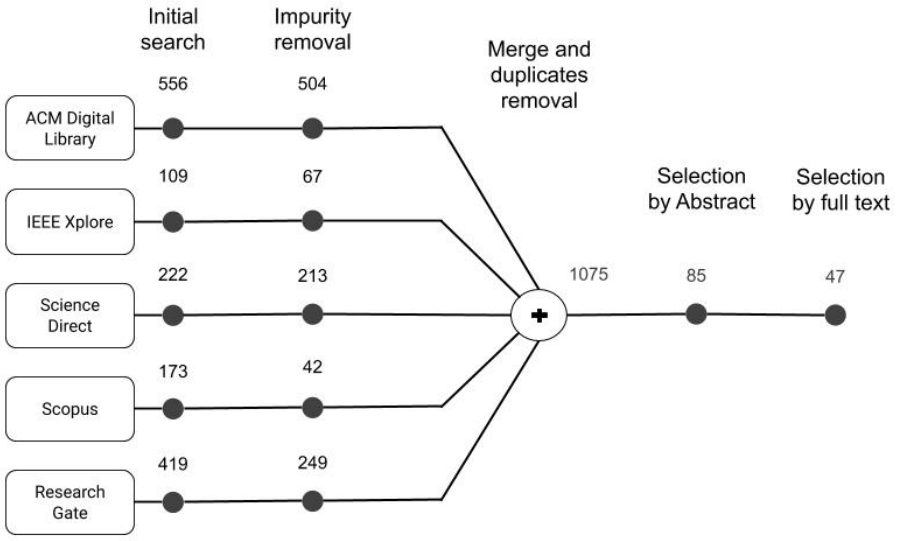

Figure 1: Overview of the search and selection process . Figura meramente ilustrativa no momento

1. Study design

In this research we follow well-established guidelines for systematic review literature studies [1] [2]. In this section we present the study goals, research questions and the design of our study. We do not use study quality assessment results to filter primary studies, similarly to [3] and perceived as a common occurrence in systematic mapping by [1]. The search and selection process of the systematic literature review was divided into six steps as shown in Figure 1. The details of each step will be explained in the next subsections.

1.1. Study Goal and Research Questions

The goal of this study, described using the Goal-Question-Metric approach [4], is: to analyze *primary studies on technical debt management tools* for the purpose of *getting a comprehensive understanding* with respect to the *technical debt types, technical debt management activities and main characteristics of available tools*, from the point of view of *researchers* in the context of *software development*. This goal can be refined into the following research questions (RQs).

RQ1: **What are the publication trends of research studies about TD tools?**

Rationale: By answering this research question we aim to assess the ongoing trends of scientific interest on TD tools in terms of publication frequency, most prominent venues where academics are publishing their results on the topic and most recurrent venue types.

Relevance for researchers: the results of this research question help researchers in (i) estimating the enthusiasm of scientific engagement on technical debt tools, (ii) identifying the academic venues where related papers about technical debt tools are published, and (iii) identifying the academic venues where new results about technical debt tools may be better received and recognised by the scientific community.

Relevance for practitioners: the results of this research question help practitioners in identifying the relevant venues where scientific knowledge is created to (i) to take inspiration for solving problems which have been already targeted by researchers, (ii0) to get a more orthogonal and cross-organizational perspective concerning tools for technical debt, and (iii) to identify research groups that are prominently contributing in the field.

RQ2: **What are the technical debt tools report in the literature?**

Rationale: Tools are of paramount importance to support development teams in the integration of technical debt management in their daily work once software projects tend to accumulate technical debt during the software development process.

Relevance for researchers: the results of this research question can help researchers (i) to provide an overview of the currently available tools for managing technical debt, (ii) to quantify the degree of scientific interest on TDM tools, (iii) to identify the academic venues where related papers

about tool addressing TDM are published.

Relevance for practitioners: the results of this research question help practitioners in identifying the relevant venues where TDM tools are created, as well as (i) to take inspiration for solving problems which have been already targeted by researchers, (ii) to get a more orthogonal and cross-organizational perspective with respect to the technical debt management tools, and (iii) to identify the research groups which are prominently contributing in the field.

RQ3: **What are the main characteristics of the tools?**

Rationale: Technical debt management is a multi-faceted discipline involving different activities and strategies, where researchers can focus on very different aspects of the technical debt concept (e.g., code, architecture, business aspects), and providing different types of approaches to addressing technical debt. This research question provides the foundation to researchers and practitioners know the main features that current tools provide.

Relevance for researchers: by answering this research question we support researchers by providing an overview of how the current solutions are implemented, thus presenting opportunities to understand or to improve them. The answer to this question can provide trends and highlight possible gaps to be investigated.

Relevance for practitioners: The results of this research question help practitioners in (I) identifying the main characteristics and features provided by the reported tools, and (II) effectively locate the tools which can be reused/customized for solving specific problems related to your technical debt issues.

RQ4: **Which technical debt management activities are addressed by the proposed tools?**

Rationale: The available tools in the technical debt management area dealing with different activities of technical debt management across different dimensions, identifying the right set of tools for a specific activity and dimension can be time consuming.

Relevance for researchers:by answering this research question, we support researchers by providing (i) an overview of the TD types and TDM activities addresses by the current tools available in the literature, and (ii) an understanding of current research gaps in state of the art on the area of TD tools.

Relevance for practitioners: the results of this research question help practitioners in (i) positioning themselves according to their organizational needs regarding technical debt management activities, and (ii) effectively locating the solution which can be reused/customized for solving problems related to technical debt management.

RQ5: **What kind of studies does the literature use to evaluate TDM tools?**

Rationale: Researchers can apply different research methodologies (industrial case studies, empirical evaluations, feasibility studies, etc.) to validate their tools.

Relevance for researchers: by answering this research question we support researchers by assessing how existing TD tools are evaluated, providing an estimate of their reliability

Relevance for practitioners: the results of this research question help practitioners in identifying existing research products that can alredy be used in industry and which research groups are already collaborating with industry. Also, the results of our study also support practitioners in identifying open-source TD tools which are one step closer to their application into an industrial context.

RQ6: **Does the tool consider any business aspect for decision support?**

1.2. Initial Search

In this stage, we developed a bunch of scripts to automatically search on electronic databases and indexing systems. The search process considered journal, conference and workshop papers indexed in the digital libraries presented in Table 1. The selection of these electronic databases and indexing systems was guided by: (I) the fact that they are the largest and most complete scientific databases and indexing systems in software engineering [1] [2], (II) they have been recognised as being an effective means to conduct systematic literature studies in software engineering [1], (III) their high accessibility, and (IV) their ability to export search results to well-defined, computation-amenable formats.

1.2.1. time period

We have not set a minimum date to search for papers in online library search engines. We consider all the papers present in each repository up to the end of the data extraction period: 05/02/2020.

1.2.2. Digital libraries

From the research bases defined in [2], we use some of them and add a new one. Although it is not in the guidelines suggested by [2], we adopted the (1) ResearchGate [1] database because it is an article indexer, it helped us to obtain the relevant papers that were left out. From the databases suggested by [2], we choose the (1) ACM digital Library [2], (2) IEEE Explorer [3], (3) ScienceDirect [4]. We consider adding (4) Scopus [5] database to obtain information from journals. The databases Citeseer library [6], Inspec [7] and EI Compendex [8] were not used for

[1] https://www.researchgate.net/search
[2] http://dl.acm.org/
[3] http://ieeexplore.ieee.org/
[4] http://www.sciencedirect.com/
[5] http://www.scopus.com/home.url
[6] citeseer.ist.psu.edu
[7] www.iee.org/Publish/INSPEC/
[8] www.engineeringvillage2.org/Controller/Servlet/AthensService

research because they have (1) low relevance compared to the selected databases, (2) we get a satisfactory amount in the primary search with the defined subset (more than 1000 papers), (3) use of scorpus and research gate databases help to obtain relevant studies that would be left out.

The Google scholar [9] database was not used due to the fact that it returned a huge amount of results (more them 5000) and we trust that the databases used were able to capture the most important studies.

Table 1: Digital libraries considered.

Digital Library	**Link**
ACM Digital Libray	http://dl.acm.org
IEEE Xplore	http://ieeexplore.ieee.org
Science Direct	http://www.sciencedirect.com
Research Gate	https://www.researchgate.net
Scopus	http://www.scopus.com

1.2.3. Keywords

Our search string is shown in the listing 1. For consistency, the search string has been applied to title, abstract, keywords of papers in all electronic databases and indexing systems considered in this research. The keywords were defined together with the authors in such a way as to seek to cover the area of technical debt tools. We use a very restrictive string in order to decrease the chance of leaving a relevant study out.

Listing 1: Search string used for automatic research studies

```
("Technical Debt") AND ("Tool" OR "Software Solution")
```

1.3. Impurity removal

Due to the nature of electronic databases and indexing systems, search results included also elements that were not research papers, such as international

[9] scholar.google.com

standards, textbooks, book series, etc. We manually removed such invalid results from our dataset. In particular, the research gate returns results from unpublished papers, so this step was necessary to ensure that only published papers are analyzed.

1.4. Merger and duplicated removal

When using several databases to search for papers, some of them being indexers, it is normal to find repeated results. To determine the equivalence of results in this step, the following criteria were considered: (1) authors names, (2) titles and (3) year of publication. In this step, there was a union of the papers from the databases so that next step will be carried out with this new resulting set.

1.5. Application of selection criteria

We defined a set of inclusion and exclusion criteria to define which papers will be used in the course of this study. The following inclusion criteria were used:

(I1) Studies written in English

(I2) The paper needs to be published in conference proceedings, workshop proceedings, book chapters or journals.

(I3) Papers that propose, extend or evaluate one or more tools that manage technical debt.

The following exclusion criteria were used:

(E1) Studies not available as full-text.

(E2) Papers that describes TD management tools that were not implemented

1.6. Selection process

We have defined two steps for the paper selection which are (1) selection by abstract and (2) selection by full text. The Table 2 shows an overview of the steps and the criteria used in each of them. The steps were carried out in order to generate a composition, that is, the input set for the next step is the result of the previous step. Details of the steps and the motivation for using the criteria will be explained in the course of this subsection.

Table 2: Criteria used in the selection process

Steps	**Criteria used**
1º Step: selection by abstract	I1, I2, I3, E1
2º Step: selection by full text	I1, I2, I3, E1, E2, E3

The selection of papers was carried out using the following steps:

1. First, we perform an analysis by abstrast, considering the criteria I1, I2, I3 and E1. A priori we do not consider the E2 criterion because we believe that it would not be a problem to obtain the papers once we have obtained the abstract. In fact there was only one paper that we have not. The E3 criterion was not used because the abstract does not always present information on whether the tool is implemented. In this step, the text of the abstract was observed, along with associated information such as keywords, names and conferences of the paper. All the papers were reading by at least two authors and any disagreement was solved through a consensus. When the consensus was not enough, the acceptance was determined by a third author.

2. Second, we analyzed the full text of paper, considering the criteria I1, I2, I3, E1, E2, E3. Again, a procedure equivalent to the previous step was adopted. Each paper was read by at least two authors and any disagreement was was solved through a consensus, when was not to solve the conflict, the acceptance was determined by a third author.

1.7. Data extraction

To answer the research questions presented in subsection 1.1, we extracted the data items listed in Table 3 from each selected study. The extracted data were recorded on a spreadsheet. Before data extraction, we discussed the definitions of the data items to be extracted to clarify the meanings of the data items to all the authors. To make sure that all the authors have the same understanding on the data items, before the formal data extraction, all authors did a pilot data extraction with ten studies. All disagreements were discussed and resolved. After the pilot data extraction, each author extracted data from part of the selected studies. Finally, the two authors checked all the extracted data together to make sure that the data are valid and clear for further analysis.

1.8. Data synthesis

Data synthesis aims to synthesize the extracted data to answer the research questions defined in subsection 1.1. Descriptive statistics and frequency analysis were employed in synthesizing the data to answer the research questions.

To answer RQ1 and RQ2, we created a classification that categorizes the main purpose of each technical debt tool. This categorization aggregates the tools around a criterion that provides a view of the performance of each tool.

To respond RQ3, we tabulate the selected tools, the types of TD handled by them, and the TDM activities they support. Besides, we map the maturity of each tool in characteristics - TD types and TDM activities. This map provides information on how the tools are distributed concerning the types of TD and TDM activities.

Table 3: Data items extracted from each study.

#	Data item name	Relevant RQ	Description
D1	Year	None	The publication year of the study
D2	Venue	None	The name of the publication venue of the study
D3	Publication type	None	Journal, conference, workshop, or book chapter
D4	TD Type	RQ3	The type of technical debt
D5	TDM activity	RQ3	The TDM activities that are discussed in the study
D6	Paper intention	RQ1	The article intends to propose, evaluate, or extend a tool
D7	Maturity	RQ1	Indicate the maturity level of the tool
D8	Language	RQ2	The implementation language
D9	Target Languages	RQ2	The languages supported by a tool
D10	License	RQ2	Academic, Commercial or Open Source Software
D11	Study type	RQ4	The validation study type, e.g, experiment, case study.
D12	Research type	RQ4	Qualitative or quantitative
D13	Industrial evaluation	RQ4	Indicates if the study performed an industrial evaluation

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