Technical Debt and Maintainability: 
How do tools measure it?

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Abstract  The technical state of software, i.e., its technical debt (TD) and maintainability are of increasing interest as ever more software is developed and deployed. Since TD and maintainability are neither uniformly defined, not easy to understand, nor directly measurable, practitioners are likely to apply readily available tools to assess TD or maintainability and they may rely on the reported results without properly understanding what they embody. In this paper, we: a) methodically identify 11 readily available tools that measure TD or maintainability, b) present an in-depth investigation on how each of these tools measures and computes TD or maintainability, and c) compare these tools and their characteristics. We find that contemporary tools focus mainly on internal qualities of software, i.e., quality of source code, that they define and measure TD or maintainability in widely different ways, that most of the tools measure TD or maintainability opaquely, and that it is not obvious why the measure of one tool is more trustworthy or representative than the one of another.

1 Introduction

The Danish Agency for Digitization, under the Danish Ministry of Finance, prescribes a model for portfolio-management of central government IT systems [6], which requires all public agencies to map the “technical state” of central government IT systems for triennial review. One of the questions in the model asks the agencies to rate “How satisfactory is the technical state of the IT system today?” for all respective IT systems under their responsibility. The question must be answered on a scale ranging from 1 (very unsatisfactory) to 5 (extremely satisfactory). The manual for the model explains that the answer should be given by
assessing each system’s TD and the maintainability ("possibility to further develop and integrate the system"). However, the manual does neither specify how to assess TD or maintainability of a system nor what precisely is meant by these terms. Since neither of the two concepts is easy to understand nor directly measurable, managers and software developers are likely to rely on readily available tools to assess TD or maintainability. Some Danish agencies, such as the tax agency or the court administration, have used commercially available tools, for example those provided by the Software Improvement Group (SIG)\footnote{https://www.softwareimprovementgroup.com} to assess TD and maintainability of software systems \cite{3,4}.

However, there exists a multitude of tools that are reported to be suitable for identification and management of TD or maintainability, see Sec. 3. In practice, questions arise, such as, “How to understand the values or ratings that various tools produce for TD/maintainability?”, or “How are these values and ratings actually measured and computed?”, i.e., “What do they represent?”. We translate these generic questions into research questions for this paper:

RQ1 How do tools define the concepts TD or maintainability?
RQ2 How do tools measure and compute values for TD or maintainability?

To study our research questions, we identify a comprehensive list of 11 readily available tools, see Sec. 3, of which six are not covered in previous academic studies \cite{18,30,37}. Unlike previously studied tools, those included in this paper actually assess TD or maintainability. That is, they report direct measurements and ratings for these two concepts. For each tool, we provide a precise description of how these two concepts are defined, measured, and computed.

After investigating RQ1 and RQ2 (Sec. 4) we report (Sec. 5) that: a) not all tools define explicitly TD or maintainability even though they report measurements for these concepts, b) tools define and measure TD or maintainability in widely different ways, c) tools focus mainly on internal quality, i.e., quality of source code, and e) most of the tools measure TD or maintainability opaquely, so that it is not directly accessible why the measure of one tool is more representative than the one of another.

Note, other organizations than the Danish Agency for Digitization are interested in assessing TD or maintainability of software too. We believe that a nationwide institutionalized requirement to periodically assess TD or maintainability of software provides sufficient motivation to gain a thorough understanding of the above research questions. Thus, the goal of this paper is:

a) to allow practitioners to better understand if and to which degree the reports of certain tools are suitable for assessing TD and maintainability in their domain, and
b) to collect information that is otherwise scattered around a plethora of sources to gain a quick overview of how certain tools measure and compute TD and maintainability.

The goal of this paper is not to systemically identify as many tools as possible that assess TD and maintainability and the goal is not to recommend which tool to use to assess TD and maintainability.
2 Background & Related Work

The **TD** concept was coined in 1992 [13], as: “Shipping first time code is like going into debt. A little debt speeds development so long as it is paid back promptly with a rewrite. […] The danger occurs when the debt is not repaid. Every minute spent on not-quite-right code counts as interest on that debt.” [13]. It is a metaphor and it is imprecise by nature as it builds upon the assumption that we know what quite-right code is. However, we do not have generally true measures for software quality, i.e., quite-right code [10,28]. Often code quality is domain specific as for example stated in the ISO/IEC 25000 standard: “for interactive consumer software, such as word processor, usability and co-existence with other software […] is considered important. For Internet and open systems, security and interoperability are most important.” [26].

Likely, due to being a metaphor, the term **TD** was defined differently by various authors since its initial occurrence. Some authors define it solely in terms of source code [14, 15, 39], e.g., as “cost of the effort required to fix problems that remain in the code when an application is released to operation.” [39].

Others, consider **TD** more broadly than to be just caused by properties of code [7,16], e.g., Avgeriu et al. consider it as “[…] collection of design or implementation constructs that are expedient in the short term, but set up a technical context that can make future changes more costly or impossible.” [7]. Some practitioners consider **TD** more pragmatically and even more general. For example, for Birchall **TD** is “a metaphor for the accumulation of unresolved issues in a software project” [9], and for Radigan from Atlassian it is “the difference between what was promised and what was actually delivered.” [3].

Often practitioners rely on tools to quantify **TD**, where it is unclear how precisely the tools measure and compute **TD**. Tornhill presents an anecdote to illustrate the “perils” of quantifying **TD**: “I visited an organization to help prioritize its technical debt. […] the team had evaluated a tool capable of quantifying technical debt. The tool […] estimated how much effort would be needed to bring the codebase to a perfect score […] and the tool reported that they had accumulated 4,000 years of technical debt!” [44]. What do these 4,000 years of **TD** mean? Where do they stem from and how are they computed? This is the motivation for this paper. We want to better understand how contemporary tools quantify **TD** or maintainability and create values like the afore-mentioned one.

Similar in goal to this study, Fontana et al. [18] investigate how five tools define and measure **TD** with respect to conformance to architecture. The paper does not describe how the tools were selected, except of being known to the authors. Furthermore, some of the studied tools do not measure **TD** as such but perhaps related concepts, such as, Excessive Structural Complexity (Structure101), Structural Debt (Sonargraph), and a Quality Deficit Index (inFusion).

In this study, we rigorously identify tools that actually assess **TD** or maintainability. A recent tertiary study [37] identifies 31 tools for identification and measurement of **TD**. Since it is a tertiary study, the authors list all tools that are reported in secondary studies, leading to inclusion of concepts, such as, continuous integration or visualization techniques such as TD Board [38] or Code Christmas Trees [27] without being clear in which way these precisely identify or measure **TD**.

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[1] https://www.atlassian.com/agile/software-development/technical-debt
In this study, we consider all the listed tools again and identify only those that actually measure TD or maintainability.

Similarly, Lenarduzzi et al. [30] identify 25 tools that support software maintenance tasks. The authors categorize each tool into at least one main goal category, such as, bug detection, testing, code review, etc. However, from the study it is not clear to which degree the mentioned tools are suitable for assessing maintainability or to which degree they are just meant to support the goal for which they were categorized.

Ernst et al. [17] study conceptions of TD amongst software professionals revealing that – except architecture – engineers do not agree on the sources of TD, that less than 20% consider problems in source code as origin of it, and that TD assessment tools are rarely used since interpreting results is too complex. With our study we hope to complement that work by making explicit what such tools consider TD or maintainability and how these are measured and aggregated.

3 The Study

In this study, we address the following research questions:

RQ1 How do tools define the concepts TD or maintainability?
RQ2 How do tools measure and compute values for TD or maintainability?

Our study is executed in two phases, see Fig. 1. Phase 1 identifies tools that actually assess TD or maintainability from literature and industrial sources. Phase 2 studies the identified tools in-depth to answer our research questions.

3.1 Methodology

To identify tools for assessment of TD or maintainability we rely on four sources: a) a recent tertiary study on TD [37], b) a study by Fontana of five tools measuring aspects of TD [18], c) code quality tools from the GitHub Marketplace[7] and d)
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AlternativeTo, a crowd-sourced list of tools, which we queried for alternatives to “SonarQube”⁵. We select these sources for the following reasons:

The Fontana et al. study ¹⁸ it is – to the best of our knowledge – the only study on how tools measure and compute \( TD \) and related concepts.

The tertiary study ³⁷ collects tools for identification and measurement of \( TD \) from 13 secondary studies (covering 703 primary sources) and such a comprehensive list is likely to include all potential tools.

The GitHub marketplace is one of the most popular collection of Software as a Service (SaaS) development tools.

The crowd-sourced platform AlternativeTo, is meant to find tools with comparable features. We know from our previous professional work that practitioners find relevant tools based on similarity recommendations. As a starting point for finding alternatives we use the widely popular quality assessment tool SonarQube ²⁰.

Based on the four sources, we follow a four staged process to identify tools that actually measure and compute \( TD \) or maintainability, see Fig. 1. From Rios et al. ³⁷, we collect all 31 tools that are listed under the categories identification and measurement of \( TD \) in appendix F. From Fontana et al. ¹⁸, we collect all five studied tools. From the Github marketplace ⁶, we collect all 19 unique verified tools (which include commercial tools ⁷) from the categories code quality and code review. From AlternativeTo, we collect 14 tools that are listed as similar to SonarQube.

After deduplication (１) in Fig. 1 of tools from the four sources the number of unique tools is 63. For each of these, we perform a text search via Google on the corresponding website or online documentation for the three search terms “technical debt”, “maintainability”, “maintainable” (２) in Fig. 1. The Google query is of the form: site:<website> “search term” Only tools for which we can find “hits” to at least one of the three search terms (only true for 33 tools) are kept for a manual inspection of the corresponding website or documentation page (３). As many tools and vendors use \( TD \) and maintainability in blog posts, for marketing, etc., we exclude in stage (３) all those tools for which we cannot find evidence, e.g., screenshots, formulas, etc., on the websites/documentation that they provide an actual measure of \( TD \) or maintainability, leaving 17 tools. By actual measure, we mean that the tools have to provide a measure that is literally labeled with “technical debt” or “maintainability”, i.e., is not up to a user’s interpretation if a certain result represents either of the two. In case we are in doubt after checking the online resources, we briefly experiment with the remaining 17 tools (４) to see if an actual measure of \( TD \) or maintainability is provided in the tool’s user interface (UI). After which we are left with 11 tools that form the basis of our study in Phase 2. The 11 identified tools in alphabetical order are:

A. Better Code Hub [https://www.bettercodehub.com], ⁶
B. CAST AIP [https://www.castsoftware.com/products/application-intelligence-platform], ⁶
C. Code Climate Quality [https://codeclimate.com], ⁶
D. Code Inspector [https://www.code-inspector.com], ⁶
E. Codescene [https://codescene.io], ⁶

⁵ https://alternativeto.net/software/sonarqube/
⁶ https://github.com/marketplace
⁷ https://developer.github.com/marketplace/#unverified-apps
We study each of the 11 tools in depth based on the available documentation, related publications, and the tools themselves, i.e., we experiment with them. The results of this step (5) are presented per tool in the following section.

4 Results

In the following sections, we answer for each of the 11 tools the two research questions RQ1 and RQ2. Each section starts with how the respective tool defines the concepts $TD$ or maintainability after which, we describe how the respective tool measures and computes values for $TD$ or maintainability.

4.1 Better Code Hub

Better Code Hub (BCH) does neither define nor measure $TD$. Neither its documentation nor corresponding publications [22, 45] mention the concept. But, BCH defines maintainability as the property of “how easily a system can be modified” [45] and measures it as a ratio of compliance to ten guidelines – the SIG/TÜVIT Evaluation Criteria Trusted Product Maintainability (SIG MODEL) [1, 22, 45].

BCH measures the internal quality characteristic maintainability and its five sub-characteristics of modularity, reusability, analyzability, modifiability, and testability according to ISO/IEC 25010 [24] based on ten “guidelines” on 17 languages ranging from C# over PHP to Kotlin. Each sub-characteristic is measured by a metric whose implementation is not available. The guidelines are: a) Write Short Units of Code, b) Write Simple Units of Code, c) Write Code Once, d) Keep Unit Interfaces Small, e) Separate Concerns in Modules, f) Couple Architecture Components Loosely, g) Keep Architecture Components Balanced, h) Keep Your Codebase Small, i) Automate Tests, and j) Write Clean Code. Code can either comply or not comply to any of these ten guidelines.

The tool uses thresholds to decide if guidelines are respected or not. For example, to comply with a) Write Short Units of Code the following distribution for LOC per unit (functions, methods, etc.) has to hold: at least 56.7% of all units have $LOC \leq 15$, at most 21.4% of all units have $15<LOC \leq 30$, at most 15.4% of all units have $30<LOC \leq 60$, and at most 6.9% of all units have $LOC>60$. We extracted these thresholds by inspecting the tool’s UI during the analysis of a Java system (Apache Commons VFS) since no other resource specifies them explicitly. It is unclear if they are the same for other systems and other languages.

8 Only for CAST AIP and Visual Studio we do not experiment with the tools themselves.

9 https://bettercodehub.com/docs/configuration-manual  https://bettercodehub.com/docs/faq
SIG offers another commercial version on BCH called Sigrid \[1, 8, 22, 45\], which considers only eight guidelines, omitting \(i\) and \(j\) from above. For each guideline a five star rating is computed by comparing the results within each area with results of analyzing multiple hundreds of undisclosed systems. The stars are allocated with a distribution of 5%-30%-30%-30%-5%. This means that for a given guideline five stars (best) are assigned when the corresponding measure is among the best 5% compared to the other systems that SIG uses as reference, four stars when the measure is among the next 30%, etc. The individual ratings are then aggregated into an overall five star rating for the entire system \[45\].

**Observations.** It is unclear why the ten guidelines with the corresponding thresholds are chosen. In particular as they seem to be a moving target. During the history of the underlying SIG MODEL (SIG/TÜViT Evaluation Criteria Trusted Product Maintainability) they increased from five source code properties that are measured by the SIG MODEL see Heitlager et al. \[22\], over six source code properties, see Baggen et al. \[8\], to respectively nine in current version of the SIG MODEL \[1\] and ten such properties in Visser \[45\] and BCH \[87\].

### 4.2 CAST AIP

The company defines \(\text{TD}^1\) as: “the effort required to fix problems that remain in the code when an application is released.” \(10\) The documentation\[11\] of CAST Application Intelligence Platform (AIP) provides a configurable formula for computing \(\text{TD} \) in USD.

\[
\text{TD} = (\sum_{i \in \{\text{low, medium, high}\}} r_i \times n_i \times t_i) \times c_{\text{staff\,hour}} \frac{\$}{h}
\]

(1)

Where \(r\) is the ratio of respectively low, medium, and high severity rules that are violated and that should be fixed. \(n\) is the amount of such rule violations, \(t\) is the time that it takes to fix a violation of a certain severity. \(c_{\text{staff\,hour}}\) is the cost for staff to fix issues in USD per hour. In its default configuration, the ratio of low priority violations to fix \((r_{\text{low}})\) is set to zero and \(c_{\text{staff\,hour}}\) is set to 75USD per hour, i.e., the default of Eq. 1 is \(\text{TD} = ((0.5 \times n_{\text{medium}} \times 0.97h) + (1 \times n_{\text{high}} \times 2.56h)) \times 75\).

To measure \(\text{TD}_{\text{AIP}}\), AIP relies on more than 1 200 code checking rules in 28 programming languages \[14\]. Examples of such rules are “Avoid Artifacts with High Cyclomatic Complexity” (Python) a medium severity rule for keeping Cyclomatic Complexity (CC) below 20, or the high severity rule “Avoid header files circular references” (C). Severity levels can be adjusted by users.

AIP defines maintainability independently of \(\text{TD}_{\text{AIP}}\) as “the cost and difficulty/ease to maintain an application in the future.” \[12\] and computes it via the Maintainability Index (MI) \[13\] in two versions:

10. [https://www.castsoftware.com/research-labs/technical-debt-estimation](https://www.castsoftware.com/research-labs/technical-debt-estimation)
11. [https://doc.castsoftware.com/display/DOC83/Technical+Debt+-+calculation+and+modification](https://doc.castsoftware.com/display/DOC83/Technical+Debt+-+calculation+and+modification)
12. [https://doc.castsoftware.com/display/CAST/Glossary#Glossary-M](https://doc.castsoftware.com/display/CAST/Glossary#Glossary-M)
13. [https://doc.castsoftware.com/display/TG/CMS+Assessment+Model+-+Information+*+Halstead+metrics+in+CAST+Engineering+Dashboard](https://doc.castsoftware.com/display/TG/CMS+Assessment+Model+-+Information+*+Halstead+metrics+in+CAST+Engineering+Dashboard)
\[
MI_{SEI,3} = 171 - 5.2 \times \ln(V_{Hal,\lambda}) - 0.23 \times CC_{\lambda} - 16.2 \times \ln(LOC_{\lambda})
\]
\[
MI_{SEI,3} = MI_{SEI,3} - 50 \times \sin(\sqrt{2.4} \times r_{\text{comment},\lambda})
\]

In Eq. 2, \(V_{Hal,\lambda}\) is the average Halstead Volume of all modules, which is computed as \(V_{Hal} = N \times \ln(\eta)\) per module, where \(N\) is the sum of total amounts of operators and operands respectively per module and \(\eta\) is the sum of unique operators and operands respectively per module \([19, 21]\). \(CC_{\lambda}\) is the average \(CC\) (McCabe Complexity \([34]\)) of all modules, which is computed as: \(CC = e - n + p\) per module, where \(e\) is the number of potentially sequential statements in a module, \(n\) is the number of statements in a module, and \(p\) is the number of connected components in a graph of sequential statements. \(LOC_{\lambda}\) the average lines of code per module. \(r_{\text{comment},\lambda}\) the average ratio of lines of comments per module.

**Observations.** It is unclear if the \(MI\) are computed as presented in \([19]\) as that source is only implicitly referenced. Measurement of the values \(N, \eta, e, n, p\) for computation of \(V_{Hal}\) and \(CC\) is unspecified.

The \(TD\) formula provided in AIP’s documentation is slightly different from earlier versions reported in \([14, 15, 18, 39]\), where it was assumed that all issues take equally long to fix and that the distribution of the amount desired fixes was different. It is unclear why the current values are as they are and whether they will change again.

### 4.3 Code Climate Quality

Code Climate Quality (CCQ)’s documentation \([14]\) does not explicitly define the terms maintainability or \(TD\). But it states that maintainability is the opposite of \(TD\) and that “can be a challenge to measure. Static analysis can examine a codebase for potential structural issues.” The authors further argue that there “has never been a single standard, and so we set out to create one.”\([15]\)

CCQ computes a \(TD\) ratio as the ratio of total remediation time (also called “total technical debt time” \([15]\)), \(TD\), and an estimated time it takes to implement the entire source code (\(t_{\text{est.impl}}\)):

\[
TD_r = \frac{TD}{t_{\text{est.impl}}}
\]

A maintainability rating of each file and the entire system is computed based on \(TD_r\) as mapping to the discrete values A to F, where A is best, F is worst, and E omitted: A: \(TD_r \in [0.0, 0.05]\), B: \(TD_r \in [0.05, 0.1]\), C: \(TD_r \in [0.1, 0.2]\), D: \(TD_r \in [0.2, 0.5]\), F: \(TD_r \in [0.5, 1]\). \(TD\) is computed based on ten rules, so-called \(TD\) checks, applying to any of the eleven supported programming languages (Ruby, Python, PHP, JavaScript, Java, TypeScript, Go, Swift, Scala, Kotlin, C\#):

1. **argument count** (too many arguments per unit),
2. **complex logic** (too long Boolean expressions),
3. **file length** (too many lines in a file).

\(14\) https://docs.codeclimate.com/docs
\(15\) https://codeclimate.com/blog/10-point-technical-debt-assessment/
4. identical blocks of code (syntactic code clones),
5. unit complexity (units with too high cognitive complexity [11]),
6. unit count (too many units per modules),
7. method length (too many lines per unit),
8. nested control flow (too deeply nested control structures),
9. return statements (too many return statements per unit), and
10. similar blocks of code (structural code clones).

Code can violate any of the ten rules. Each rule has an associated time to fix a violation. The total remediation time \( t_{TD} \) is likely just the sum of the remediation time of each violation but that is not explicitly documented. \( t_{est \_impl} \) is computed based on the LOC. It is unspecified how it is done precisely. We contacted ccq’s support for clarification, e.g., on the factor to compute \( t_{est \_impl} \) out of LOC, but our questions were not addressed.

**Observations.** It is unspecified how the ten checks are precisely computed/implemented for the various languages. Also unspecified is the computation of \( t_{est \_impl} \), which remediation cost is associated to each of these rules, if they are the same from language to language, or where they stem from. This makes computation of reported maintainability rating and the \( t_{TD} \) ratios/remediation times intransparent.

### 4.4 Code Inspector

Code Inspector (CoIn) is likely the youngest tool in this study. We tested its beta version in Nov. 2019. CoIn defines \( t_{TD} \) via: “The technical debt Principal is the core issues that might incur rework/interests in the future.” [16] which it reports as amount of hours and as cost in USD (conversion rate: 70 USD per hour). CoIn does neither mention, define nor measure maintainability.

It is not specified how precisely \( t_{TD} \) in hours is computed. We contacted the author and he did not want to reveal the precise computation.

In the following we describe what we can infer from the online documentation [17] while analyzing the Java project Apache Commons VFS. The \( t_{TD} \) principal lists times and cost for remediation of four issue types that are each estimated differently:

* Code complexity as a \( CC \) value
* Readability as the length of units
* Duplicated code as density of number of duplicates per LOC
* Code violations as density per LOC of the number of violations of an unspecified amount of rules that are checked on source code [18]. Examples of such rules are style of variable names, undocumented functions, too many parameters per function, etc.

[16] https://www.code-inspector.com/analysis/plan/1961#collapsePrincipal
[17] http://doc.code-inspector.com/metrics.html
[18] https://www.code-inspector.com/analysis/plan/1961
[19] For each of the eleven supported programming languages (Java, Javascript, C, C++, Go, Ruby, Python, PHP, Scala, Shell scripts, Typescript)
Code violations are associated to severities critical, major, medium, and low.

It is stated that missing documentation on functions has a low impact on \( \text{TD} \), whereas inefficient code or code that might induce buffer overflows has a high impact on \( \text{TD} \), suggesting that different code violations influence \( \text{TD} \) differently. However, no more precise computations are specified. Additionally, it is unspecified how the mapping of measurement results to the values good, warning, and critical, via various thresholds, influence the final \( \text{TD} \) values.

Observations. The actual formulas for computing the \( \text{TD} \) (and any other given metric) are neither readily accessible nor documented in a way that allow to understand how analysis of \( \text{TD} \) works precisely. The reported \( \text{TD} \) values represent the expertise of the tool’s authors.

4.5 CodeScene

CodeScene (CoSc) – one of the youngest tools – is the only tool in this study that bases its analysis dually on information from version control system (VCS) history and source code artifacts. The authors call the inclusion of VCS history, behavioral analysis and they argue that: “we need to consider the temporal dimension of the codebase to avoid spending valuable time improving parts of the code that won’t have an impact.” [43].

CoSc defines \( \text{TD} \) as a “metaphor that lets developers explain the need for refactorings and communicate technical trade-offs to business people. […] Just like its financial counterpart, technical debt incurs interest payments.” [44]. No other definition can be found in the related publications [41–44]. CoSc does neither define nor measure maintainability.

Unlike other tools, CoSc does not compute \( \text{TD} \) as a single value. Instead the tool groups the four feedback categories listed below as \( \text{TD} \) in its UI:

1. Hotspots are modules with high complexity (LOC) and development activity (number of commits), which are visualized using a circle packing layout. They are considered to serve as a proxy for both \( \text{TD} \) and the interest on it [42].
2. Hotspot Code Health, lists a set of code biomarkers for the worst hotspots. Biomarkers are a set of code quality and maintainability metrics – the author wants to avoid using the terms quality and maintainability for detecting: code duplication, low cohesion, long methods, deeply nested logic, modularity issues, overall code complexity, etc. Biomarkers are computed on a scale from zero to ten and they are mapped to discrete color codes (red, yellow, green) for the current state of refactoring targets and their states during the last month and year. It is unspecified which code biomarkers exist for which language, how they are computed precisely, and what the corresponding thresholds are that lead to a certain color code.
3. Temporal Coupling (i.e., how often a file was committed with others) is used to indicate hidden architectural coupling in a code base and is listed under

\[\begin{align*}
\text{http://doc.code-inspector.com/metrics.html} \\
\text{https://codescene.io/docs/guides/technical/hotspots.html} \\
\text{https://codescene.io/projects/174/jobs/17668/results/code/hotspots/system-map} \\
\text{https://codescene.io/docs/guides/technical/biomarkers.html}
\end{align*}\]
too. It is not indicated how that influences precisely the computation of refactoring targets or how precisely it is related to "technical debt" (TD).

4. Refactoring Targets are computed by an unspecified algorithm from the list of hotspots. In the computation, parameters such as amount of temporally coupled files, amount of affected developers/teams, and likeliness of being a bottleneck for other developers are included.

Observations. As refactoring targets and biomarkers are computed transparently, CoSc merely recommends files worth refactoring instead of assessing TD of an entire system. The book [41] gives code examples for some of the performed computations but it remains unclear to which degree these are actually performed by CoSc.

CoSc seems to rely on three complexity measures at various points of the analysis [42]: Hotspots seems to be identified via LOC, complexity trends seem to be based on whitespace complexity [23], and code biomarkers seem to be based on McCabe complexity [34]. However, it is not clear nor argued why the various measures are used in these contexts (e.g., they could be also swapped around).

4.6 Kiuwan Code Analysis (QA)

Kiuwan Code Analysis (QA) (KQA) defines maintainability as “The capability of the software product to be modified.” [24] TD is defined as “a global effort measure to correct [...] detected defects” [25] where global indicates that KQA can measure TD for a portfolio of applications and for single applications.

KQA measures TD and maintainability via its own quality model called “Checking Quality Model for Software” (CQM), which according to the vendors implements the ISO/IEC 25000 standard focusing on internal quality. Similar to other tools it is based on static source code analysis rules. KQA calls rule violations defects. For the more than 20 languages that KQA supports (ranging from ABAP over Cobol, JavaScript, Java, Swift, to VB.NET) [27] per default, more than 1,300 rules are available, e.g., 216 default rules for Java. Each rule is implemented either as a Java class or via XML [28]. Associated to rules are one of the five quality characteristics security, reliability, efficiency, maintainability, or portability from the ISO/IEC 25010 standard [24]. Thus, maintainability is measured as the amount of defects associated with the that quality characteristic [29]. Out of the 1,300 default rules 32 are maintainability rules, of which six are for Java.

Additionally, each rule is associated to one of the five severities – also called priorities – very hard, hard, normal, easy, and very easy, which, per default, are

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24 https://www.kiuwan.com/docs/display/K5/Models+and+CQM
25 https://www.kiuwan.com/docs/display/K5/Governance+Summary
26 KQA is a commercial product, with which one cannot experiment independently. Instead one has to request a demo with a Kiuwan employee. To avoid a marketing session that could bias our investigation, we experimented with the sibling product “Kiuwan Code Security (SAST)”, which is accessible for trial, relies on the same quality model CQM, the same rules, and based on investigating the documentation only computes extra security related metrics and ratings.
27 https://www.kiuwan.com/docs/display/K5/Kiuwan+Supported+Technologies
28 https://www.kiuwan.com/docs/display/K5/Create+new+Kiuwan+Rules
29 https://www.kiuwan.com/docs/display/K5/Action+Plans+in+Code+Analysis
mapped to the effort values 8h, 4h, 30min, 6min, or 3min respectively, indicating the effort in time (man-hours) to fix defects. Without given formulas, TD said to be the amount of all detected defects weighted by the respective effort in time to fix them.\\(^{30}\)

An example for such an easy to fix rule is “Avoid assignments inside conditional expressions”, which corresponds to CWE-481. It identifies occurrences of assignments in, e.g., if conditions which can be confused with the more often desired comparison for equality.

Rules and their parameters, such as effort or priority values, are configurable. Also, they can be created by implementing Java classes or XML files. Next to the default rules, KQA allows to integrate results of other static analyzers such as PMD, Findbugs, Checkstyle, etc.\\(^{32}\)

**Observations.** In KQA maintainability and TD are not dialectic concepts. Maintainability measures are aggregated into TD. Even though all rules are listed and described, there is no implementation available for public inspection.

4.7 NDepend

NDepend, a tool for C# and other .Net platform languages, defines TD as time it takes to fix occurrences of code that do not conform to certain specifications. NDepend does neither define nor measure maintainability.

TD is measured via 216 static code analysis rules, which are readily accessible. Each rule is expressed in Code Query Linq (CQLinq), i.e., Linq queries that query .Net code via a particular API. Due to space constraints we cannot show the implementation of a rule here, but each rule’s implementation is accessible online too. For example, the CQLinq rule Nested types should not be visible checks that nested types are declared private. When source code violates a rule, NDepend creates a corresponding issue i with associated severity level and TD debt(i). The latter can be freely computed per rule, see line 12 of the CQLinq Source Code and the tool’s authors define it as “the estimated man-time that [it] would take to fix the issue” for the entire source code is measured in man-days and computed as the sum of debt associated with each issue, normalized to man-days (t_{work}=8h in the formula below being a customizable default):

\[ \text{TD} = \frac{\sum_{i \in \text{Issues}} \text{debt}(i)}{t_{work}} \] (4)

\\(^{30}\) [https://www.kiwan.com/docs/display/K5/Governance+Summary#GovernanceSummary-TechnicalDebt]
\\(^{31}\) [https://cwe.mitre.org/data/definitions/481.html]
\\(^{32}\) [https://www.kiwan.com/wp-content/uploads/2018/09/Datasheet-Code-Analysis-QA.pdf]
\\(^{33}\) Although not formally identified by the methodology presented in Section 3.1, the discussion applies also to the sibling products JArchitect for JVM based languages [https://www.jarchitect.com/] and CppDepend for C++ [https://www.cppdepend.com/].
\\(^{34}\) [https://www.ndepend.com/default-rules/NDepend-Rules-Explorer.html]
\\(^{35}\) [https://www.ndepend.com/docs/cqlinq-syntax]
\\(^{36}\) [https://www.ndepend.com/default-rules/NDepend-Rules-Explorer.html?ruleid=ND1306]
\\(^{37}\) [https://www.ndepend.com/docs/technical-debt]
Technical Debt and Maintainability: How do tools measure it?

Technical Debt (TD) can be converted to a monetary value where the default price for a man-hour is 50USD, both price and currency are customizable.

NDepend also computes the annual-interest ($p_{yr}$) of TD either via the severities or via a dedicated annual-interest clause per rule. The severity values info, minor, major, critical, blocker are associated to annual-interest ($p_{yr}$) as: info:$p_{yr} \in [0 \text{ min yr}, 2 \text{ min yr}]$, minor:$p_{yr} \in [2 \text{ min yr}, 20 \text{ min yr}]$, major:$p_{yr} \in [20 \text{ min yr}, 2 \text{ h yr}]$, critical:$p_{yr} \in [2 \text{ h yr}, 10 \text{ h yr}]$, and blocker:$p_{yr} \in [10 \text{ h yr}, \infty]$. That is, severities are discrete annual-interest values given in rules. In case continuous values are desired, annual-interest clauses can implement arbitrary computations. The total annual-interest is the sum of the interest declared for all issues.

NDepends shows the TD ratio ($TD_r$) as a second value for TD (both the values are listed next to each other under TD):

$$TD_r = \frac{c_{rem}}{c_{dev}}$$

Where $c_{dev}$ is the cost to develop the software and $c_{rem}$ is the remediation cost, i.e., the cost to fix all issues, the TD value computed above. The development cost is computed as $c_{dev}=8.64 \text{min} \times \text{LLOC}/t_{work}$ as NDepend estimates that it takes 18 man-days to develop 1 000 logical lines of code (LLOC) that are fully tested and documented. NDepend operates with the measure of logical lines of code, which are inferred out of assembled artifacts.

A TD rating is a mapping of the $TD_r$ to the discrete values A to E (A is best, E is worst). It is computed as in the following A:$TD_r \in [0,0.05]$, B:$TD_r \in [0.05,0.1]$, C:$TD_r \in [0.1,0.2]$, D:$TD_r \in [0.2,0.5]$, and E:$TD_r \in [0.5,1]$. Both TD ratio $TD_r$ and the TD rating are computed according to the SQALE method.

Observations. NDepend offers fine-grained control over computation of TD via clauses for TD and annual-interest computation in each rule. Via these rules, the measurement and computation of TD is transparent.

4.8 SonarQube

SonarQube (SQ) defines TD as the “Effort to fix all Code Smells.” The effort per “code smell” is given in minutes and aggregated across all of the identified smells. When converted to man-days an 8 hour working day is assumed. The term maintainability is not defined explicitly.

For SQ code smells are certain patterns in source code that are considered bad practice, e.g., “Something that will confuse a maintainer or cause her to stumble in her reading of the code.” The default installation of SQ (version 7.8) contains 1 740 code smell detection rules for many programming languages (Python 417, Java 340, C# 261, JavaScript 137, PHP 114, TypeScript 96, VB.NET 89, Flex 64, HTML 41, Kotlin 39, Ruby 38, Scala 38, Go 33, CSS 14, XML 14, JSP 5). For example, the rule S1871 (in the design category) checks that alternative blocks of if statements should not be the same. Due to space constraints we cannot

38 https://www.ndepend.com/docs/code-metrics/NbLinesOfCode
39 https://docs.sonarqube.org/latest/user-guide/metric-definitions/#header-6
40 https://docs.sonarqube.org/7.8/extend/adding-coding-rules/
41 https://github.com/SonarSource/sonar-java/blob/62670ebc03aa01346f96640a2aa999d3487d973/java-checks/src/main/java/org/sonar/java/checks/IdenticalCasesInSwitchCheck.java
show the implementation of a rule here, but they are all accessible online. Rules are typically implemented via XPath or Java code via classes containing methods analyzing AST nodes.

Rules are categorized into one of the six remediation effort categories: trivial, easy, medium, major, high, and complex, that indicate how hard it is to fix a corresponding issue. The associated remediation effort depends on the programming language that a rule checks. Per default, they are: 5–10min (trivial), 10–20min (easy), 20–30min (medium), one hour (major), three hours (high), and 8 hours (complex). The sum of all remediation efforts, i.e., the total time to fix each detected code smell, forms the remediation cost ($c_{rem}$). SQALE calls this cost both $TD$ and $SQALE$ index, using thus three terms for the same concept. Additionally, a $TD$ ratio ($TD_r$) is computed as:

$$TD_r = \frac{c_{rem}}{(c_{per\_line} \times LOC)}$$

where the cost to develop a line of code ($c_{per\_line}$) is set to 0.06 days, with an 8h man-day conversion, $c_{per\_line} \approx 30\text{min}$.

Using the $TD_r$, a maintainability rating (also called SQALE rating) on a discrete scale from A to E (A is best and E is worst) is computed. The documentation states that the mapping from $TD_r$ to maintainability rating is: “A=0-0.05, B=0.06-0.1, C=0.11-0.20, D=0.21-0.5, E=0.51-1”. Consequently, for maintainability is a discretized ratio of $TD_r$ (per software development cost).

Observations. Computing $TD$ and maintainability rating is done with the SQALE method [32], which provides the formulas above though with different names. SQALE provides documentation on how a user can create their own rules. Current rules target source code; but as far as we understand it would be possible to define rules for non-code artifacts.

4.9 SQuORE Software Analytics

For SQuORE Software Analytics (SSA), $TD$ is the “cost of refactoring software to remove all defects and comply with quality requirements” [2] or “the human effort that shall be invested for the project in order to fix all deviations from the quality standard.” [44] Maintainability, as in ISO/IEC 14764 [25], is the “capability of the software to be modified.” [45]

$TD$ is computed based on 1,857 static code analysis rules – called the SQuane Sources –, which are listed in the manual for 17 programming languages ranging from ABAP to Xaml. [45] An example for such a rule is Commented-out Source Code is not allowed, which raises a violation if commented out source code exists. Additionally, SSA can integrate metrics from 84 tools, such as, PMD, CheckStyle, FindBugs, etc.

Rules are associated to a remediation cost ($c_{rem}$) and so called ISO characteristics. Remediation costs can be tiny, low, medium, high, and huge, which are mapped

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42 https://github.com/SonarSource
43 https://docs.sonarqube.org/7.8/extend/adding-coding-rules/
44 https://demo.squore.net/SQuORE_Server/XHTML/MyDashboard/Dashboard.xhtml
45 https://demo.squore.net/SQuORE_Server/api/documentation/reference_manual/index.html
ISO characteristics are the quality characteristics maintainability, reliability, efficiency, portability, security, testability, changeability, which – in this form – come from the SQALE model [32] which is not an ISO standard.

SSA computes $TD$ per artifact, which can be anything from a method, a file, to a package, and entire systems [36]:

$$TD = \sum_{v \in V} (n(v) \times c_{rem}(v))$$  \hspace{1cm} (7)

where $V$ is the set of all reported rule violations, $n(v)$ the amount of violations of a certain rule and $c_{rem}(v)$ the cost in minutes according to associated remediation cost. $TD$ is reported either in minutes, hours, or man-days. From inspecting the UI, we observe that 8 hours and 20 minutes correspond to one man-day, which is unspecified in the manual [47].

Maintainability is computed as the sum of remediation cost of all violations associated to the maintainability quality characteristic. The manual is explicit about that $TD$ and maintainability are two separate concepts [36] $TD$ can be computed for the other quality characteristics besides maintainability.

**Observations.** SSA is highly complex with a quite convoluted UI presenting a plethora of measurements and the information in the UI and in the manuals is inconsistent. For example, the UI lists the seven quality characteristics maintainability, reliability, efficiency, portability, security, testability, changeability where the manual mentions only five omitting testability and changeability, $TD$ of some artifacts is reported as, e.g., 7min 30s, where the question arises from where 30s stem from when the lowest remediation cost is set to one minute and the $TD$ formula operates with integer multiples. It is unspecified how the tools’ proprietary rules are implemented.

4.10 SymfonyInsight

SymfonyInsight is a tool to automate $TD$ monitoring and quality of PHP based web-applications [48]. Maintainability is not explicitly defined by SymfonyInsight and $TD$ is defined as the “estimated time a single developer would need to fix all the issues detected by SymfonyInsight”, which in the tool’s UI is also called remediation cost. The value for $TD$ is provided in days, months, or years. It is unspecified how that number is computed and if it is in man-days or plain days.

Likely, computation is based on the results of applying 110 static analysis rules [49] (which can be disabled by the user). An example of such a rule is #11-013 *Database queries should use parameter binding*, which finds code that is prone to SQL injections and suggests possible fixes. Rules are organized into seven categories security, architecture, performance, dead code, bug risk, readability, and coding style. Each rule has a severity like info, minor, major, and critical and a

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46. https://demo.square.net/SQuORE_Server/api/documentation/swan_handbook/index.html#sect_computation
47. https://demo.square.net/SQuORE_Server/api/documentation/index.html
48. https://insight.symfony.com/
49. https://insight.symfony.com/what-we-analyse
time to fix attached to it. That time does not seem to be related to severity as we find rules in the major category that take 15 minutes vs. two hours to fix. We understand that \( TD \) is just the sum of all the times to fix each single issue. The \( TD \) is – in an unspecified way – mapped to five discrete values a quality score given as medals (no medal, bronze, silver, gold, or platinum).

Even though not explicitly defined, a maintainability measure as percentage of change compared to the latest analysis is provided\(^{50}\). From the UI it appears as if the dead code rules correspond to maintainability. Dead code comprises of seven rules, including commented out and unreachable code. It is unspecified how the change of maintainability is computed.

**Observations.** Using the term remediation cost and mapping quality metrics to discrete measures (medals) suggests that computation of \( TD \) is inspired by the SQALE method. However, without feedback from the vendors, one cannot be sure about this. We contacted the tool vendors, to mitigate high-level documentation and unspecified formulas for \( TD \) and maintainability but we did not receive a reply detailing these.

### 4.11 Visual Studio

According to its documentation\(^{51}\), Visual Studio (\( vs \)) does neither define, measure, nor compute \( TD \). Although the documentation mentions maintainability, the concept is not explicitly defined. However, it is documented to be computed using a modified\(^{52}\) version of \( MI \) which is calculated as a normalized value between 0 and 100, where higher values represent better maintainability\(^{53}\). Other than Eq. 2, the modified \( MI \) does not consider comments in source code.

\[
MI = \max(0, (171 - 5.2 \times \ln(V_{Hal}) - 0.232 \times CC - 16.22 \times \ln(LOC))^2 \times \frac{100}{171})
\]  

\( VS \) reports a \( MI \) at various granularities, ranging from project, over file, all the way down to a function or method. When presenting this information, the value is complemented by an icon, which maps maintainability to one of the three “levels”: high (between 20-100), moderate (between 10-19), and low (between 0-9).

Seemingly simple functions, it is unspecified how exactly \( V_{Hal} \), \( CC \), and \( LOC \) are computed. It is likely that \( V_{Hal} \) and \( CC \) are implemented as in \(^{21,34}\) and as described in Sec. 4.2. Based on the documentation it seems that \( CC \) is computed as originally defined: \( v = e - n + 2p \) \(^{34}\) (which is a difference of factor two compared to the way AIP computes it, see Sec. 4.2).

**Observations.** Transparently, the documentation mentions the use of \( MI \). However, the authors stop short of describing how exactly \( V_{Hal} \) is implemented. For \( CC \) the documentation does not specify what \( VS \) considers operands and operators

\(^{50}\) https://insight.symfony.com/docs/manager/the-portfolio.html
\(^{51}\) https://docs.microsoft.com/en-us/visualstudio/?view=vs-2019
\(^{52}\) https://blogs.msdn.microsoft.com/zainnab/2011/05/26/code-metrics-maintainability-index
\(^{53}\) https://docs.microsoft.com/en-us/visualstudio/code-quality/code-metrics-values?view=vs-2019
Tab. 1 presents the eleven TD/maintainability assessment tools. From these, two tools measure solely maintainability (A, K), four tools measure solely TD (D, E, G, J), and the remaining five tools measure both. That is, more tools provide a measure for TD than for maintainability. Six tools (A, D, E, F, I, J) are newly identified in this work compared to previous academic works [18,30,37]. Notably, all eleven tools provide an actual measure of TD or maintainability.

5.1 RQ1: Defining TD/Maintainability

Unlike in academia, where there is a trend and effort on settling on a common definition of TD [7], there seems to be no such trend in the world of the creators of the studied tools. The tools that provide a measure for TD provide their own and distinct definitions of it, see Sec. 4. Even the two tools SonarQube and NDepend that explicitly state that they are based on the same method for managing TD (SQALE), do not define TD in the same way. Nevertheless, the TD definitions of CAST AIP, Kiwan Code Analysis (QA), NDepend, and SonarQube are conceptually similar in that they consider TD to be: the cost/time/effort it takes to fix a certain set of problems/issues/defects in code. However, the formulas for computing TD and estimating times do not share these similarities. Of the seven tools...
that measure maintainability only three define it explicitly, and each defines it differently as the cost and difficulty to maintain an application (B), the capability of software to be modified (I), and as an estimate of TD (C). Consequently, the users of any of the tools must ensure that their understanding of TD or maintainability is aligned with that of the tool builder.

5.2 RQ2: Measuring TD/Maintainability

All nine tools that measure TD (except of CodeScene) are based on the concept that a set of static analysis rules – ranging from 10 to over 1000 – check source code for certain undesired patterns. These rules are either categorized into severities with associated remediation cost (B, H, I, J) or have remediation costs assigned directly on a per-rule basis (C and G). The way the remediation costs are aggregated and converted to other values is different from tool to tool.

All TD measures are computed on source code only. Only CodeScene enhances the static code analysis by including a social aspect of software engineering via the analysis of VCS histories. Such a low-level understanding of TD may differ from the mental model of stakeholders applying a tool. For example, Ernst et al. [17] demonstrated that software engineers might misinterpret the results presented by the tools since they would expect them to express more architectural issues of the software.

The maintainability measures seem to fall into three categories, either a) based on a variation of the MI [12,35] (B and K), b) based on a set of static analysis rules associated to maintainability (A, F, I), or c) as a mapping from TD measures to discrete values (C and H).

Interestingly, two tools (B and K) still apply the MI to assess maintainability. The index is not undisputed [22,29], for example, because it “does not provide clues on what characteristics of maintainability have contributed to that value, nor […] what action to take to improve this value.” [22]. Additionally, simpler metrics such as LOC or whitespace complexity are proposed as proxies for it [23].

Six tools (A, B, F, G, H, I) are either based on SQALE [33], which is based on the ISO/IEC 25000 [26] series of standards, or they are inspired by these two. However, all these tools actually only consider the internal quality model of ISO/IEC 25010. But that standard actually contains another “quality in use” model and a “data quality model” in ISO/IEC 25012. The latter two models are not regarded by any of the tools, which might lead to a wrong understanding of the reasons of TD as there seems to be a dualism between program complexity as for example measured by the McCabe Complexity and a corresponding data model.

5.3 Implications

None of the tools in this study provides a rationale for why certain static analysis rules are applied or why particular parameters for aggregation are appropriate. Moreover, definitions and ways of measuring TD or maintainability are diverse across vendors and tools, and customers applying these tools have to trust that given a vendor knows how to identify TD or maintainability. It would be in the
interest of the vendor to be as transparent as possible to increase the confidence of the customer.

As discussed in Sec. 4, multiple tools allow the user to configure which rules are active while analyzing software. Some tools (e.g., G and H) allow users even to implement custom rules. With such tools one could – as advised by SQALE or ISO/IEC 25000 – “start by making a list of nonfunctional requirements that define the ‘right code’ [architecture, etc.]” [33], specify how to assess these requirements, and decide how to aggregate them into higher-level reports or map them to quality characteristics, such as, maintainability. Thereby, one can assure that all stakeholders share a common understanding of \( \text{TD} \) or maintainability. Otherwise, when applied directly, i.e., without specifying nonfunctional requirements a-priori, all tools will generate values similar to Tornhill’s anecdotal and opaque 4000 years.

In fact, it is possible that one of the reasons of the relative popularity of SonarQube compared to other tools in this study [54] is that measurements and computations in it are traceable and configurable. That is, it is transparent how values are measured based on which input data and how precisely they are aggregated into higher level measures. Thereby, users have the possibility to tailor, and be aware about the qualities that contribute to \( \text{TD} \) and maintainability. To our understanding the only two tools in this study that are configurable and traceable are SonarQube and NDepend.

However management might be inclined to apply one of the studied tools directly to increase maintainability and decrease \( \text{TD} \) in the hope that developers that know their work is observed will likely think twice before implementing “not quite right code” similar to people that change their online behavior when they know they are surveilled [36].

5.4 Threats to Validity

Likely, there exist more tools for assessing \( \text{TD} \) or maintainability. However, by receiving the input for our study from academic and industrial sources, we believe that we covered a wide-range of potential tools, especially since our list of tools extends previous academic work [18,30,37] substantially. After also inspecting the tools from [30], we believe that we would not have found fundamentally different ways – only more variation in formulas – for measuring and computing \( \text{TD} \) or maintainability than those described above.

We might have misunderstood or misinterpreted available documentation of the tools. We tried to carefully gather and understand all available information. When in doubt we tried to contact the vendors with our questions and examples via their official support channels as indicated in the respective sub-sections of Sec. 4.

6 Future Work

Since the contribution of this paper is to properly understand how the identified tools actually assess \( \text{TD} \) or maintainability, we have to refer a deeper analysis of

54 https://trends.google.com/trends/explore?q=SonarQube,NDepend,CAST%20AIP,Kiuwan%20Code%20Analysis,SQUORE%20Software%20Analytics
similarities and differences across tools as well as a study of possible convergence to a more uniform understanding of TD to future work.

Furthermore, we plan an experiment in which we apply the listed tools to assess
and maintainability of a set of predefined systems. The goal is to quantify how much these measures vary depending on the chosen tool for the same system.

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