in military software development. While they are not always tracked formally, they are commonly acknowledged, with participants stating that both strategic and pragmatic decisions about when to accept or mitigate them are made. Four subthemes emerged from the interviews: tracking and visibility, consequences, sources and the handling of existing technical debt.

4.4.1 Tracking and Visibility of Technical Debt

The interviews showed that tracking of technical debt varies between projects. In some cases, teams maintained issues of known technical debt in a backlog, even when they could not address them immediately. One participant explained, ‘die potenziellen Verbesserungen [werden] als Issue aufgenommen und mit einem Won’t do Label markiert, [. . .] sodass wir im Nachgang jederzeit gucken können, das sind Dinge, die wir besser machen könnten.’ However, others stated that such documentation is often missing. As another interviewee noted, ‘Also getrackt wird es auf jeden Fall nicht. Das wüsste ich jetzt nicht, dass sich das jemand irgendwie merkt, dass da und da irgendwie was noch zu tun wäre.’ This discrepancy indicates inconsistent practices regarding the visibility of known technical debt, often depending on project maturity or individual initiative.

4.4.2 Consequences of Technical Debt

Unaddressed technical debt was widely viewed as having long-term negative consequences on development efficiency. One interviewee reflected, ‘Man hat, glaube ich, eine Menge Zeit da verloren und man hätte, glaube ich, wenn man im Vorwege schon solche Dinge gemacht hätte, [. . .] eine Menge Aufwand sparen können.’ This sentiment was confirmed by others, highlighting that the cost of technical debt is often not immediately visible but manifests in the long run, leading to increased maintenance efforts and reduced system reliability.

4.4.3 Sources of Technical Debt

Through the interviews, several sources of technical debt, ranging from outdated infrastructure to organizational pressure could be identified. Time pressure emerged as a dominant cause, with participants stating that deadlines often constrain quality practices: ‘Andererseits haben wir auch die Deadlines [. . .] von daher is es immer eine Abwägung [. . .], gerade eher gegen Ende der Laufzeit [. . .], wenn Software nicht optimal ist, solange eben keine Fehler drin sind.’ This acceptance of a ‘good enough’ solution under time constraints is a recurring pattern.

Additionally, legacy systems contributed significantly to the accumulation of technical debt. Outdated tooling and incomplete test maintenance were cited repeatedly as evident in the following example: ‘Da hat man die Testskripte ewig nicht angefasst [. . .] und jetzt habe ich gefühlt wieder ein paar Monate gebraucht, um die alle auf Stand zu kriegen [. . .]. Das ist halt [. . .] diese technische Schuld, die wir im Vorweg hätten verhindern können.’ Moreover, knowledge gaps introduced by inconsistent documentation and employee turnover were another root cause: ‘Wenn Dinge behoben worden sind im Quellcode, aber in den Testskripten nicht’.

4.4.4 Handling of Existing Technical Debt

Participants reported both proactive and passive strategies for handling technical debt. In more proactive cases, debt was addressed during related work. One participant described this approach as follows: ‘Wenn wir jetzt neue Dinge überarbeiten, gucken wir, können wir das an anderen Stellen auch vereinfachen, können wir Sachen zentralisieren.’ In contrast, there were also instances where technical debt was ignored due to effort or time constraints: ‘Wenn es dann wirklich nur um nicht optimale Implementierung geht, dann wurde es dann meistens doch eher unter den Teppich gekehrt.’ This underscores the role of effort-benefit considerations in managing long-term quality.

4.5 Mitigation Strategies in Military Software Projects

In order to address the accumulation of technical debt and the long-term effects of software decay, the interviewed experts described several mitigation strategies that have been implemented in their projects over time. These include improvements to the documentation, an increase in automation, use of refactoring and formalized code review processes.

4.5.1 Documentation Improvements

While documentation was often described as historically lacking, recent practices have begun to address this gap. Lightweight documentation tools like Markdown became the preferred choice for documenting over traditional tools like Word. This is due to ease of use and the ability to integrate them directly into the development workflow. One expert emphasized the convenience of ‘einfach in der Entwicklungsumgebung heraus, da schnell was zu dokumentieren,’ particularly using Markdown-based approaches. Additionally, issue tracking systems like Jira were mentioned not only for task management but to trace changes and problem resolution, providing a project memory. Nevertheless, some participants acknowledged that automated document generation is still not used widely due to complexity.

4.5.2 Automation

Automation emerged as a particularly influential strategy, seen as both a time-saver and quality enabler. All three interviews highlighted a move from legacy CI tools like Jenkins toward more integrated solutions like GitLab. Automation is now widely used in builds, tests and static code analysis. One practitioner noted that, 'man kann es nicht auslassen [. . .] es wird ja automatisch gemacht', referring to the inevitability of running the automated test pipelines on commits to the codebase. This shift has not only allowed for faster feedback loops but also for parallel testing through containers as well as enhanced scaling and efficiency. Test reliability and frequency have improved as well, especially in regression testing.

4.5.3 Refactoring

Refactoring is practiced increasingly, although with some constraints. While historically uncommon, agile workflows have made it more normalized. According to experts, this is due to code reviews or developer initiative and sometimes results in a complete rewrite of problematic components. One developer recounted the rewrite of a poorly maintainable test script: 'wir schmeißen ihn weg und schreiben ihn komplett neu, [. . .] dadurch ist er jetzt viel besser, viel wartbarer.' This illustrates how refactoring can increase long-term maintainability, even at the cost of short-term effort. Nevertheless, the previously mentioned procurement and approval processes hinder such refactoring efforts, especially of older, already established code. Adding on to this are resource constraints, limiting the formalization of refactoring tickets in some teams.

4.5.4 Code Reviews

Systematic code reviews were described consistently as a critical practice for modern mitigation efforts. The standard has shifted from informal peer checks to mandatory multi-eye reviews, often documented in GitLab creating a clear audit trail. As one interviewee explained, 'jede Änderung wird eben nochmal gereviewt' underscoring that no code is merged without review. These processes are not only seen as a quality assurance measure but also as a knowledge transfer opportunity. Review discussion often helps to find hidden issues and prevent accidental technical debt early on. In some contexts, less experienced developers also participate, allowing for a teamwide transfer of code knowledge.

4.6 Quality Assurance and Testing

Ensuring long-term software quality is essential in military software projects, particularly due to the extended lifespans and strict regulatory demands. The interviews revealed a combination of different strategies to ensure quality, an approach which has evolved over time. Core elements included overcoming testing challenges, the use of tools and metrics, maintaining test coverage and developing systematic testing processes.

4.6.1 Testing Challenges

Participants noted several recurring challenges in maintaining test quality. The most significant of these was sustaining automated testing pipelines: ‘Wenn man jetzt ein Schwäche nennen müsste, ist es natürlich der Aufwand dahinter, das Ganze so weit zu automatisieren.’ Additionally, legacy testing processes and infrequent test execution in earlier project phases were cited as obstacles. As a result problems with the tests were detected much later, resulting in high maintenance efforts. As one interviewee noted, ‘bei gewissen Projekten war es halt so, da hat man die Testskripte ewig nicht angefasst,’ which highlights how neglecting test maintenance can cause significant issues in the future.
Another challenge was the lack of traceability, especially when tests were changed much later than the code. One interviewee stated that ‘wenn man dann nicht nachvollziehen kann, was im Quellcode geändert worden ist, [. . .] dann ist das schon sehr lästig’, indicating the importance of maintaining a clear connection between code changes and test updates. Furthermore, a lack of consistency in responsibility for test maintenance was noted. This responsibility was often divided between developers and testers, which created additional coordination issues. Requirements themselves were sometimes found to be vague, making precise testing difficult.

4.6.2 Use of Metrics and Tools

Quantitative quality metrics have been increasingly used to assess and improve software quality. Metrics such as code coverage, complexity and static code analysis findings were frequently mentioned. One interviewee stated: ‘Wir haben die Codecoverage als Kennzahl und wir haben die statische Codeanalyse, die uns dann Findings quasi hochwirft.' Tools like Logiscope and Jenkins play a key role in these evaluations and are integrated into the CI pipelines for continuous feedback.

The use of unit test metrics and graphical feedback was also mentioned as a way to improve code quality. Thresholds for metric violations were set by the client, creating external pressure as well as standardization. In addition to technical tools, project management tools like Jira contribute to traceability and error tracking, showing that quality encompasses both code and process aspects.

4.6.3 Test Coverage and Test Maintenance

Ensuring high test coverage as well as maintaining test scripts were identified as key strategies to prevent software decay. Automated coverage reports allow developers to monitor how well the code is covered by tests: 'dann halt auch so Messwerte wie Test-Coverage mir auch ausgeben lassen [...] und kann da halt gegebenenfalls nachbessern.' The integration of test automation into CI/CD pipelines was described as both a reliability and a knowledge preservation mechanism.

Participants emphasized the need to regularly update test scripts immediately after code changes, especially in long-lived projects. One expert advised: 'Testskripte immer direkt nach der Softwareanpassung auch mit anpassen,' warning that even developers might struggle to remember the reasons for their own code changes after a few months. The benefit of nightly test runs and regression detection was also highlighted, described as crucial for sustainable quality assurance.

4.6.4 Testing Practices

Over the last years, testing practices have evolved from manual execution to a more automated and systematic approach. Several interviewees recalled earlier practices where tests had to be executed manually over days: 'Vor zehn Jahren [...] mussten viele von diesen Testprozessen per Hand durchgeklickt werden.' In contrast, today's pipelines integrate code compilation, test execution and reporting using tools like GitLab or Jenkins. The resulting transparency was described as a significant improvement, allowing developers to receive detailed failure reports and even screenshots in case of User Interface (UI) errors. As one expert stated, 'den Überblick zu haben [...] ist schon ein großer Gewinn.' Despite these advancements, some areas like system-level tests still rely on manual testing. Nevertheless, the overall trend is towards a more automated and integrated testing approach and is seen as a major improvement in software quality assurance.

4.7 Agile Methodologies in Military Projects

The introduction of agile methodologies into military software development marks a significant shift from traditional approaches. While usually reliant on plan-driven models such as the V-Modell XT, participants described how agile methodologies, particularly Scrum, are being adopted in some form in certain projects. The reported effects of this shift include a change in team dynamics, software quality and the ability to adapt to changes. Nonetheless, several constraints still remain.

4.7.1 Knowledge Sharing and Collaboration

A key benefit of agile practices in the military context is improved knowledge sharing and collaboration. Participants emphasized the positive impact of regular stand-ups, code reviews and a collaborative problem-solving culture: 'Dadurch, dass wir täglich miteinander reden und täglich Fragen stellen und im Review mit anderen Personen zusammensitzen, da wird sowas dann halt immer [. . .] gefördert.' Agile methods work against the silo knowledge structure typical in legacy projects. By encouraging broader ownership of code and increased onboarding support for new team members, a participant noted a shift away from the 'Keller-Mentalität'. According to him, this shift creates more learning opportunities as well as project resilience.

4.7.2 Limitations in Agile Implementations

Despite the positive aspects, the implementation of agile methodologies faces several structural challenges in military software projects. Firstly, agile practices are still relatively new: 'Agil ist tatsächlich ein neues Thema im Bereich militärisch. Das gab es bisher gar nicht.' Secondly, organizational and contractual constraints restrict the iterative nature of agile development. For example, procurement officers would be required to be more involved and responsive in iterative decisions, which would increase their workload. Additionally, early-phase resource investments, common in agile approaches, clash with the traditional planning and fixed-scope contracts: 'Es wird natürlich im Vorwege teurer, damit man hinten raus [. . .] technische Schuld [. . .] abfedert.' These constraints highlight the need for an adapted agile model that can accommodate the regulatory and hierarchical structures of military software development.

4.7.3 Use and Impact of Agile Methods

In practice, the use of tools like GitLab and Jira has enabled a more agile-friendly development environment. Participants highlighted the benefit of a closer connection between issue tracking, branching strategies and code delivery pipelines. Agile processes also improve responsiveness. Teams can now react more easily to changing requirements or design flaws. By breaking work into smaller increments and regularly revisiting priorities, scope issues can be identified and addressed earlier: 'Der Scope [ist] zu groß geworden und [wir] haben das dann abgekapselt in ein eigenes Item.' Moreover, the agile approach of having a potentially shippable product at the end of each sprint has improved planning discipline and improvement cycles. Nevertheless, participants stressed that the full potential of these benefits can only be realized with a more flexible and responsive organizational structure.

4.8 Influence of Regulatory and Security Requirements

The development and maintenance of military software is heavily influenced by regulatory and security requirements. These requirements not only shape the development process but also impact both technical decisions and organizational flexibility. The interviews revealed that while these requirements are essential for maintaining safety and reliability, they also introduce significant challenges that can hinder adaptive development practices.

4.8.1 Impact on Flexiblity

A recurring theme which emerged is the limited flexibility in making changes to the software once it has been delivered. Participants described how even minor adjustments need to pass through extensive testing and approval processes, which can take weeks or even months. As one interviewee noted: 'Software kann nicht einfach geändert werden, sondern wir müssen einen recht komplexen Prozess durchlaufen,' which highlights the bureaucratic complexity that can restrict maintenance and optimization efforts. Even clearly obsolete components such as unreachable or ‘dead’ code often remain in the system due to the time and effort required for formal approval.

The flexibility issue has a direct impact on the maintainability. As another expert pointed out, even if a better solution is available, ‘wir dürfen nicht einfach beliebig irgendwelche Sachen ändern,’ due to certification status and client approval. A lack of contractual agility further increases the problem, with interviewees emphasizing that small changes which could improve quality are often not pursued because ‘die Spielräume aktuell zu wenig genutzt werden.’

4.8.2 Standards Compliance

The interviews underscored the stringent compliance requirements around coding standards and documentation. All projects adhere to formal coding guidelines defined in cooperation with the client and use tools like Logiscope to automatically enforce these standards. These metrics not only insure code quality and maintainability but also serve to enforce compliance with the regulatory framework. As one expert noted, ‘wir haben im Projekt auch feste Codierrichtlinien [. . .] die dafür gemacht sind, den Code am Ende wartbar zu halten.’ Furthermore, a formal review is required for any delivered code, with audit trails and standardized documentation ensuring traceability and accountability. One participant described how ‘es mussten regelmäßige Reports angelegt werden, die dann auch auf Nachfrage dem Kunden vorzulegen sind,’ reinforcing how compliance processes are integrated into the development.

4.8.3 Security and Reliability Requirements

The security and reliability requirements tied to critical military systems add another layer of complexity. Systems with higher criticality are required to have elevated test coverage, often reaching 95%, and must adhere to strict validation practices. That was framed both as a challenge and a motivator as one participant remarked that ‘je kritischer die Software, desto höher ist eben auch der Testaufwand.’

Despite these requirements, the interviews suggest that the security and reliability standards are also intrinsically motivating for the team. One interviewee observed that teams are ‘ehr intrinsisch getrieben,’ indicating a strong internal commitment to quality, beyond the external regulations. Some participants even suggested that, in certain cases, regulatory pressure may be less than the actual quality standards that the teams set for themselves, describing the standards as ‘ehr ein bisschen lascher.’

4.9 Successful Examples

Despite the many challenges discussed throughout the interviews, the participants also described a number of successful practices that have mitigated software decay and reduced technical debt in their projects. These successful measures offer insights into the strategies which have worked well in practice and could be applied to other projects.

4.9.1 Effective Measures against Software Decay

One of the most frequently mentioned successful measures was the introduction of automation, particularly in the areas of testing and continuous integration. The shift from isolated VM-based tests to containerized, pipeline-driven environments was described as a key improvement. This change enabled faster, parallel test execution and improved visibility across the codebase. As one participant stated, the move to GitLab and automated pipelines allowed for ‘schnelle Ergebnisse’ and ensured that ‘jeder, der ein Issue bearbeitet, auch sicherstellen muss, dass die Tests [. . .] durchlaufen.’

Another significant improvement came from refactoring efforts, often initiated through broader modernization efforts. During the migration from SVN to Git, teams took the opportunity to ‘Ballast ab[zu]werfen’ removing unnecessary legacy code and simplifying complex structures. These efforts directly improved code clarity and maintainability, making it easier for new developers to engage with the system: ‘Viele Methoden sind eben kürzer geworden, leichter lesbar . . . [so dass es] auch einem Laien dann leichter fällt . . . zu verstehen.’

The CI/CD infrastructure was described as a continuously evolving system. Originally implemented as a basic build pipeline, it has grown to incorporate automated testing, static code analysis and compiler warning tracking. This evolution has made the development process ‘praktischer und bequemer,’ illustrating how technical investments translate into tangible benefits for the team.

Lastly, the use of agile practices was highlighted as a driver of responsive and adaptive development. In one case, an agile approach allowed a fast response to a customer request that otherwise would have been ignored due to implementation complexity: ‘. . . sehr schnell auf einen Kundenwunsch reagiert . . . korrigiert und mit wenig Aufwand umgesetzt.’ This example illustrates how agile and technical practices can directly reduce software decay by addressing issues early and efficiently.

4.10 Recommendations For Future Practices

The final theme of this study focuses on the recommendation for future practices by practitioners to reduce long-term software decay and technical debt. Interviewees consistently highlighted proactive measures and early intervention as key strategies. This is reflected in the recommendations targeting agile adoption, continuous documentation, sustained test maintenance and upfront investment.

4.10.1 Agile Expansion

Agile practices, while still uncommon in military software contexts, were regarded as promising in counteracting technical debt. Participants reported greater responsiveness to emerging needs and improved alignment with user priorities when using agile methods. As one interviewee described, agile approaches made it possible to 'mit wenig Aufwand' adapt systems quickly to customer demands. The iterative nature of sprints also enabled isolation of complex issues and allowed for more focused problem-solving. In a broader view, agile working was seen as an opportunity to address usability shortcomings and allow for better prioritization. However, participants noted that realizing these benefits requires contractual flexibility and the ability to reallocate resources mid-project, an area that still is problematic due to the rigid procurement settings.

4.10.2 Focus on Test Maintenance

Interviewees emphasized the importance of maintaining and adapting test scripts. Neglect in this area was seen as a major source of avoidable technical debt. One expert reflected that without timely updates, even small code changes resulted in significantly high maintenance efforts. Automated pipelines helped reduce this burden, but maintaining the relevance and accuracy of test scripts remains a manual task. In long-lived software systems, proactively synchronizing code and test logic was viewed as a foundational element of sustainability.

4.10.3 Continuous Documentation

Improving documentation emerged as another important mitigation approach. Experts pointed out the necessity of reducing the threshold of developers to contribute to documentation, particularly by adopting lightweight and integrated tools. For example, Git and Markdown were favoured due to their accessability and ease of use. Beyond technical documentation, traceability through issue tracking and automated records of reviews was also seen as a step towards preserving architectural and design knowledge over time. As one interviewee stated, clear documentation ensures that 'auch Jahre später . . . nachvollzogen werden kann', supporting maintainability across generational changes.

4.10.4 Early Investment

A recurring insight across all interviews was the value of early, deliberate investment in software maintainability. Participants stressed the benefits of planning from the beginning for a system's long lifecycle. Strategic choices such as introducing modularity, automated tools and test infrastructure early on were seen to yield long-term benefits. One practitioner noted that 'wenn man es direkt zu Beginn macht, . . . hat [man] auch den geringsten Aufwand nachher', capturing the concept that frontloading technical quality reduces costs and complexity in the long term. Moreover, even small-scale improvements, if made consistently and early, were regarded as effective in preserving system health over time.

5 Discussion

5.1 Introduction

This chapter interprets the results of the study and discusses their implication, based on the guiding research questions and the literature review. The goal is to deepen understanding of how software decay manifests in military software systems and how it can be successfully mitigated, while having to deal with highly regulated environments and long lifecycles. The central research question of this thesis is:

How can software decay in military systems be prevented or slowed down?

To explore this overarching question, two sub-questions were examined:

- What are the main causes and symptoms of software decay specific to the military software domain?
- Which mitigation strategies are currently in use at T-Systems IFS, Chapter Defense Systems and how effective are they?

The following discussion is structured around these questions. Firstly, the main cause and contributing factors of software decay are discussed, based on the challenges identified in the previous chapter. Particular attention is given to legacy constraints, procurement processes and organizational practices unique to the military domain. Following this, the mitigation strategies currently employed at T-Systems IFS are evaluated, focusing on their practical implications, effectiveness and limitations. Finally, the implications of these findings are assessed in terms of their relevance to broader software engineering practices, particularly in regulated, long-lived systems.
The discussion aims to bridge the gap between empirical observations and theoretical concepts as well as to provide practical recommendations for future projects to reduce technical debt and maintain long-term software quality in military systems.

5.2 Causes and Symptoms of Software Decay in the Military Domain

Addressing the first sub-question regarding the main causes and symptoms of software decay, the findings align with existing literature. The interviews highlighted the inherit complexity of long-lived military systems, reinforcing Brooks' (1987) concept of 'essential difficulties', like complexity, conformity and changeability, which are increased over time.

One of the most prominent causes is the long life cycle of military systems, which often leads to accumulation of outdated code, architectural rigidity and the use of obsolete technologies such as older C++ or Ada versions. This is a problem all throughout the military domain, as can be seen by the previously mentioned example of the German Air Force, where the Tornado system is still in use after 40 years. This supports the findings of Lehman and Belady (1976) who argued that software evolution inevitably leads to increased complexity and decay, especially in systems with long lifecycles. Additionally, interviewees reported difficulties caused by loss of knowledge when original developers retire, an issue Parnas' (1994) highlighted regarding documentation inadequacies and implicit knowledge.

Another recurring theme was the lack of early investment into the maintainability of the software as well as adaptability of the architectures. Several interviewees pointed out that many systems were designed decades ago, meaning the original architects and developers are no longer available. This makes it difficult to fully understand the system's architecture and design decisions, in turn making modifications and updates more risky and time-consuming. Over time, this contributes to a buildup of technical debt, particularly when quick solutions are chosen to meet delivery deadlines. This aligns with Parnas 'Lack of movement' theory, where a lack of proactive maintenance and refactoring leads to these problems. These issues were also noted by Shyu (2017), who emphasized that due to the long lifecycles, patchworks of legacy code are very common. She proposed more use of flexible architectures as well as self testing modular code to allow for easier updates and modifications.

Another notable finding is the influence of regulatory rigidity on software decay. The military domain's stringent compliance and documentation requirements, while necessary for safety and reliability, lead to an increase in software decay, due to limited flexibility. The constraints prevent proactive refactoring and architectural improvements, resulting in a focus on short-term fixes over long-term stability. This backs the findings of Kruchten (2012) where compliance-driven environments often inadvertently accumulate technical debt.

Organizational challenges also play a central role. Teams often work under rigid procurement and approval processes, where minor improvements may require extensive justification and approval from the stakeholders. This leads to non-functional aspects such as internal refactoring being neglected. Often developers are aware of weaknesses in the code but are unable to address them due to lack of authority and budget. This was also methioned by Schröder (2022) who stated that the current standard contracts do not allow some form of agility or iteration.

Furthermore, the interviews revealed a form of acceptance towards technical debt as an inevitable cost of doing business. This acceptance not only allows technical debt to persist but also can create a cycle where decay is managed reactively rather than proactively. This acceptance of technical debt underscores the need for a cultural shift on all levels, where by technical debt is recognized as a critical issue to be addressed rather than the implementation of new features. These findings align with McConnell's (2007) observations regarding the impact of organizational constraints on technical debt management.

Symptoms cited by participants included unreliable test scripts, incomplete documentation as well as system behaviour that is difficult to predict or reproduce. A particularly significant indicator of software decay is the difficulty in onboarding new developers. When new personal struggles to understand the system architecture, legacy code and the rationale behind design decisions, it often reflects insufficient documentation, lack of modularization and a high need for implicit knowledge. These problems can be found in Kruchten et al. (2012) definition of technical debt, which encompasses not only the code itself but also the surrounding processes and practices. These symptoms reflect structural issues such as lack of modularization, outdated documentation practices and insufficient test infrastructure, confirming theoretical assertions by Cunningham (1992) regarding the long-term maintenance consequences of technical shortcuts.

In summary, long lifecycles, legacy constraints, regulatory rigidity and organizational challenges not only align with theoretical concepts but also provide a practical understanding of how software decay manifests in military systems.

5.3 Mitigation Strategies and Their Effectiveness

Regarding the second sub-question about current mitigation strategies and their effectiveness, the analysis of the interviews reflects practices that align with other commercial practices, albeit with some unique military constraints.

One of the most prominent developments across all interviews was the increased use of automation in testing, building and deployment. The introduction of containerized environments and CI/CD pipelines allows for regular execution of tests and static code analyses, without the need for manual intervention. This improves not only the frequency of tests but also their reliability, as regressions and integration issues can be detected earlier. This is due to the fact that developers can no longer skip tests easily, since they are now part of the automated build process. This automation forces discipline that might otherwise be neglected under time pressure. Additionally, the automated pipelines allow for a scaled development process and ensure consistent quality, which is particularly important in long-lived systems. However, as Fowler stated, a functioning test suite and build process is key for CI to work correctly. Therefore both factors need special attention to make sure the pipeline gets used as intended. Additonally, it has to be insured that the pipeline is overall correctly configured as Silva and Bezerra (2022) found that the wrong quality levels and configuration can lead to a decrease in software quality.

Another practice used against software decay was the formal code review. This has evolved from inconsistent and informal peer checks into structured, documented processes involving multiple reviewers. Participants emphasized that code reviews not only help to catch mistakes and prevent technical debt but also serve as a way to share knowledge and create a team wide quality assurance. Code reviews are often combined with Git-based workflows, allowing a transparent history of changes and discussions. This is backed McIntosh et al. (2016) although he emphasized that the right participants play a major role in the effect of the the review, which was seen not as important by the interviewees.

Refactoring, while not always practiced over the entire codebase, is used in projects that have a more agile approach. In these projects, problematic components are occasionally rewritten or restructured. However, resource constraints and rigid approval processes limit a more systematic approach to refactoring. As one developer explained: 'wir haben jetzt keine festen Refactoring-Tickets, aber prinzipiell ist es jedem freigestellt, eigene Tickets zu erstellen.' This indicates that while there is a local initiative to address technical debt, a border process is still lacking. These reasons against refactoring align with the studies of Kim et al. (2014) and Tempero et al. (2017), which named costs, risks and lack of support from management as the main reasons why developers did not refactor, even though they would see it as beneficial.

Interviewees also stressed the importance of documentation improvements, especially the use of lightweight tools like Markdown or systems like Jira to track changes and decisions. Documentation is often a weak spot in legacy projects, but newer practices emphasize the importance of keeping documentation up to date by lowering the barrier for contributions by embedding it into the development process.

Despite these promising strategies, their effectiveness are often limited by domain constraints. These are either procurement, budgeting or legacy constraints. Automation, for example, can be highly effective once implemented, but requires significant initial investment which is not always feasible in the military domain. Similarly, while reviews and refactoring add value, they require time and the freedom to act, which is often limited by rigid processes and approval hierarchies.

In summary, mitigation strategies such as automation, code reviews, refactoring and better documentation are being adopted to prevent software decay. Although they are deemed as effective by practitioners, their impact on each project and its restrictions can vary considerably. Team maturity and organizational willingness to invest in the long-term health of the software are crucial factors in determining the success of these strategies. This aligns with the literature, which suggests that technical debt management is not only a technical challenge but also cultural and organizational.

5.4 Recommendations for Future Practice

Based on the current practices and challenges, the interviewed experts outlined several recommendations directed at better preventing software decay in future projects. These suggestions aim to improve the long-term maintainability and reduce the accumulation of technical debt within the constraints of the military domain.

A key recommendation was the expansion of agile practices, enabling a more flexible and iterative approach to the development. Agile methods were not only seen as useful to provide short feedback loops but also to prevent a misinterpretation of requirements. Additionally, interviewees found that sprints, issue prioritization and iterative delivery allowed a better communication with stakeholders and prevented technical debt. This aligns with the findings of Leite et al. (2024), who found that agile practices were the most used method for managing technical debt and by integrating them into the workflow, teams could reduce technical debt accumulation. However, successful and effective agile practices require the contractual framework to allow more flexibility and adaptability, which is not the case in many projects.

Another important theme was the prioritization of test maintenance. Several participants stressed the fact that test script should be updated with the code changes, rather than being an afterthought. Interviewees emphasized that even when the code is your own, the difficulty of understanding the code increases with time. By maintaining the tests parallel to the code, consistency of the tests is ensured as well as knowledge loss prevented. Through this a common issue is also avoided, where old tests decay while new features are introduced.

Closely related to this is the recommendation to work on continuous documentation, especially in a domain where software is bound to have a long lifespan. Documentation should be integrated into the development process, rather than being a separate task. Tools like GitLab or Jira allow the easy documentation of changes, decisions and the history of the project. In addition to the technical documentation, a focus on clear code comments is recommended. All these practices also help new developers to onboard faster, as the issue of rotating or retiring developers was mentioned as a major challenge.

Finally, the experts underlined the importance of early investment into maintainability. They emphasized that making initial costly decisions like modularization, testability or automation pays off significantly over time. As the average lifecycle of military systems is often decades, the initial investment is mostly negligible compared to the long-term costs of maintaining a decaying system. To prevent the initial cost being too high, the recommendation was to start small and gradually build up these practices, rather than trying to implement them all at once. This would allow them to be implemented even under tight timelines and budget constraints.

One aspect that was not mentioned as often by the interviewees as it was in the literature is the refactoring process. While Moser et al. (2008) provided evidence in a case study, that regular refactoring decreases complexity and prevent maintenance issues, the interviewees presented a reluctance to refactor. This is largely due to the fact that to refactor old code, a new contract from the customer is needed, which rarely happens as new features are prioritized over refactoring. Additionally, the risk of introducing new bugs is often seen as too high, especially in a domain where safety and reliability are paramount. This could be prevented by having a functioning test suite, which would allow for a more confident refactoring process. With a proper test suite as a safety net, the customer could be convinced to allow for refactoring, as the risk of introducing new bugs is significantly reduced.

Another practice that was not mentioned by the interviewees is the use of quality gates in the pipelines. While the interviewees confirmed the use of static analysis tools, there is no direct enforcement of the metrics. Due to the fact, that the metrics are already investigated, the recommendation would be to enforce certain thresholds in the pipeline, preventing addition of new code that does not meet the requirements. Uzunova et al. (2024) found that the use of quality gates allows for real time feedback and allows developers to catch issues early in the development process.

All in all, these recommendations show a clear awareness among practitioners of the challenges posed by software decay and the need for a proactive approach for mitigation. While the constraints of the military domain are significant and unlikely to change in the near future, even small procedural and cultural changes can make a substantial difference in the long-term maintainability of military software systems.

5.5 Limitations of the Study

Due to the nature of the qualitative research design, this study is not without limitations. Firstly, the empirical results are based on a semi-structured interview with a relatively small group at a single organization. While this allows for a detailed, in-depth exploration of specific organizational practices it also introduces context-specific bias, potentially limiting the applicability of the findings to other military organizations or domains.

Secondly, the selection of interviewees could create an additional bias, as the participants were directly involved with military projects within a single organization. Other, potentially external stakeholders such as procurement agencies or regulatory bodies were not captured. This omits different viewpoints that could have provided further context or insights into the constraints and practices.

Furthermore, the qualitative approach involves a subjective influence of the researcher. While efforts were made to employ a rigorous coding process, the risk of bias remains unavoidable to some extent.

Lastly, given the dynamic nature of software development, even within the military domain, the findings present a view of the current conditions and practices. Changes in regulations, technology or organizational practices may alter the relevance of the findings over time.

Despite these limitations, the insights gained from this study offer a valuable understanding into practical challenges and mitigation strategies within the military domain. Potential further research could expand on these findings by using a quantitative approach to validate the results across a broader sample of organizations and projects.

Appendix

Interviewleitfaden – Bachelorarbeit Softwareverfall

1. Einstieg und Hintergrund

1. Welche Rolle haben Sie aktuell im Bereich der Softwareentwicklung militärischer Systeme? Seit wann sind Sie in diesem Umfeld tätig und wie sieht Ihre typische Projektarbeit aus?
2. Mit welchen Arten von Softwaresystemen arbeiten Sie hauptsächlich? (z. B. eingebettete Systeme, einsatzkritische Plattformen, Verwaltungssoftware, Legacy-Systeme)

2. Legacy-Systeme und lange Lebenszyklen

3. Welche Herausforderungen begegnen Ihnen beim Umgang mit Legacy-Systemen oder langlaufenden Projekten?
4. Kommt es im Projektverlauf regelmäßig zu Problemen, die durch veraltete Strukturen oder historisch gewachsene Systeme entstehen?
5. Welche Auswirkungen haben lange Lebenszyklen auf Wartbarkeit und Weiterentwicklung?

3. Strategien zur Qualitätssicherung

6. Welche Maßnahmen setzen Sie ein, um Softwareverfall oder technische Schuld zu vermeiden oder zu reduzieren? (z. B. Refactoring, Reviews, Automatisierung) Sehen Sie diese Maßnahmen als sinnvoll?
7. Gibt es Bedingungen, unter denen technische Schuld bewusst in Kauf genommen wird? Wird bewusste Schuld getrackt?

4. Agile Methodik

8. Verwenden Sie agile Methodiken wie Scrum oder XP? Falls ja, wie wirken sich diese Praktiken auf den Umgang mit technischer Schuld und Softwareverfall aus?
9. Wenn keine agilen Methodiken verwendet werden, wie werden Refactoring und Schuldenabbau sonst durchgeführt?

5. Architekturmanagement

10. Wie wird die Systemarchitektur geplant, dokumentiert und gepflegt?
11. Wie wird sichergestellt, dass sich die Umsetzung an der vorgesehenen Architektur orientiert, insbesondere bei älteren Projekten?
12. Welche Herausforderungen treten bei der Weiterentwicklung von Architekturentscheidungen auf?

6. Automatisierung und CI/CD

13. Setzen Sie CI/CD in Ihren Projekten ein? Wie sehen die Prozesse konkret aus und hilft CI/CD gegen die zuvor genannten Probleme?
14. Welche Werkzeuge und Metriken verwenden Sie zur Qualitätssicherung im Build- oder Deployprozess? Was sind Ihre Erfahrungen mit diesen Werkzeugen? Gab es bestimmte Stärken oder Schwächen, die sich auf die Codequalität oder Wartbarkeit ausgewirkt haben?

7. Reviews und Tests

15. Wie wird bei Ihnen mit Code Reviews gearbeitet? Wer beteiligt sich, und wie wird der Prozess organisiert?
16. Welche Rolle spielen Tests? Nutzen Sie automatisierte Verfahren wie Unit-Tests oder Test-Driven Development? Gibt es bestimmte Tests, die Ihrer Meinung nach am besten zur Vermeidung von technischen Schulden helfen?

8. Besondere Rahmenbedingungen im militärischen Umfeld

17. Welche Anforderungen an Sicherheit, Zuverlässigkeit oder regulatorische Vorgaben wirken sich auf Ihre Arbeit aus?
18. Inwiefern beeinflussen Beschaffungsprozesse oder lange Freigabeschleifen Ihre Projekte in Bezug auf technische Schulden und Softwareverfall?

9. Abschluss

19. Können Sie ein Beispiel nennen, in dem eine Maßnahme zur Reduktion von technischer Schuld oder zur Vermeidung von Softwareverfall besonders erfolgreich war? Was genau machte diese Maßnahme aus Ihrer Sicht erfolgreich?
20. Gibt es weitere Erfahrungen oder Empfehlungen, die Sie im Zusammenhang mit Softwareverfall oder technischer Schuld teilen möchten?

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