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A Tertiary Study on Technical Debt Management over the last lustrum

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Abstract. Technical Debt (TD) can be defined as any incomplete, immature, or inadequate artifact resulting from delayed activities or tasks that, if not resolved in a timely manner, may cause future problems. The objective of this article is to present a state of the art on TD, according to what has been reported in the last five years. To identify and interpret the results of the available research on TD on its management in the context of Software Engineering, a tertiary study was carried out under the approach of a mapping study, in which 19 secondary studies that included aspects related to TD were analyzed. A set of research questions were posed regarding types of TD, management activities, as well as human factors mentioned in the studies. The authors found areas of opportunity on the relationship between TD and human factors in topics such as morale, experience, human participation, and feelings.

Keywords: Software Engineering, Technical Debt, Tertiary Study.

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1 Introduction

Almost six decades after the so-called “Software Crisis”, Software Engineering (SE) has a body of knowledge recognized by professionals and researchers linked to the discipline [1, 2], however, since its conception as an engineering discipline, has maintained a dynamic of continuous improvement in relation to methods, techniques, tools and good practices, this dynamic being what motivates the need for research in it.

The study of approaches linked to software development, operation and maintenance processes has been analyzed considering various variables, however, the intrinsic social aspect of the discipline [3] has led to considering the use of empirical methods [4] to contrast theoretical or innovative proposals with observations regarding their applicability in real or close to reality contexts. One of the variables that has results of interest to the authors is the construct called “technical debt”, which can be described as those software development processes that consciously generate incomplete artifacts or, where appropriate, that avoid certain tasks, with the intention of prioritizing other artifacts or other activities. The objective of this article is to present a state of the art on said construct, according to what has been researched and reported in the last five years; for the above, the findings of the tertiary study developed by the authors are described.

2 Background

2.1 The Construction of Technical Debt

The term “debt” in the software area was cited for the first time in 1992 by Cunningham [5]; in this report, the author comments that "borrowing" with immature code in small quantities could accelerate development without harming the client's expectations, as long as it is "paid" with rewriting as soon as possible, since, if this

is not paid on time or never paid, it would generate "interest" for every minute spent on code that is not entirely correct; as you can see, the term implies a metaphor that alludes to a type of financial debt.

Although initially the construct was limited to the programming phase, it has currently been expanded to the complete software process, that is, to the requirements, design, testing phases and any activity related to software development and that has a certain impact on the project life cycle [6]. We can define technical debt as any incomplete, immature, or inadequate artifact resulting from suboptimal processes, activities, or tasks that, if not resolved in a timely manner, can cause future problems [7, 8, 9]; however, these definitions do not analyze whether this is done on purpose or by accident. In this sense, according to [10], we can classify technical debt into two types: (1) unintentional, and (2) intentional. The first basically refers to the incompetence, little care, and attention of those involved in the project, that is, it is the non-strategic result of incorrectly carrying out a job, which is not aware of its existence [11]. On the other hand, in intentional debt, the conscious decision is made to incur the debt to obtain a benefit within a certain period [12]. The latter can be divided into short and long term; The first is reactive, that is, it is used as a late measure to be able to obtain a benefit quickly, which, in the same way, must be paid just as quickly; for its part, the second is proactive, taken in a more strategic way, it can be paid years later [10].

On the other hand, in the context of technical debt management, [13] comments that the causes of this metaphor can be analyzed from the perspective of four quadrants, on one axis there is a continuum that goes from prudence to recklessness, and in the second axis we have at the extremes, deliberation and inadvertence.

2.2 Previous Studies

According to [14], primary studies are those that use primary research methods, and allow obtaining empirical evidence on a topic of interest. On the other hand, secondary studies are those that use secondary research methods, with such studies the research dynamic consists of collecting and synthesizing available evidence from reported (published) primary studies to answer certain research questions. Finally, tertiary studies are defined the same as secondary studies, but these extract their information from secondary studies and the questions are broader.

In this century, the topic of technical debt has become a topic of interest in Software Engineering. An informal review of secondary studies allowed us to identify a set of fourteen studies published between 2013 and 2022, which led us to search for tertiary studies on the topic, finding a couple of such studies [15, 16].

The first of the tertiary studies analyzed was published in 2018 [15] and establishes as its main objective to investigate the current state of research on technical debt evidenced by secondary studies; uses as methodology the guidelines for conducting systematic literature reviews proposed by Kitchenham and Charters in [17] and the procedures defined by Brereton et al. in [18]. The study considers seven digital libraries: IEEE Xplore, ACM Digital Library, Science Direct, Engineering Village, Springer Link, Scopus and Scitepress; with which after the search and filtering process it reports thirteen selected secondary studies. The research questions posed were: (1) What study topics have been investigated? (2) What research directions and practical insights can be identified, (3) What are the known types of technical debt? and (4) What are the activities, strategies and tools that have been proposed to support technical debt management? The authors reported as identified themes: (1) Concepts of technical debt, (2) Debt management and (3) Identification of technical debt; The study also reports a set of implications: 19 for researchers and 15 for professionals; Regarding the types of technical debt, the authors identify 15 types, the same ones proposed by Alves in [19]; Finally, the authors build a map that represents the panorama of technical debt management, which is structured by four main elements: Macro technical debt management activity, Technical debt management activity, Technical debt management strategy and Tool of support.

The second study analyzed was published in 2022 [16]; This study, developed with a qualitative approach, declares as its objective to synthesize evidence on the conceptualization, characteristics and management of technical debt in software projects; They obtained a total of 19 secondary studies; defines three research questions: (1) What is the current understanding of technical debt and its characteristics as evidenced by secondary studies in technical debt?, (2) What is the current understanding of technical debt management as evidenced secondary studies in technical debt? and (3) What are the main challenges in technical debt research? As results of the study, contributions of definitions, characteristics, actions and technologies on technical debt were reported; causes of the presence of technical debt, such as project constraints and team members; identified

the impact and challenges of technical debt; Likewise, a conjectured conceptual model of technical debt was built; Finally, they conclude that there is an overload of interpretation regarding the definition of technical debt, causing any problem that arises during software development to be classified as technical debt.

Based on what was identified with the two previous studies, the authors decided to carry out a new tertiary study, since in principle, there is an important set of secondary studies; On the other hand, the first tertiary study described above is from six years ago, so it is not very recent and does not take into account certain nuances about the type of research carried out, such as knowing whether the studies found are reviews or systematic mappings, expand your question five to "solutions", to take into account approaches, techniques, practices and methods or the link between technical debt and the human factor, that is, we want to extend this study a little, in addition to updating it; For its part, the second study identified, although it is more recent, focuses on the development of a state of the art on technical debt, its management, concepts and characteristics in general; Finally, it was decided to carry out the study in order to find an area of opportunity to carry out a systematic literature review on a topic linked to technical debt, but that has not yet been addressed or at least not sufficiently.

3 Research Method

In order to identifying, evaluating and interpreting the results of the research available on the construct of Technical Debt, in particular its management in the context of Software Engineering, the proposal in [17] was used as a methodological reference, with adaptations of the guide proposed in [20]; However, given that the studies selected and analyzed are secondary studies, formally our study corresponds to a tertiary study, in which a comprehensive view of the evidence collected is provided [14]. The activities considered in the planning, execution and dissemination of results phases are listed below:

- *Planning.* Formulation of research questions, selection of Data Bases, elaboration of the search string, and definition of eligibility criteria.
- *Execution.* Configuration of the search string in Data Bases and selection of relevant studies.
- *Dissemination of results.* Extraction of data and preparation of the report.

4 Planning Phase

In the Planning phase, the research questions that will guide the study, the Data Bases selected to carry out the searches, the terms and chain created for the search process, as well as the inclusion and exclusion criteria that will serve to refine the selection are established of the studies found.

4.1 Formulation of Research Questions

For the study, a set of research questions (RQ) were defined that will allow establishing a state of the construct of technical debt, in particular, in a series of aspects of its management that are of interest to researchers. The questions that guide this tertiary study are the following:

RQ-01: What is the distribution in the last lustrum of the different types of secondary studies published on the construct of technical debt?

Purpose: Identify the magnitude of research conducted on technical debt, as well as the type of secondary studies conducted.

RQ-02: What solutions (approaches/techniques/strategies/practices/methods/tools) have been proposed in secondary studies published from 2018 to 2023?

Purpose: Identify the type of solutions proposed for technical debt management most reported in secondary studies, as well as the relationship between them.

RQ-03: On what type of management activities have the solution proposals described in the secondary studies published from 2018 to 2023 been focused?

Purpose: Identify the technical debt management activities most investigated and reported by secondary studies, according to the proposal of [21].

RQ-04: What types of technical debt have been characterized in secondary studies published between 2018 and 2023?

Purpose: Identify the types of technical debt most researched and reported in the selected secondary studies, according to the typology proposed in [19].

RQ-05: What are the human factors mentioned in the problems and/or solutions regarding technical debt described in the secondary studies reported between 2018 and 2023?

Purpose: Identify the role that human factors play in the solutions and problems related to technical debt in software development activities.

4.2 Selection of Data Bases

The Data Bases (DB) considered for carrying out the searches are the following: (1) IEEE Xplore, (2) ACM Digital Library, (3) Science Direct; Additionally, the inclusion of a repository such as (4) Google Scholar was considered. The choice of these DB is due to the fact that, when performing a quick search of different secondary studies on technical debt, these DB were the most used by the articles found. In the case of Google Scholar, it was selected because it contains studies from a great diversity of DB, so we considered it appropriate to include it in order to identify secondary studies from data sources other than those already considered.

4.3 Elaboration of the Search String

In accordance with the theoretical framework, the analysis of previous studies, as well as the agreed upon RQ, a set of terms were identified that were used to create a search chain, which could be configured subsequently, depending on the characteristics of each of the selected DB. For the construction of the search string, the AND operator will be used to join the two sets of keywords; in the case of the OR operator, it will be used to integrate the alternative words identified in each set. The generic search string is as follows:

"Technical debt" AND ("Secondary study" OR "Systematic review" OR "Mapping study" OR "Scope study" OR "Systematic mapping" OR "Literature review")

4.4 Definition of Eligibility Criteria

To select the relevant studies to answer the five research questions, a set of Inclusion and Exclusion criteria were established.

Inclusion Criteria (IC):

- CI1. Secondary studies linked to the topic of Technical Debt in the area of Software Engineering.
- CI2. Completed studies published in magazines and reports of specialized events in the area of Software Engineering.
- CI3. Articles published in the time window between 2018 and 2023.
- CI4. Articles whose content is in English or Spanish.

Exclusion Criteria (EC):

- CE1. Reports of duplicate studies (the one found in the original database will be maintained).

- CE2. Reports that refer to the same study (the most complete study will be selected).

5 Execution Phase

5.1 Configuration of the Search String

Based on the elements described in the Planning phase, the search chains were configured according to the characteristics of the handlers of each of the four selected DBs; For example, in the case of ACM Digital Library, the specific search string used was the following:

Abstract: ("technical debt") AND Abstract:("secondary study" OR "systematic review" OR "mapping study" OR "scope study" OR "systematic mapping" OR "literature review")

5.2 Selection of Relevant Studies

Using the chains duly configured for each database, the search process was carried out, subsequently the inclusion and exclusion criteria were applied (in that order), obtaining at each stage the number of studies indicated in Figure 1; finally, a total of 19 secondary studies were selected for analysis.

6 Results

The nineteen selected secondary studies were exhaustively reviewed with the purpose of responding to each of the RQ that guided the study; as part of this, a summary was developed with the most important characteristics of each of the selected studies; this information can be consulted in the following link:

Summaries

To illustrate the magnitude of the research carried out, Table 1 presents, for each of the four Data Bases consulted, the number of primary studies analyzed, the number of secondary studies analyzed, as well as the identifiers of said studies.

It is possible to observe that of the 924 primary studies, the database that makes up the highest percentage (43.7%) is ACM Digital Library with 7 secondary studies, followed by Google Scholar (23.6%) with 3 studies, Science Direct (16.6%) with 3 studies and the one with the smallest set of studies is IEEE Xplore (16.1%) with 6 secondary studies.

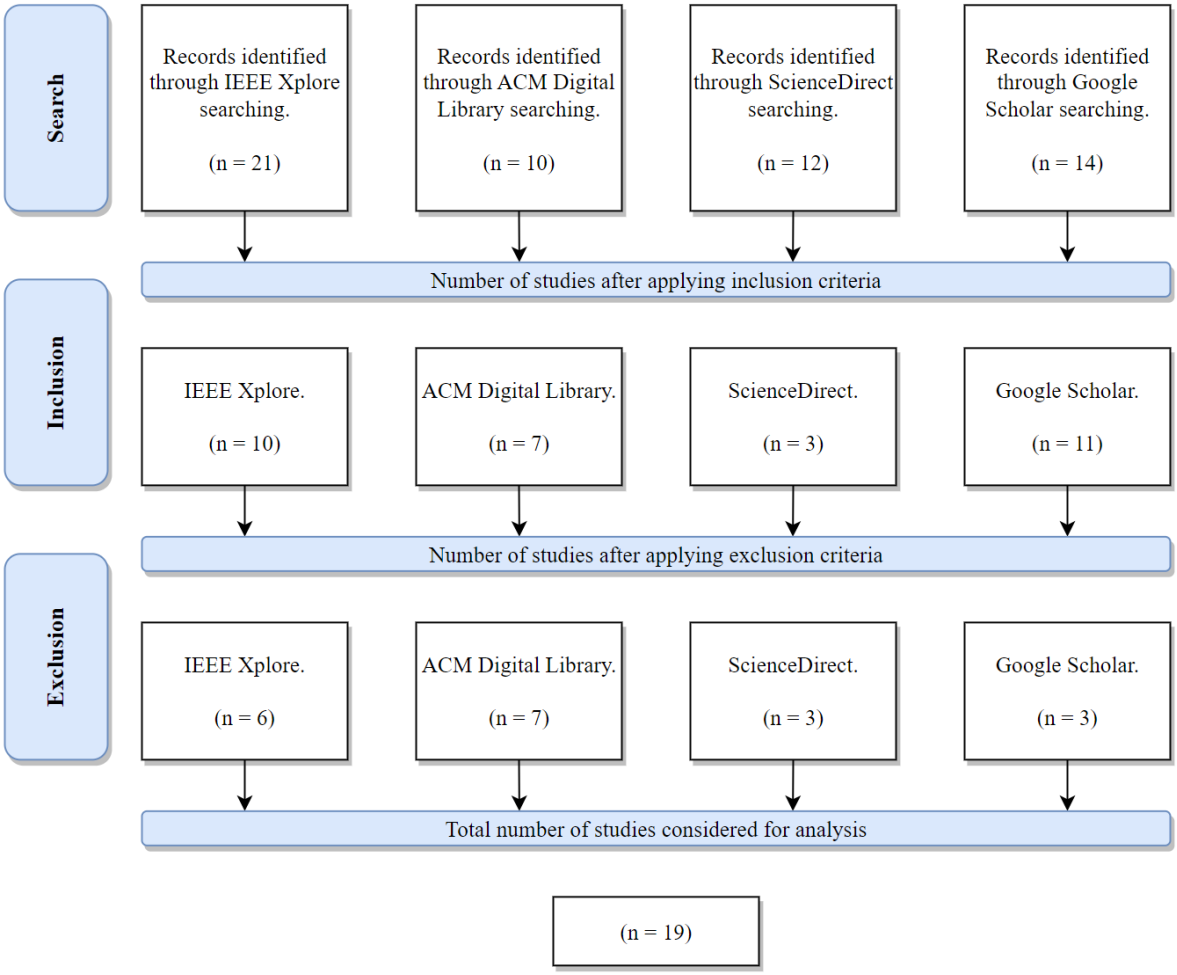

Figure 1. Selection process of relevant secondary studies

Table 1. Magnitude of the study based on the # of primary studies analyzed by the secondary studies selected.

DB Consulted	# of primary studies	# of secondary studies	SS Identifier
IEEE Xplore	149	6	SS1 – SS6
ACM Digital Library	404	7	SS7- SS13
Science Direct	153	3	SS14 – SS16
Google Scholar	218	3	SS17 – SS19

RQ-01: What is the distribution in the last lustrum of the different types of secondary studies published on the construct of technical debt?

Figure 2 illustrates the number of publications per year in the last five years, on average 3 articles per year are reported in the sale of time from 2018 to 2023, however, the lack of publications in 2019 may not be representative in the period of analysis, since as we all know the world was going through a pandemic. In the

case of the type of secondary study, according to its objective, there is a minimal difference between the two best-known types: 10 secondary studies are Systematic Literature Reviews (SLR) and 9 are Mapping Studies (MS), not however, regarding its distribution, it can be seen that in 2018 and 2020 the SLR predominated, and from 2021 to 2022 the MS presented a greater frequency, even in 2023, the only secondary study identified at the time of carrying out the study was a MS.

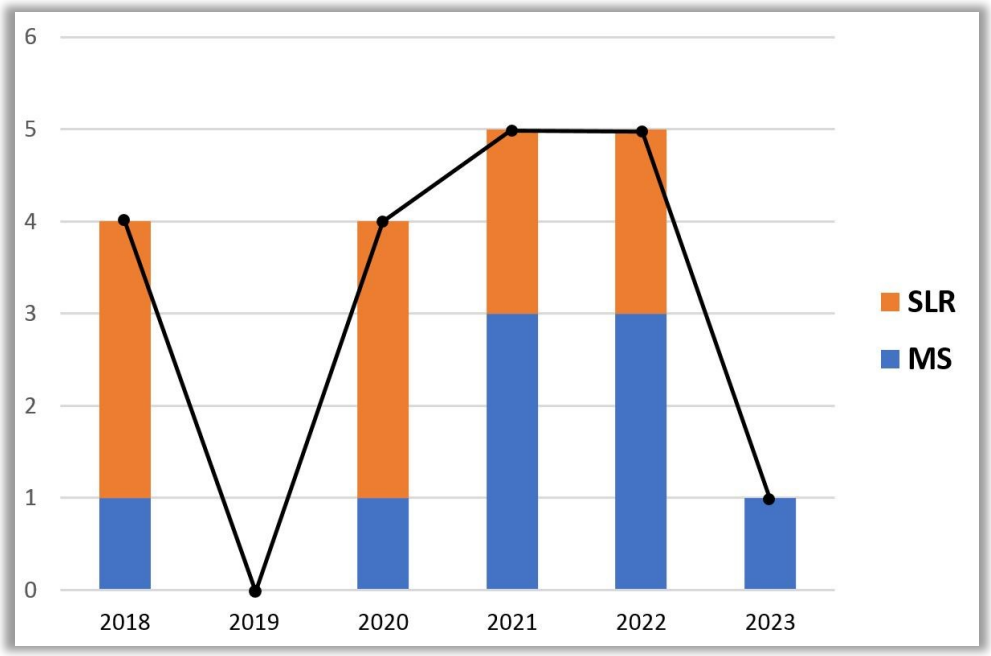

Figure 2. Selected Secondary Studies between 2018 and 2023 according to their type (purpose)

The topic of technical debt is a research topic on which research has been reported since the last decade of the last century, which explains why secondary studies have been published since 2018, and with the exception of 2019, the number of publications per year has been more or less constant; As for the small number of 2023, it is explainable because the search process was carried out in the first quarter of the year.

RQ-02: What solutions (approaches/techniques/strategies/practices/methods/tools) have been proposed in secondary studies published from 2018 to 2023?

All secondary studies report solutions for managing technical debt; Being more specific, in Figure 3 we can see that tools are the most mentioned in eight secondary studies, followed by approaches with six mentions and methods with five. In the case of techniques and strategies, they are mentioned in four studies each. For its part, the practices were only mentioned in two studies. It should be noted that some studies mentioned several types of solutions and, on the other hand, one of the studies, although it presents solutions, does not specify its type.

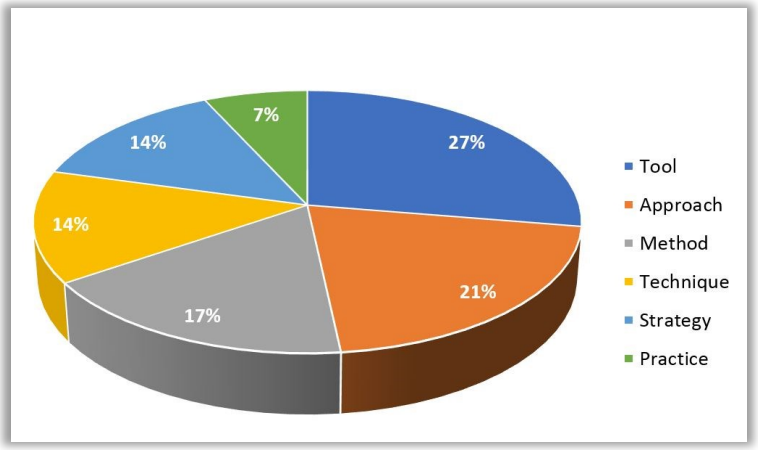

Figure 3. Distribution of solution types identified in secondary studies

RQ-03: On what type of management activities have the solution proposals described in the secondary studies published from 2018 to 2023 been focused?

Regarding the types of management activities (see Figure 4), measurement is the most reported activity in secondary studies with six mentions, followed by identification and management activities in general with five studies each. Finally, the least cited type of activity was known as payment with only one study. It should be noted that a study could have focused on several activities without counting as the general type.

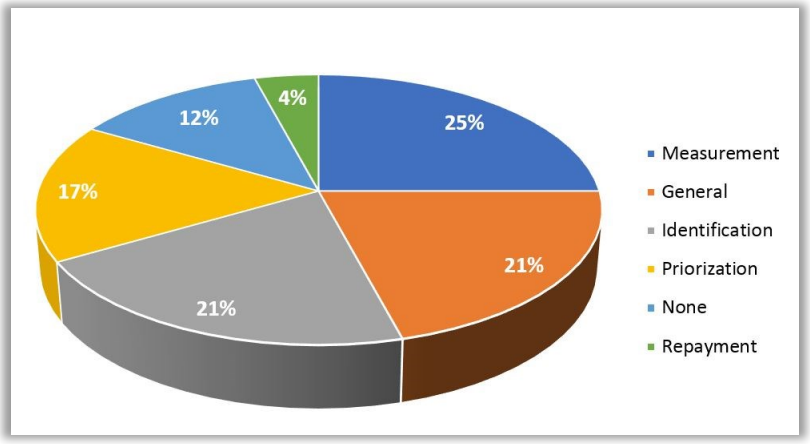

Figure 4. Distribution of types of management activities identified in secondary studies

RQ-04: What types of technical debt have been characterized in secondary studies published between 2018 and 2023?

Nine of the secondary studies focus generally on the types of technical debt, five correspond to technical debt in Architecture, followed by studies in which they do not refer to any type of technical debt and Code, which has three studies each. one; Finally, with two studies there is the Design type and with only one the Requirements type (see figure 5). It is worth noting that some studies mentioned various types of technical debt.

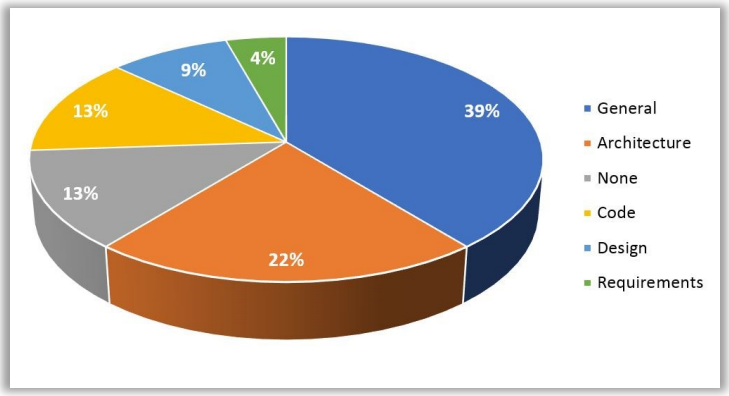

Figure 5. Distribution of types of technical debt identified in secondary studies

Figure 6 illustrates on its left side that from 2018 to 2023 the type of technical debt characterized as Architecture has been considered in all types of solutions, and although the General type presents a greater frequency in tools, it is absent in terms of practices. On the other hand, all types of technical debt reported in the studies present strategies, while only one has practices.

On the right side of the graph, it is observed that the type of debt characterized as Architecture is the one that is considered in the most reported management activities, with General being the second most cited with one least activity (repayment). It is also possible to identify that there is an absence of proposals for Prevention, Monitoring, Documentation and Communication activities. Finally, the Identification and Measurement activities are referenced for all types of debt reported in the secondary studies, while the Payment activity has only one mention in the type of Architecture.

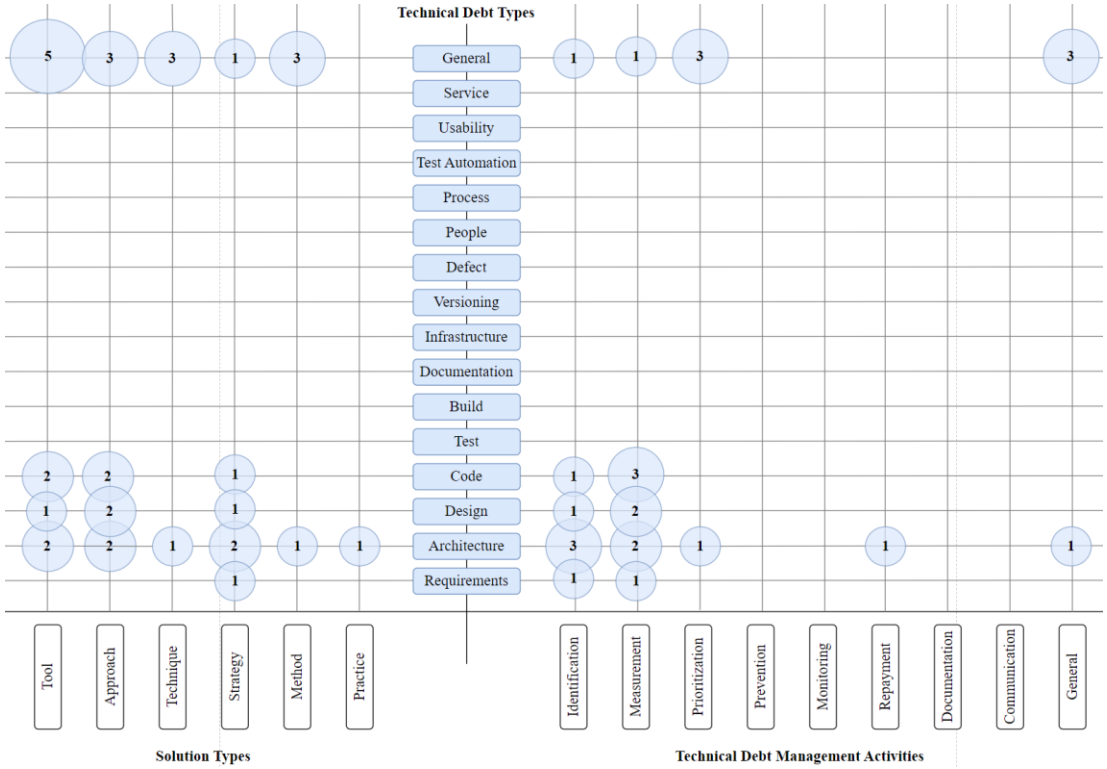

Figure 6. Relationships between TD type, solution types and TD management activities

RQ-05: What are the human factors mentioned in the problems and/or solutions regarding technical debt described in the secondary studies reported between 2018 and 2023?

The analysis of the 19 secondary studies allowed us to identify aspects or human factors that are in some way considered in the reported studies:

In SS3, it states that one of the causes of the presence of technical debt in microservices is the lack of experience or, where appropriate, an adequate level of knowledge on the part of the staff on issues related to this area. In SS6, high-level categories of maintenance cost factors are presented, in which the human factor is found, and although it refers to the use of five metrics, these are not specified. For its part, SS9, although it does not investigate it, proposes for future studies to investigate the role that factors such as affect play in perceptions for decision making in the context of technical debt management. In SS11 it is mentioned that to identify elements of technical debt in Architecture there is analysis based on human knowledge, which extracts human knowledge through structured and unstructured processes, such as surveys, interviews, and questionnaires. SS12 also states that in some cases human participation during technical debt prioritization activities can be important since relevant information could be overlooked if it is carried out in an automated manner. In addition, it mentions that human participation should be minimal and therefore classifies prioritization approaches according to the level of human participation (None, Minor or Major). SS14 allows us to identify the main difficulties in the Requirements technical debt management process, in which it mentions that the team's morale may be affected if the technical debt is not corrected. It also mentions that among the difficulties in understanding the technical debt in the requirements is the team culture or personal feelings, in which depending on the feelings that the staff has at that moment, it may cause them to prefer or not to reduce the technical debt. In SS15, one of the primary studies it describes mentions that the technical debt identification process requires a trained human observer to establish the final priority of the technical debt. Finally, SS18 reports several findings such as: a) community-related factors contribute to technical debt intensity, b) developer morale can increase if debt is managed properly, c) organizational factors such as size Team size, project size, and developer experience all influence the amount of debt.

We can see overlaps in SS3 and SS18 in that developer experience affects the amount of technical debt; In studies SS9 and SS14, feelings are cited as a factor to take into account in the management process; For their part, SS12 and SS15 mention that some human intervention is required for technical debt management activities; and finally, SS14 and SS18 identify that staff morale can be positively or negatively affected depending on the degree of technical debt management.

7 Threats to Internal and External Validity

The validity of a study refers to the reliability of its results and the extent to which its results are true and are not biased by the researchers' point of view [22]. In the present study, the authors use the interpretation developed in [23] regarding threats to internal and external validity, in the context of secondary studies.

7.1 Internal Validity

Considering that Internal Validity must be analyzed around the conduct of the study, particularly with the extraction and synthesis of data, in the sense of the possibility that there are factors that could bias the general process. The main threat to internal validity is because no synthesis technique was consciously used in the data extraction process. However, in general we believe that the internal validity of this study is high given the use of a systematic procedure of the activities proposed by [17, 18] as well as the constant discussion between the researchers.

7.2 External Validity

External Validity corresponds to the evaluation of the scope covered by the selected primary studies, in terms of their environments, materials and participants. The main threat to external validity is due to the number of bibliographic sources consulted (IEEE Xplore, ACM Digital Library, Science Direct and Google Scholar), as well as the quality of the search engines, which could have influenced the integrity of the data selected primary studies. On the other hand, being a mapping study, the protocol does not consider an evaluation of the quality

of the selected studies. However, the authors consider that the tertiary study maintains adequate external validity, because the three DB consulted are the ones that have the greatest recognition in the context of Software Engineering, and the combination with a recognized repository (Google Scholar) allowed access literature not available in other DB.

8 Conclusions

Since the incorporation of the construct of technical debt in 1992 [5], researchers in the context of Software Engineering have been increasing their interest in this topic; however, it is a topic that requires further research, since its concepts need to be delved deeper, strategies, tools, as they are not yet completely clear, and for example, primary studies continue to be carried out that propose new tools and methods to support technical debt management and rarely approve those that have already been developed by others researchers.

This study aims to verify the results of the tertiary study reported in [15] in terms of aspects such as the proposed "solutions", the relationship between technical debt and human factors, for which some of the results obtained are contrasted with the from the previous study. A second, no less important objective was to find an area of opportunity to conduct a SLR (as a bachelor's degree thesis) on a topic related to technical debt that has not yet been sufficiently researched. It is not omitted to comment that the reported study is an extension of the study reported in [24], with the findings of research questions 2, 3, 4 and 5 being totally new content.

In the present study, 19 secondary studies are analyzed, which, together, summarize the research with a magnitude of 924 primary studies; Although from 2019 to 2023 the research - except for 2019 - has been constant, regarding the purpose of secondary studies, there is practically a balance between SRL and MS, with the second type of studies prevailing in recent years.

With this study it can be stated that there is a certain consensus in the use of the typology proposed in [19], and depending on the depth or specificity of the study, new types are proposed; All secondary studies report some solution for technical debt management, with tools being the most reported; The management activity in which researchers have been most interested is measurement; There is no type of technical debt that secondary studies are more focused on, so they are more general in this aspect; Through the bubble graph prepared (see figure 6) it has been possible to analyze the relationships between the types of technical debt, types of solution and management activities, hence it was possible to identify the least researched areas and in which more is required investigation; Finally, the authors found areas of opportunity on the relationship between technical debt and human factors in topics such as morale, experience, human participation and feelings. It is worth mentioning that it is widely known that the human aspect has an important impact in the success or failure of the software process.

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