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Polish Contribution to Software Engineering Research 1992–2021

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Abstract. Since the collapse of the Soviet Bloc, Polish researchers in the software engineering area made a large effort to close the gap developed during the times of the Iron Curtain and the ensuing limited access to Western technology. The question arises as to whether they eventually managed to attain – or maybe even to surpass the scientific output in this area of the developed Western countries. In this paper, we perform analysis on papers published in 16 high-quality software engineering journals within the last 30 years to measure the Polish contribution to the global scientific output in the area of software engineering. We observe how the Polish contribution changed in quantity in relation to the global scientific output in subsequent years. We also identify the journals that attracted the Polish authors the most, the institutions located in Poland that contributed the most, as well as the most productive Polish authors and the most acknowledged works (in terms of citation number) written by Polish authors. Moreover, we investigate the topics most often chosen by them.

Keywords: bibliometric analysis, software engineering in Poland, scientific productivity

1. Introduction

The restrictions endorsed by Coordinating Committee for Multilateral Export Control (COCOM) greatly hampered the development of software engineering in Poland under communist regime. As there were a few holes in the barrier (see, e.g., [4]), computers did come to Poland, but their proliferation was not sufficient for the local software sector to develop. There was also an economic barrier: the computers as other goods imported from the other side of the Iron Curtain were relatively very expensive and thus rare [27]. A big part of the software developed locally were Polish adaptations of reverse-engineered Western programs and developing software was a poor business as

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it could be legally freely copied and borrowed [10]. Such conditions did not provide good base for the Polish software engineering research to flourish.

The situation changed after the collapse of the Soviet Bloc, which not only removed the barriers in the access to Western technologies, but also led to gradual increase of wealth of Polish companies and consumers, enabling them to purchase computers and software. An important milestone was the copyright protection law imposed in 1994, rendering copying of copyrighted software illegal [24]. Polish software sector started to grow considerably [6], which was accompanied with an increased programming education leading to Polish programmers becoming ranked among the top coders in the world [11].

In this paper, we investigate if and to what extent the above-mentioned progress of software industry in Poland is mirrored by the progress in Polish research activity in the area of software engineering. To accomplish this, we perform bibliometric analysis on all peer-reviewed articles published in sixteen well-established software engineering journals within the last 30 years. In our study, we strive to answer the following research questions:

RQ1 How did the share of Polish contribution to the scientific output in the area of software engineering change in the last 30 years?

RQ2 How did the share of Polish contribution to software engineering in the last 30 years compare to the countries leading the research in this area?

RQ3 Which of the considered software engineering journals were mostly attracting the Polish authors?

RQ4 Which of the Polish research institutions did contribute the most to the scientific output on software engineering?

RQ5 Who were the Polish authors that contributed the most to the scientific output on software engineering?

RQ6 What were the most influential publications on software engineering by Polish authors, as measured by the number of received citations?

RQ7 Which software engineering topics were most often addressed by Polish authors, as measured by the keywords they used?

2. Methods, data sources and tools

The primary research method of the presented study is bibliometric analysis. Bibliometric analysis is "a scientific computer-assisted review methodology that can identify core research or authors, as well as their relationship, by covering all the publications related to a given topic or field" [12]. Bibliometric analysis has been proven effective in many diverse research areas, from medicine [19], through social sciences [26], to mathematics [3]. In the area of software engineering, it has been used to investigate

the quantity, characteristics and scope of the studies pertaining to, among others, software testing [28], model-driven software engineering [2], agile software development [1], software product lines [13], and search-based software engineering [5]. It has also been successfully applied to explore the contribution to the software engineering research of specific countries [9].

Our work belongs to the same vein, and can be seen as a direct continuation and extension of the research presented by Jurkiewicz, Kosiuczenko, Madeyski, Ochodek, Orłowski and Radliński at the KKIO 2014 conference [14]. It covered five years (2010–2014) and 16 carefully picked top software engineering journals, listing a total of just 28 relevant papers.

In the presented research we decided to follow the same procedure with the exception of expanding the analyzed timeframe to 30 years. Moreover, our search included only already issued publications (i.e., works in press were excluded) which were classified as article, conference paper or short survey (i.e., excluding editorials or book reviews).

Therefore, following [14]:

- by Polish research we consider publications authored or co-authored by an author affiliated with an institution based in Poland (in the respective publication, not career-wise);
- only publications in the selected 16 software engineering journals were considered;
- Scopus has been used as the source of bibliographic data, as it indexes all 16 journals listed below.

The considered 16 software engineering journals, as selected in [14], are:

- ACM Transactions on Software Engineering and Methodology (TOSEM),
- Automated Software Engineering (ASE),
- Empirical Software Engineering (EMSE),
- IET Software (IETSW),
- IEEE Software (SW),
- IEEE Transactions on Software Engineering (TSE),
- Information and Software Technology (IST),
- International Journal of Software Engineering and Knowledge Engineering (IJSEKE),
- Journal of Software: Evolution and Process (JSEP),
- Journal of Software Maintenance and Evolution: Research and Practice (JSME),
- Requirements Engineering Journal (REJ),

- Software and Systems Modeling (SoSyM),
- Software Quality Journal (SQJ),
- Software Testing, Verification and Reliability (STVR),
- Software: Practice and Experience (SPE),
- Journal of Systems and Software (JSS).

In the search query, the covered journals were indicated by their respective ISSNs. Consequently, the following search criteria were used:

- to obtain the list of Polish-affiliated publications:
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( ISSN ( 1049331x ) OR ISSN ( 09288910 ) OR ISSN ( 13823256 ) OR
ISSN ( 17518806 ) OR ISSN ( 07407459 ) OR ISSN ( 00985589 ) OR
ISSN ( 09505849 ) OR ISSN ( 02181940 ) OR ISSN ( 1532060x ) OR
ISSN ( 09473602 ) OR ISSN ( 20477481 ) OR ISSN ( 09639314 ) OR
ISSN ( 09600833 ) OR ISSN ( 00380644 ) OR ISSN ( 01641212 ) OR
ISSN ( 16191366 ) ) AND PUBYEAR > 1991 AND PUBYEAR < 2022 AND
AFFIL ( poland ) AND ( LIMIT-TO ( PUBSTAGE , "final" ) ) AND
( LIMIT-TO ( DOCTYPE , "ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) OR
LIMIT-TO ( DOCTYPE , "sh" ) )
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- to obtain the list of publications from all countries:
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( ISSN ( 1049331x ) OR ISSN ( 09288910 ) OR ISSN ( 13823256 ) OR
ISSN ( 17518806 ) OR ISSN ( 07407459 ) OR ISSN ( 00985589 ) OR
ISSN ( 09505849 ) OR ISSN ( 02181940 ) OR ISSN ( 1532060x ) OR
ISSN ( 09473602 ) OR ISSN ( 20477481 ) OR ISSN ( 09639314 ) OR
ISSN ( 09600833 ) OR ISSN ( 00380644 ) OR ISSN ( 01641212 ) OR
ISSN ( 16191366 ) ) AND PUBYEAR > 1991 AND PUBYEAR < 2022 AND
( LIMIT-TO ( PUBSTAGE , "final" ) ) AND ( LIMIT-TO ( DOCTYPE ,
"ar" ) OR LIMIT-TO ( DOCTYPE , "cp" ) OR LIMIT-TO ( DOCTYPE ,
"sh" ) )
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The query yielded 115 results with the affiliated country filter and 20,633 without it, in total for the 30-year period. The retrieved data were processed with Microsoft Excel, Python 3.9, and its Pandas library.

3. Findings

3.1. Polish Research Output in Software Engineering

In order to estimate the share of the Polish contribution in the global software engineering research, the number of publications (retrieved in the search described in section 2) having at least one author affiliated to a Polish institution (115) was compared to the total number of publications (20,633). The Polish contribution share

was estimated in this way at about 0.56%. Interestingly, this number is very close to the one reported in 2014 by [14], where the Polish contribution over a 5-year period was estimated at 0.6%.

Nonetheless, it was not at the same level for the whole 30 years. Figure 1 shows how the Polish contribution share changed in the analyzed period in relation to the 30-year average.

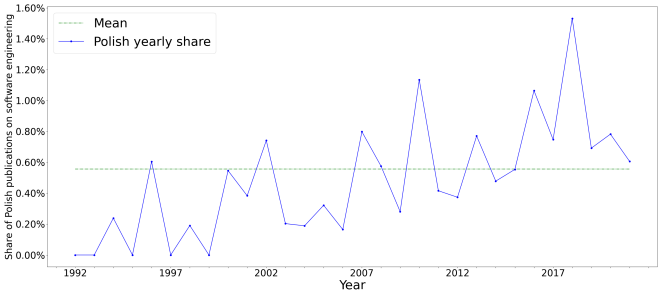


Figure 1. Polish contribution by year.

While the absolute number of papers having Polish-affiliated authors published yearly grew considerably from 0 in 1992 to 7 in 2021, looking at Fig. 1, it is apparent that although the overall trend was positive, no substantial growth of the Polish contribution share could be observed. There were a few local peaks, and the 30-year peak in 2018, when the Polish contribution attained its highest share of 1.5% . The worst years in the records were 1992, 1993, 1995 and 1999 for which no publications with authors affiliated in Poland were found.

In order to put the share of the Polish contribution in the context of other countries' contribution, Fig. 2 shows the share of publications on software engineering having at least one author affiliated to an institution located in the respective country in the total number of identified country affiliations.

As can be observed in Fig. 2, the Polish contribution, ranked 36^{th} among countries, is around 50 times smaller than that of the top-ranked United States. When compared to countries of roughly similar population, Polish contribution is on average fifteen times smaller than that of Canada, and ten times smaller than that of Spain. We can thus sadly conclude that the gap between the Polish and Western software engineering research has not been greatly reduced despite 30 years that have passed.

The countries that contributed a share similar to Poland are Pakistan and Argentina, which had both exceeded Polish contribution by a small margin of two publications, and Malaysia and Mexico which had fallen short of Polish contribution with the difference of nine and nineteen publications, respectively.

Looking at the other Central-European countries having a similar historical background, Hungarian share was 0.39% (i.e., $1/4^{\text{th}}$ less, whereas the population of Hungary is $3/4^{\text{th}}$ smaller than the population of Poland), and Czech share was 0.26% (i.e., about 46% of the Polish one, whereas the population of Czech Republic makes

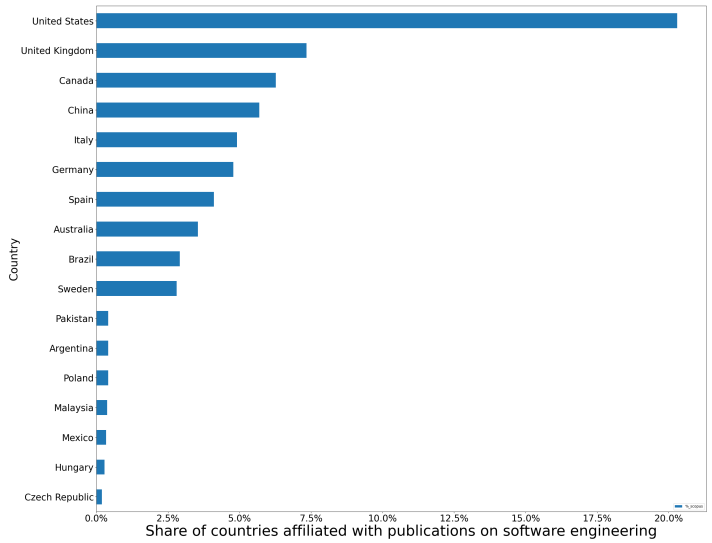


Figure 2. Polish contribution vs. the leading countries.

about 28% of the population of Poland). This means that both these countries contributed less in absolute numbers, but relatively fared much better than Poland if the population size is considered.

3.1.1. The most popular place of publication

Aiming to find out the most popular place of publication on software engineering for Polish authors, the number of publications having authors affiliated to Polish institutions was counted for each of the considered journals, and presented in Fig. 3. As can be observed, the "Information and Software Technology" (IST) has the largest share of 20%, followed closely by "Software: Practice and Experience" (SPE) at 19%. Third in the ranking, at 15%, is "International Journal of Software Engineering and Knowledge Engineering" (IJSEKE).

At the other end of scale, two journals have each published only one publication on software engineering affiliated with Poland: "Journal of Software Maintenance and Evolution: Research and Practice" (JSME) and "Software and Systems Modeling" (SoSyM), and four journals have not published any such publication in the whole 30-year period ("ACM Transactions on Software Engineering and Methodology" (TOSEM), "Automated Software Engineering" (ASE), "Requirements Engineering Journal" (REJ), and "Software Testing, Verification and Reliability" (STVR).

Surprisingly, two of these are devoted to subareas of Software Engineering that were of high interest for Polish researchers (see section 3.4).

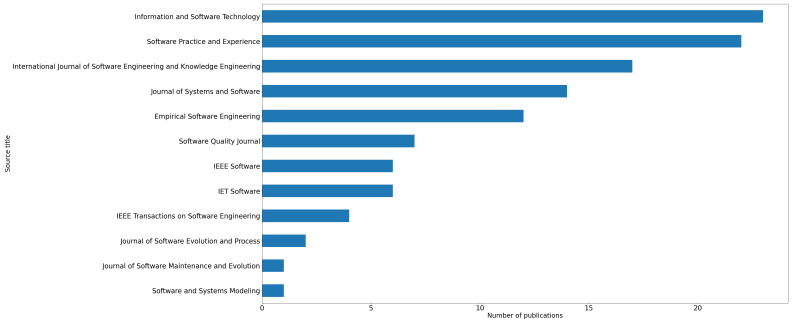


Figure 3. The most popular place of publication.

3.1.2. Number of publications per institution

The institutions responsible for the Polish contribution to software engineering research are listed in Fig. 4, showing the number of publications for each Polish institution that was encountered in the analyzed data.

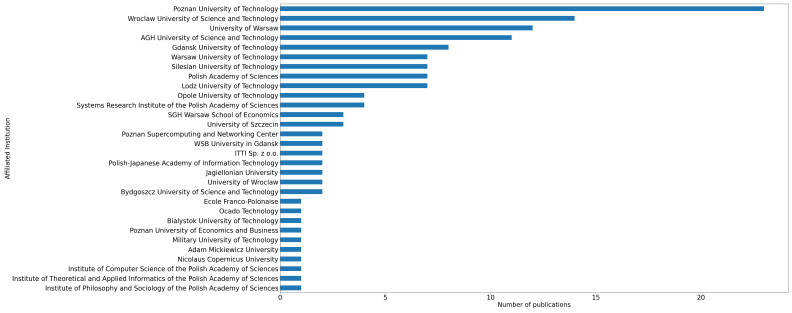


Figure 4. Number of publications for each affiliated Polish institution

Institution affiliated with the highest number of publication turned out to be Poznan University of Technology with 23 publications. Second best is Wrocław University of Science and Technology with affiliation to 14 works and third with just two publications less - University of Warsaw. The fourth place is taken by AGH University of Science and Technology with 11 publications. Worth noticing is the substantial decrease in number of affiliated publications between the first and second best institution. On the fifth place in this ranking is Gdansk University of Technology with 8 publications. The sixth spot in the ranking is shared by: Warsaw University of Technology, Silesian University of Technology, Polish Academy of Sciences and Lodz University of Technology (each with 7 affiliated works). Seventh place was taken by

Opole University of Technology and Systems Research Institute of the Polish Academy of Sciences both affiliated with 4 publications. Following are SGH Warsaw School of Economics and University of Szczecin, both with 3 publications. One spot below are seven institutions connected to 2 works each: Bydgoszcz University of Science and Technology, University of Wrocław, Jagiellonian University, Polish-Japanese Academy of Information Technology, Poznan Supercomputing and Networking Center, ITTI Sp. z o.o. and WSB University in Gdansk. The last, tenth spot was taken by ten institutions, each affiliated with 1 publication: Ecole Franco-Polonaise, Ocado Technology, Bialystok University of Technology, Poznan University of Economics and Business, Military University of Technology, Adam Mickiewicz University, Nicolaus Copernicus University, Systems Research Institute of the Polish Academy of Sciences, Institute of Computer Science of the Polish Academy of Sciences, Institute of Theoretical and Applied Informatics of the Polish Academy of Sciences, Institute of Philosophy and Sociology of the Polish Academy of Sciences.

3.2. The Most Prolific Contributors

In order to find out who contributed the most to Polish research output in software engineering, the number of publications of each author affiliated with institutions located in Poland was counted. The top ten authors with the highest number of authored or co-authored publications are shown in Fig. 5.

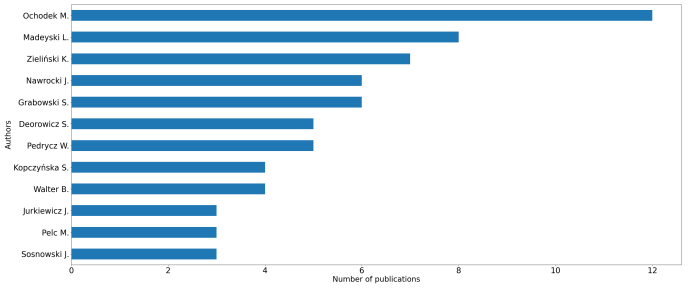


Figure 5. The most prolific Polish authors.

The researcher who contributed the most is M. Ochodek from Poznan University of Technology with 12 publications in the analyzed set. The second place was taken by L. Madeyski from Wrocław University of Science and Technology whose 8 papers were found in the selected journals, followed by K. Zieliński associated with AGH University of Science and Technology in Cracow with 7 papers. The next on the list were: Sz. Grabowski from Lodz University of Technology and J. Nawrocki from Poznan University of Technology – both with 6 contributions, S. Deorowicz affiliated with Silesian University of Technology in Gliwice and W. Pedrycz, affiliated with the Systems Research Institute of Polish Academy of Sciences in Warsaw – both

with 5 contributions, then S. Kopczyńska and B. Walter from Poznan University of Technology – both with 4 contributions. Three authors contributed with three papers each: J. Jurkiewicz from Poznan University of Technology, M. Pelc from Opole University of Technology and J. Sosnowski from Warsaw University of Technology.

We can thus say that the Polish contribution to the software engineering research was not limited to a single institution, as the listed top contributors hail from eight different institutions located in seven Polish cities (Poznań, Wrocław, Kraków, Łódź, Gliwice, Warszawa and Opole). Nonetheless, the results show clearly that the most productive center of software engineering research in Poland is Poznań University of Technology, from which a half of the top ten contributors hailed.

3.3. The Most Acknowledged Works

The basic measure of research impact is the number of citations received by a paper. Therefore, in order to identify the most acknowledged works, the papers were ordered by the number of their citations, and the ten most cited articles are listed in table 1.

The top cited paper in the analyzed dataset is "Which process metrics can significantly improve defect prediction models? An empirical study" authored by L. Madeyski and M. Jureczko [16] form Wrocław University of Science and Technology, a paper about an empirical evaluation of several process metrics aimed to significantly improve the defect prediction models based on product metrics.

The second most cited paper is "Overcoming the equivalent mutant problem: A systematic literature review and a comparative experiment of second order mutation" coauthored by L. Madeyski, W. Orzeszyna and M. Jozala [17] from Wrocław University of Science and Technology, addressing a problem specific to mutation testing.

The third place was taken by "Robust statistical methods for empirical software engineering" coauthored by L. Madeyski [15] from Wrocław University of Science and Technology. This publication explains the new results in the area of robust analysis methods and presents an analysis of a large-scale software engineering experiment to illustrate their use.

It should be noted that the three top cited papers have one common coauthor: L. Madeyski, who also took the second place in the top contributors list (see Fig. 5).

The fourth most influential work is "On the effectiveness of early life cycle defect prediction with Bayesian nets" coauthored by Ł. Radliński [8] affiliated with the Institute of Information Technology in Management at University of Szczecin. The paper presents an analysis of a large-scale software engineering experiment to explain the use of various parametric and non-parametric statistical methods in software engineering.

The fifth paper in the ranking is "Simplifying effort estimation based on Use Case Points" by M. Ochodek, J. Nawrocki and K. Kwarciak [20] from Poznan University of Technology. It proposes a simplification of the Use Case Points (UCP) method and its application to estimate software development effort based on a use-case model and two sets of adjustment factors relating to the environmental and technical complexity of a project.

Table 1. The most influential publications.

	Authors affiliated with Polish institutions	Title	Year	Cited by
1	Madeyski L., Jureczko M.	Which process metrics can significantly improve defect prediction models? An empirical study	2015	115
2	Madeyski L., Orzeszyna W, Jozala M. et al.	Overcoming the equivalent mutant problem: A systematic literature review and a comparative experiment of second order mutation	2014	113
3	Madeyski L. et al.	Robust statistical methods for empirical software engineering	2017	109
4	Radliński Ł. et al.	On the effectiveness of early life cycle defect prediction with Bayesian nets	2008	107
5	Ochodek M., Nawrocki J., Kwarciak K.	Simplifying effort estimation based on Use Case Points	2011	106
6	Pospieszny P., Czarnacka-Chrobot B., Kobylinski A.	An effective approach for software project effort and duration estimation with machine learning algorithms	2018	83
7	Madey J. et al.	Precise Documentation of Well-Structured Programs	1994	73
8	Madeyski L., Radyk N.	Judy - A mutation testing tool for Java	2010	70
9	Turski W.M.	Reference Model for Smooth Growth of Software Systems	1996	66
10	Pedrycz W. et al.	Genetic granular classifiers in modeling software quality	2005	58

The sixth is "An effective approach for software project effort and duration estimation with machine learning algorithms" by P. Pospieszny, B. Czarnacka-Chrobot, A. Kobylinski [23] from Warsaw School of Economics. This publication presents effective models for effort and duration estimation in software development projects.

The paper ranked seventh is "Precise Documentation of Well-Structured Programs" coauthored by J. Madey [21] from Warsaw University. It proposes a new form of program documentation that is precise, systematic and readable.

The eighth place is taken by a publication titled "Judy – A mutation testing tool for Java" by L. Madeyski and N. Radyk [18] from Wrocław University of Science and Technology. It introduces and discusses an innovative approach to mutation testing which allows to estimate the fault detection effectiveness of test suites of much larger systems.

At position nine in the ranking is "Reference Model for Smooth Growth of Software

Systems" by W.M. Turski [25] from Warsaw University. It presents a model of smooth software system evolution which assumes constant effort per release and takes into account the growth of system complexity.

The last spot in the top ten was taken by "Genetic granular classifiers in modeling software quality" coauthored by W. Pedrycz [22] affiliated with Systems Research Institute of Polish Academy of Sciences in Warsaw. It describes a comprehensive design process of hyperbox classifiers and shows how such classifiers allow for an immediate interpretation of data concerning software maintenance.

To put the impact of the Polish contribution in the context of the global software engineering research, the top ten most cited works among the 20,633 in the analyzed set were cited 21,205 times (according to Scopus), which is about 10 times more than the combined number of citations of all 115 papers having Polish contribution (2100, according to the same database).

3.4. The Most Frequent Topics

In order to identify the topics that were most often chosen by Polish authors writing on software engineering, first, the list of authors' keywords of each paper having Polish-affiliated authors was extracted, and then, the number of appearances of each of the keywords was counted. The results are presented in a form of word cloud in Fig. 6, where the size of each word denotes its frequency.

The most frequently used keywords were: "Software Quality", "Requirements Engineering", "Information Granules", "Empirical Study", "Functional Size Measurement", "Software Measures", "Natural Language Processing", "Non-Functional Requirements", and "UML". We can thus conclude that the topics chosen by Polish researchers addressed diverse areas and various aspects of software engineering.

3.5. Threats to validity

The three main potential threats to validity characteristic for bibliometric analyses come from the selection of bibliometric database, the selection of search keywords, and the selection of the considered timeframe (see Sec. 5 in [13]).

As for the last of them, as explained in the Introduction, the chosen timeframe is naturally defined, comprising the whole period since Poland regained freedom.

The first two potential threats to validity were avoided by following an alternative data collection methodology: instead of choosing bibliometric database and defining the search keywords, we considered all articles published in a set of journals. This approach, however, has potentials threats to validity of its own, consisting in: (1) whether the journal articles are representative of the total research output; (2) whether the considered set contains all relevant journals and only journals which are relevant; (3) whether the identified articles are actually original peer-reviewed scientific publications.

Regarding the first of the above, it can be argued that although focusing only on



Figure 6. The most frequently used keywords.

journal articles ignores the larger part of research which is published in conference proceedings, the considered part contains research which is more mature and of higher quality, and high-importance conference papers are usually followed by their extended versions published in journals.

The second threat was mitigated in several ways. Firstly, we used the same set of journals as the prior work [14], to avoid any personal bias from our side in journal selection. Secondly, we verified that the selection remains relevant – the considered list contains all 14 journals pointed to by Robert Feldt as the most relevant for software engineering [7]. Thirdly, we examined top cited publications having software engineering listed in their keywords, published in other, non-software-engineering-focused journals, and found out that their contribution is mostly to the field of the respective journal, not software engineering, so including them would be disputable.

The third threat was addressed by excluding non-peer-reviewed publications (such as editorials or book reviews) from the set of analyzed articles.

4. Conclusion

Although 30 years have passed since the end of Soviet rule which enabled the fast development of software industry in Poland, so far there was no similar research striving to analyze the Polish contribution to software engineering research in the long period.

The applied research method was adopted from the work by Jurkiewicz et al. [14], which however covered only short period of time. By specifying the list of relevant journals rather than search keywords, two important aims were achieved: (a) the survey included all main areas of software engineering research, regardless of what keywords were chosen by the authors to describe their publications, and (b) only high-quality research which passed the demanding peer review procedure of the top scientific journals was considered.

Among the 20,633 identified publications, only 115 had at least one author affiliated to an institution located in Poland. The Polish contribution to the global software engineering research can only be described as very small, and the distance to the countries leading the global software engineering research is extensive.

During the last 30 years, the number of Polish software engineering papers published yearly varied, hitting the bottom four times (in 1992, 1993, 1995, and 1999), with no publications recorded in any of the considered journals, and attaining the best result in 2018 with 16 publications.

In general, the growth in the number of publications has been observed. The bad news is the global research output grew as well, so that the share of the Polish contribution has not increased much, with the level in the last analyzed year (0.61%), being little above the 30-year average (0.56%). In this regard, Poland not only did not reduce its distance to the Western countries, but also posed no competition for quickly developing countries which, during the 30 years, increased the shares of their contribution greatly: in 2021, China's share was about 2.7 times the 30-year average, whereas the shares of India and Brazil – 1.8 times.

On the positive side, the software engineering research is not a niche topic in Poland as it involves a number of renowned scientific institutions from various regions of the country, from Bialystok in the east, to Szczecin in the west, and from Gdańsk in the North to Kraków in the south. Poznan University of Technology can be seen as the institution leading the field in Poland, contributing about $1/5^{\text{th}}$ of the publications. Also, the software engineering research in Poland is not focused at a single vein, as the covered topics were highly diverse, stretching from requirements engineering, through agile software development, to software quality.

Taking this into consideration, we can conclude that there is a strong base for a future growth of Polish research on software engineering, but it is doubtful that its growth rate will be sufficient to greatly increase the share of Polish contribution, as evidenced by the last 30 years. For that to happen, either a large break-through in Polish software engineering research would be needed, or a significant drop in the global research output (less affecting Poland) would have to happen, both events being difficult to foretell.

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