From Academia to Industry: What Makes for a Successful AR Product

Jacinto Manuel Peixoto Graça

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Supervisor: Prof. Augusto Emanuel Abreu Esteves

Examination Committee

Chairperson: Prof. Alberto Abad Gareta
Supervisor: Prof. Augusto Emanuel Abreu Esteves
Member of the Committee: Prof. Daniel Jorge Viegas Gonçalves

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Declaration
I declare that this document is an original work of my own authorship and that it fulfills all the requirements of the Code of Conduct and Good Practices of the Universidade de Lisboa.

Acknowledgments

I would like to thank my parents for their friendship, encouragement, support and caring over all these years, for always being there for me through thick and thin and without whom this project would not be possible. Their belief in me and constant support have been a tremendous source of motivation.

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Abstract

Augmented Reality (AR) has witnessed substantial growth in the past couple of years, culminating in commercial devices from Meta and Apple in 2023. This was only possible due to vast research efforts in both academia and in industry, but the link between the two remains largely unexplored. To address this gap, we conducted a scientometric analysis to investigate the impact of academic research on the development of commercial AR products.

Through an extensive review of scholarly literature, we established a direct link between academic papers and the development of commercial products, as evidenced by patent data. Notably, our analysis revealed a time discrepancy between scientific research and its practical implementation in real-world products, indicating a delay in knowledge transfer from academia to industry.

In conclusion, this study provides valuable insights into the connection between academia and industry, particularly within the realm of AR. These findings serve as a catalyst for further research on the link between academia and industry, extending beyond the domain of Augmented Reality. By exploring this relationship, we can foster better collaboration and knowledge transfer, facilitating innovation and advancements across various fields.

Keywords

Augmented Reality; Industry; Academic Research; Patents; Scientometrics; Bibliometric data.

Resumo

A Realidade Aumentada (RA) tem testemunhado um crescimento substancial nos últimos anos, culminando em dispositivos comerciais como os da Meta e da Apple em 2023. Isto só foi possível devido a vastos esforços de pesquisa tanto na academia como na indústria, mas a ligação entre os dois permanece amplamente inexplorada. Com vista a abordar essa lacuna, realizamos uma análise cientométrica para investigar o impacto da pesquisa académica no desenvolvimento de produtos comerciais de RA.

Através de uma extensiva revisão da literatura académica, estabelecemos uma ligação direta entre os artigos académicos e o desenvolvimento de produtos comerciais, evidenciado através de dados de patentes. Notavelmente, com a análise foi-nos revelado uma discrepância temporal entre a pesquisa científica e sua implementação prática em produtos do mundo real, indicando um atraso na transferência de conhecimento da academia para a indústria.

Em conclusão, este estudo fornece insights valiosos sobre a conexão entre a academia e a indústria, especialmente no âmbito da RA. Essas descobertas servem como um catalisador para pesquisas adicionais sobre a ligação entre a academia e a indústria, estendendo-se além do domínio da Realidade Aumentada. Ao explorar esse relacionamento, podemos promover uma melhor colaboração e transferência de conhecimento, facilitando a inovação e avanços em diversos campos.

Palavras Chave

Realidade Aumentada; Industria; Pesquisa Académica; Patentes; Cienciometria; Dados bibliométricos

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Acronyms

ACM DL Association for Computing Machinery Digital Library

AI Artificial Intelligence

AR Augmented Reality

CHI Conference on Human Factors in Computing Systems

EJM European Journal of Marketing

HMD Head Mounted Display

HCI Human-Computer Interaction

ISMAR International Symposium on Mixed and Augmented Reality

MR Mixed Reality

VR Virtual Reality

WIPO World Intellectual Property Organization

1

Introduction

Contents

Augmented Reality (AR) is a rapidly evolving field that combines the real world with virtual concepts, overlaying computer-generated imagery onto physical objects in real time [4]. With its ability to supplement reality and its widespread applications in various domains such as education, healthcare, marketing, entertainment, and architecture, AR has emerged as a prominent technology in modern society [6]. The significant growth and commercialization of AR, as well as its recognition as one of the pillars of Industry 4.0, highlight its importance and impact on the industry [13].

1.1 Motivation and Objectives

Despite the substantial growth of AR and the abundance of research publications in this field, there appears to be a gap in understanding the connection between academic research and the launch of new AR products. Understanding the connection between academic research and the launch of new AR products is of great importance as it bridges the gap between theoretical advancements and practical implementations. This link enables the translation of innovative ideas and scientific discoveries into tangible AR products that can enhance various industries and benefit end-users.

While studies have explored the link between science and technology in specific fields, such as Narin et al.'s work [28], such investigations are limited in their scope and complexities. We cannot generalise the link between science and industry for multiple fields, this connection is multifaceted and involves numerous variables such as funding, collaboration, market demand and other complex criteria that make it challenging to fully comprehend and analyze the dynamics between both worlds. Given the size and impact of the AR field, combined with the lack of studies examining this specific relationship, there is a compelling need to investigate the interplay between science and technology in the context of AR.

In light of this motivation, our study aims to contribute to the field of AR by examining the relationship between academic research and technological advancements. While previous research has focused on mapping concepts and identifying trends in academic literature [11, 16], our proposal takes it in a different direction. We not only seek to uncover the current trends in academia but also to explore how these trends are connected to the technological world. Specifically, we aim to investigate whether the development of new AR devices, their characteristics, and areas of application are directly influenced by academic research or driven by other factors.

1.2 Contributions

To achieve our research objectives, we have made a bibliometric review of AR academic literature from the past decade and associated patent data. By studying the characteristics of current AR technologies and literature we provide a better understanding of the link between academic research and technological developments. This analysis will enable us to discern the alignment between research directions and technological advancements, shedding light on the influence of academia on the evolution of AR devices.

Ultimately, this research contributes to a deeper understanding of the interplay between science and technology in the dynamic field of AR.

1.3 Organization of the Document

This thesis is organized as follows: Chapter 1, provides a concise introduction that outlines the problem we intended to solve, presents our proposed solution, and highlights the objectives we aimed to accomplish. Chapter 2, serves as a foundation for our work by exploring existing literature and works that have influenced our approach. We discuss the strengths and limitations of these sources, providing valuable context for our own solution. In chapter 3, we go over the preliminary work done in order to understand if the proposed solution was viable, as well as a comprehensive understanding of what was implemented. Next, in chapter 4 we present a comprehensive analysis of the relevant data obtained from our study. Finally, chapter 5 concludes this paper by offering our final reflections, encapsulating the essence of our work and the opportunities for further exploration in the field.

2

Related Work

Contents

We decided to study the relation between science and technology and focus mainly on scientometrics, its techniques and how they can be applied on academic literature and patents.

2.1 Science and Technology

The relationship between science and technology is often portrayed as a unidirectional link, where scientific discoveries drive the development of new technological products. However, the work conducted by Brooks [8] provides a deeper understanding of the intricate connections between science and technology. In his study, Brooks describes science, technology, and innovation as separate yet interconnected domains. He characterizes them as ”two parallel streams of cumulative knowledge, which have many inter-dependencies and cross relations, but whose internal connections are much stronger than their cross connections.” This perspective highlights the interplay and interdependence between science and technology, emphasizing that while they influence each other, their internal developments and advancements are of significant importance. The impact of science on technology extends beyond providing novel technological ideas. It encompasses the introduction of new techniques, analytical methods, and design tools that can be integrated into diverse fields, even those unrelated to the original scientific concept. Conversely, technology serves as a catalyst for research by presenting new challenges and demanding innovative solutions. It also opens up new avenues for exploration, enabling breakthroughs and paradigm shifts that were previously unattainable.

One of the most relevant works that sought to quantify the relationship between technology and scientific papers was conducted by Narin, F. et al [28]. Their study aimed to demonstrate the close connection between high-tech patents and related scientific papers, suggesting that the two are intricately intertwined to the point of being nearly indistinguishable. To achieve this, they selected scientific papers from various biomedical journals, encompassing a broad range of disciplines within the field, and patents from the top ten patent office classes with the highest patent counts in the United States.

Their analysis focused on comparing the citations in patents with citations in scientific papers, specifically examining the time distribution and frequency of references. The results revealed that patents tend to draw upon recently published scientific papers, highlighting an important concern: a reduction in research investment could have detrimental effects on technological advancements, given that scientific contributions play a significant role in the development of new patents.

While this study has certain limitations, such as the lack of historical data to showcase the evolution of the relationship over time, it remains highly relevant to the solution we have developed. It is worth noting that their reliance on citation analysis for observations restricts the quantity of available insights. For instance, determining the most popular concepts within a particular field based on cited papers requires manual observation in their study. In contrast, our work benefits from more recent analysis techniques and access to a significantly larger corpus of works spanning an extended period.

2.2 Scientometrics

Scientometrics was originally defined by Nalimov in his book ”Measurement of Science. Study of the Development of Science as an Information Process” [9], and is concerned as the field responsible for the analyses, exploration and evaluation of scientific research. Some of the major applications of Scientometrics are the study of relations between science and multiple fields and the evaluation of the quality and impact of publications in the increasingly more complex amount of scientific research being produced [25].

Through out the development of the field, different techniques have been discovered and shown its value, with some of the most common analysis methods currently employed being:

- **Bibliographic references**, where the research accounts for details such as publication year, journal title, author name or address, keywords or a combination of all the above.
- **Bibliographic coupling**, I that connects publications based on the fact that they share references.
- **Co-citation analysis**, the technique that studies citation relationships.
- **Scientometric indexes**, that quantify the impact of publications through numerous factors.
- **Co-word analysis**, the technique that studies the occurrence of co-words in publications.

The work by Bartneck, C. et al [7] for instance, makes use of bibliographic references and indexes to identify the quality and impact of research discussed at conferences in the Human-Computer Interaction (HCI). With their scientometric analyses they conclude that the acknowledged works are not related with an increased number of in citations or other metrics, presenting the idea that this award is of questionable value.

Our main focus was on this fields capability to identify trends, and scientific or technological advances through the analysis of the available information [12, 15, 21, 30, 33]. Some early works in this area, through indicators [31] or comparing patent citations and research articles [28, 29] as we discussed earlier, have already shown the value of metrics studies to confirm the existence(or lack) of a link between different areas.

2.2.1 Co-citation analysis

The first concept of co-citation analysis was initially proposed by Small, H. [34]. Co-citation analysis focuses on examining the frequency with which two publications are cited together in other research papers. Small's work concludes that robust co-citation links indicate the presence of connections within a specific field of study. These connections can give rise to co-citation clusters, which enable the mapping of specialized areas within the field and the tracking of changes that occur over time.

The technique of co-citation analysis has proven valuable in detecting temporal changes and emerging trends. In the study conducted by Morris et al. [27], the analysis of co-citation clusters enables the identification of research fronts. The presence of a field being cited without previous mentions suggests a potential new research front, while the absence of citations indicates a field in decline or regression.

In a similar fashion, Erdi et al. [14] proposed a method for predicting emerging technologies. By analyzing patent publications in the United States, they constructed a citation network and developed a predictor system. Figure 2.1 provides a visual representation of the temporal changes in patent clusters. The figure demonstrates the splitting process, which indicates the formation of a new class. Interestingly, the separation of patents was observable well before the official establishment of the new class, which occurred in 1997. This method however, has its own limitations given that there is a high time discrepancy from the launch of a new technology and it achieving a respectable amount of citations to be considered as a valuable contribute to the citation network.

While there were many more works that used co-citation in their methodology, we believed that the above are more than enough to show how it is a technique extremely useful to detect how a field changes over time, new fields and declining ones, and it can even be combined with other methods to generate new and more robust solutions.

2.2.2 Co-word analysis

Since this method was firstly introduced [10], it has become a well-established and common approach used in various fields that studies the relation between words present in documents. As described

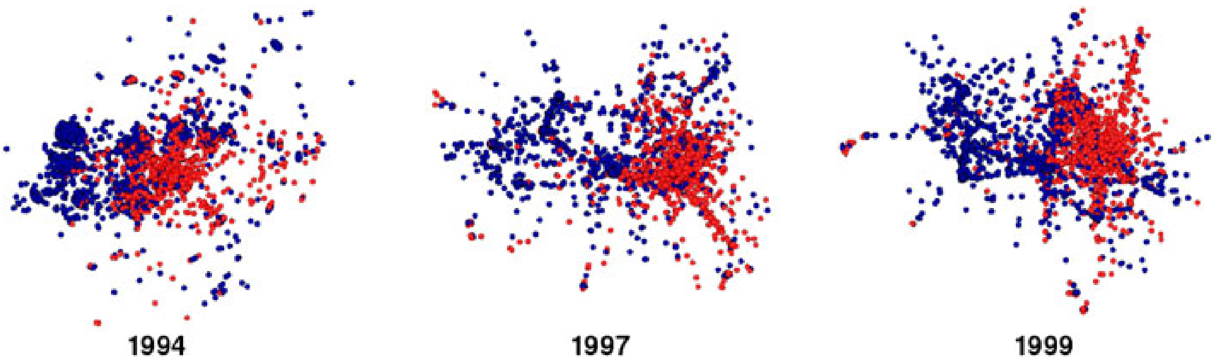


Figure 2.1: Splitting process in the citation space, underlying the formation of a new class. The position of the circles denote the position of the patents in subcategory, red circles show those patents which were reclassified during the year 1997, while those that preserved their classification after 1997 are denoted by blue circles., from Erdi et al work [14].

by Callon, M. et al., the underlying principle of this technique is ”the idea that the co-occurrence of key words describes the contents of the documents in a file” [9]. Words that frequently appear across papers carry greater significance in a field compared to less referenced terms. By aggregating these keywords, it becomes possible to identify emerging or declining themes and even gain insights into the trajectory of research [18]. Employing this technique enables us to ascertain the most extensively researched topics in a field, understand their knowledge structure, and track their evolution over time [17].

A very relevant example of the use of this technique, since it was implemented in a research area that contains the topic of Augmented Reality, is the study conducted by Liu, Y. et al [22]. This study aimed at quantifying and describing the progress of the HCI field over the years. The Conference on Human Factors in Computing Systems (CHI) is one of the most impactful in the field of HCI, according to the authors, the analyses of the articles published should then be a good representation of the field's evolution. The keywords in publications are then used as nodes and their co-occurence is represented as a link between them, leading to the creation of a network graph. In order to map the field of HCI, as earlier discussed in the work by Callon, M. et al [9], they rely on two graph theory concepts:

- **Density** - represents the strength of the links that tie the words making up the cluster together
- **Centrality** - measures the degree(intensity) of a cluster with other parts of the network.

After applying the study of the degree and centrality on the network, it is possible to represent it in a simplified manner for a dynamic analysis. The four categories generated can be represented as in Figure 2.2.

- Quadrant I, are clusters both central and coherent to the network, with high centrality and density.
- Quadrant II, represents the coherent but not central, peripheral to the network, these themes have high density but low centrality
- Quadrant III, are the weakly developed and peripheral clusters of the network, themes with low density and centrality.
- Quadrant IV are central but relatively low dense clusters in the network, themes with a high centrality and low density.

Using this method, the researchers are able to classify the generated clusters, thereby identifying the predominant research themes in the field, as well as the underlying trends in the area of HCI and the emerging topics. However, it is important to acknowledge the limitations of this study. The use of a single source of publications and a relatively small sample size of works may restrict the generalizability of the findings. Additionally, the accuracy of the results is influenced by the authors' ability to precisely

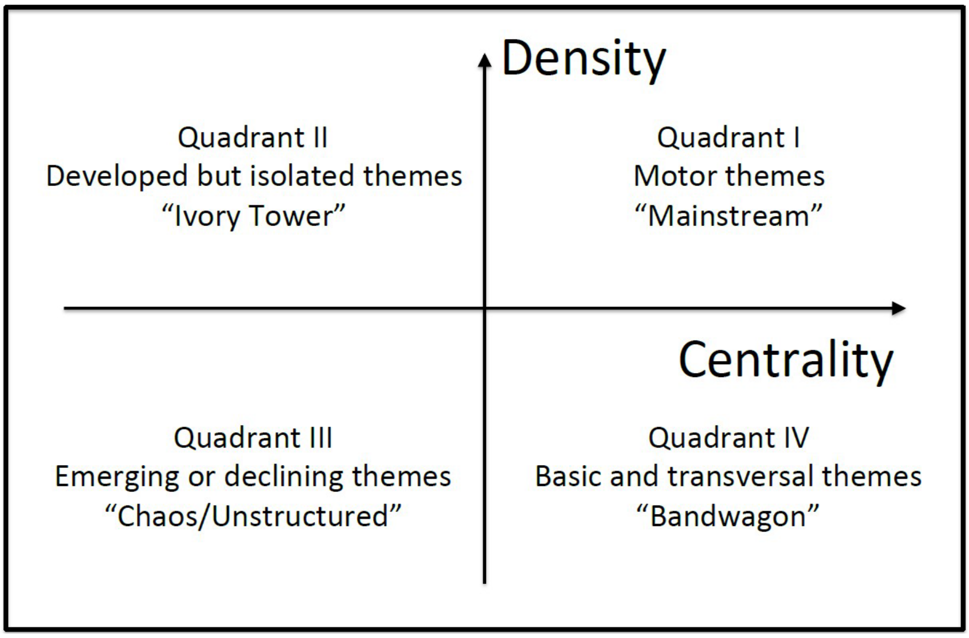


Figure 2.2: Strategic diagram's degree of density and centrality, by Liu, Y. et al [22].

describe the contents of their work, introducing another variable that could impact the quality of the results.

Co-word analysis has also been applied in works to detect new and emerging fields. One of these works is from Lee [19], who uses it to identify emerging research fields within the area of Information Security. Following the acquisition of data, they generate a matrix of keywords occurrence followed by the creation of clusters using hierarchical clustering based on Ward's work [28]. With these clusters a new matrix is generated and a multi-dimensional scaling technique is used to obtain the position of all clusters. In order to find ”hubs”, the fields that are developing the most, three concepts of graph theory are used: measure of degrees, betweenness and level of closeness. Clusters that present a low value of degree, high betweenness and low closeness are then deemed as the most likely to become emergent fields.

Lastly, it is worth mentioning that this technique can be complemented by integrating other methods, thereby offering a more comprehensive and insightful understanding of a specific field. For instance, the combination of co-word analysis and co-citation has been employed in previous studies. One example is the research conducted by Tan Luc, P. et al [35], which explores the domain of Social Entrepreneurship. Another example is the work by Leung et al [20], which presents a comprehensive review of the academic literature on Social Media. By utilizing multiple methodologies, researchers can obtain a more comprehensive understanding of the subject matter and discover valuable insights.

2.2.3 Bibliometric analysis

While co-citation and co-word analyses have demonstrated their effectiveness in identifying connections and trends within a specific field, our work has found that bibliometric analysis could also be a suitable approach for our research.

Bibliometric analysis is a research method involving the statistical analysis of bibliographic data, such as publication and citation counts, to evaluate and understand the research literature within a particular field or discipline. Similarly to the previous shown methods, it can be used to identify trends, and relationships among publications, authors, institutions, and other bibliographic elements [26].

An example of application is the work conducted by José M. Merigó et al. (2017) [24], where the main objective of the study was to identify the most relevant research in the field of operations research and management science, as well as to uncover the newest trends based on the information retrieved from the Web of Science database. The authors delve into the scholarly literature in this field, utilizing bibliometric techniques to gain valuable insights into the research trends, influential authors, top journals, and key research topics.

Another example of this method can be found in the research made by Martínez-López et al [23], which presents a bibliometric overview of the European Journal of Marketing (EJM) during its 50-year history. The study gives its readers insights on the historical trends and key contributors of the EJM, offering a comprehensive understanding of its scientific productivity and influential sources.

2.3 Discussion

The presented related work section played a fundamental role in supporting the employed solution by establishing the significance of studying the connection between science and technology, highlighting the relevance of scientometric methods to explore the intrinsic relationship in academic literature.

We showcased three of the scientrometric methods that we initially considered using for our solution. Overall, presenting several methods in the related work section served to provide a comprehensive overview of the different scientometric methodologies available. It demonstrated our familiarity with alternative approaches and methodologies while reinforcing the rationale behind our selection of bibliometric analysis as the method for our research objectives.

In the end, we chose bibliometric analysis over co-word or co-citation analysis due to its practicality, direct relevance to patent analysis, and ability to capture the relationship between academic research and real-world applications without introducing unnecessary complexity. By analyzing the bibliographic data and the references within patents, we could establish a direct connection between the scholarly literature and real-world applications. This approach provided a more direct and reliable means of understanding the impact and transfer of knowledge from academia to industry.

3

Methodology

Contents

This section begins by outlining the encountered challenges during the development of the initial proposed solution, subsequently detailing the adapted approach and the architecture resultant from those changes.

3.1 Challenges and Methodological Adaptations

3.1.1 Proposed Solution

The development of our work began by gathering research publications and product information, followed by a scientometric review of the chosen literature and analyses of the product characteristics. The results of these processes will be discussed in the next chapter.

The initial proposed solution could be categorised into three sequential segments:

1. **Data acquisition**, both research papers and commercial products
2. **Data processing**, by cleaning the retrieved data and applying transformations such as the scientometrics analysis
3. **Data visualization**, including the gathered data and their subsequent evaluation

During the development of our solution, we encountered unforeseen challenges in accessing academic literature and acquiring products. As a result, we had to adapt our data acquisition process, which we will discuss in the following subsection.

Furthermore, the new data available influenced the scientometric methods we applied, eliminating the need for the development of any visual tools to navigate the data and instead we will present the most significant findings in this paper.

3.1.2 Academic Literature

Initially, our proposal as depicted in Figure 3.1 aimed to retrieve academic literature from the Association for Computing Machinery Digital Library (ACM DL), specifically focusing on works related to AR in the field of HCI.

However, during the process of gathering publications from CHI, we encountered several challenges. Many papers were inaccessible due to paywalls, that even with an academic license we could not have access to, leading to a very scarce pool of articles. Additionally, the ACM DL imposed limitations on mass article retrieval, even banning the IP addresses from accessing the digital library for a period of time.

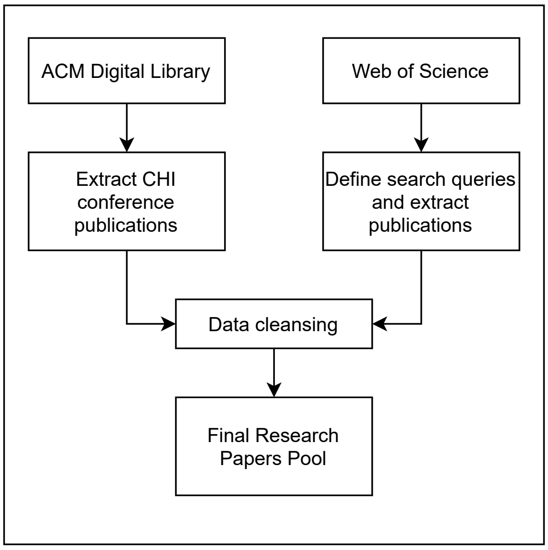


Figure 3.1: Visual representation of the research publications acquisition process

To overcome these limitations, we devised an alternative solution. Instead of accessing full-text papers, we focused on gathering publicly available metadata, keywords, abstracts, and other relevant information. Scopus [3] emerged as our primary source for retrieving papers from a renowned conference, as well as Lens [1] to complete our pool of articles.

The selection of the conference for our study was based on the CORE (Conference Ranking) and the influence of AR in those conferences.

CORE (Conference Ranking) is a well-established system that ranks academic conferences in computer science and related fields, classifying them into different tiers based on their perceived quality and impact in the research community.

Table 3.1: Conferences considered due to CORE ranking

Conference	CORE ranking (2021)
IEEE Conference on Virtual Reality and 3D User Interfaces	A*
ACM Virtual Reality Software and Technology	A
IEEE/ACM International Symposium on Mixed and Augmented Reality	A*
International Conference on Human Factors in Computing Systems	A*

With that in mind, we determined that articles presented at the International Symposium on Mixed and Augmented Reality (ISMAR) conference would be the most suitable representation of the field of augmented reality as the main focus of it is in AR

3.1.3 Industry data

The original plan, as depicted in Figure 3.2, involved collecting commercial product information from various crowdfunding platforms. Specifically, we intended to use keywords to search Kickstarter and Indiegogo for AR projects. In case these platforms yielded insufficient results, we planned to explore other platforms.

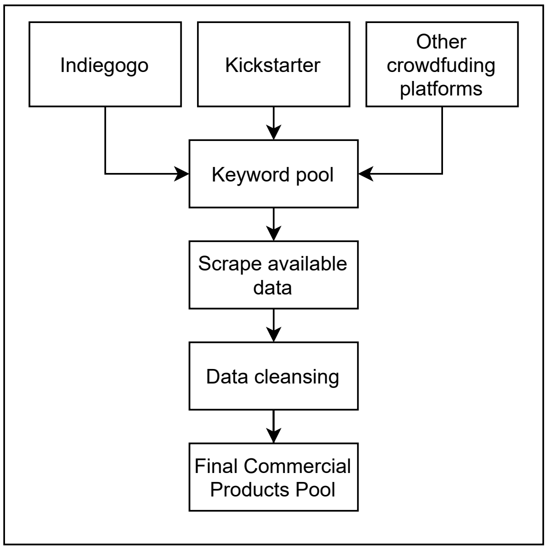


Figure 3.2: Visual representation of the scientometric analysis process

During the implementation phase, the reality was that we encountered projects with limited or inadequate information on the crowdfunding platforms. This included examining the product websites and other available sources to gather additional details and improve the quality of the collected data. However, despite our efforts, there were cases where the information quality remained insufficient, leading us to exclude certain products from our dataset.

Recognizing the need for reliable and comprehensive data, we resorted to our contingency measure, which involved incorporating AR patents as an alternative representation of technology. By considering the potential value of patents in our analysis, we aimed to compensate for the limitations of the crowdfunding platform data and ensure a more robust and comprehensive evaluation of the technological landscape.

Relating patents directly to papers can be challenging due to the inherent differences in their structures. Patents often have complex and technical language, making it difficult to establish direct connections with academic papers. Additionally, patents may lack comprehensive citations or clear references to specific papers, further complicating the task of linking them to relevant scholarly literature.

To overcome these challenges, we focused on analyzing the papers that were cited by patents. Cited papers serve as a foundation for patents, providing valuable insights and supporting the claims made in the patent documents. By examining the papers that patents reference, we were able to establish a connection between the current academic literature and the patents in the field of interest.

3.2 Technology Stack

We opted to utilize both Python [2] and R [32] languages as the foundation for this project

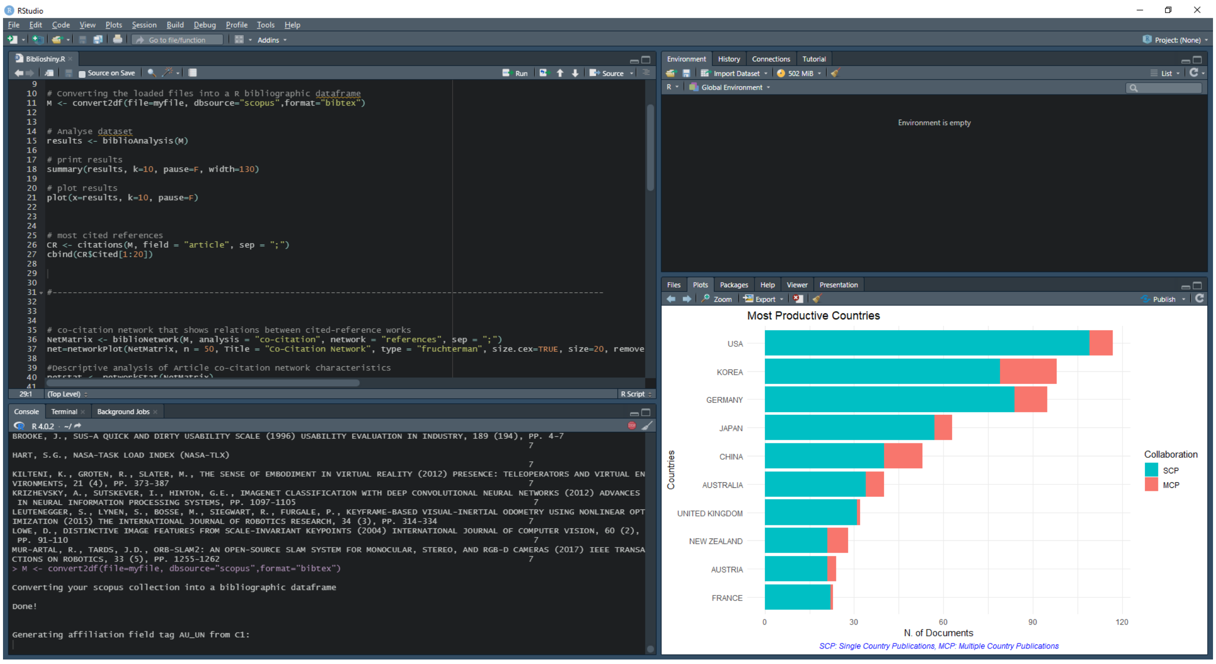


Figure 3.3: Bibliometric analysis in RStudio

. While Python offered the advantage of easier code comprehension and writing, it also provided a wide range of packages that facilitate data manipulation, analysis, visualization, and scientific computing. These packages greatly simplify the data processing tasks involved in our research, including the analysis of both the collected papers and patents.

Python's versatility, extensive library ecosystem, user-friendly syntax, and robust community support make it an exceptional choice for conducting data analysis and research across various fields. It served as the primary tool for manipulating and analyzing the acquired data, ensuring efficient and effective research outcomes.

To complement our analytical toolkit, we incorporated R, specifically utilizing the Bibliometrix package [5], for in-depth analysis of the bibliometric data we gathered.

3.3 Architecture Design

Chosen time window: Our analysis focuses on the period from 2012 to 2022, encompassing the last decade. It captures a significant period of advancements and innovations in the field of AR, providing us with up-to-date insights into its current state. Additionally, the availability of scholarly articles, patents, and related data has notably expanded during this decade, ensuring better dataset for our analysis. By narrowing our scope to this specific timeframe, we have established a consistent basis for comparison, enabling us to identify patterns and changes over time accurately.

After implementing all the necessary adaptations and adjustments, our solution can be visualized as depicted in Figure 3.4.

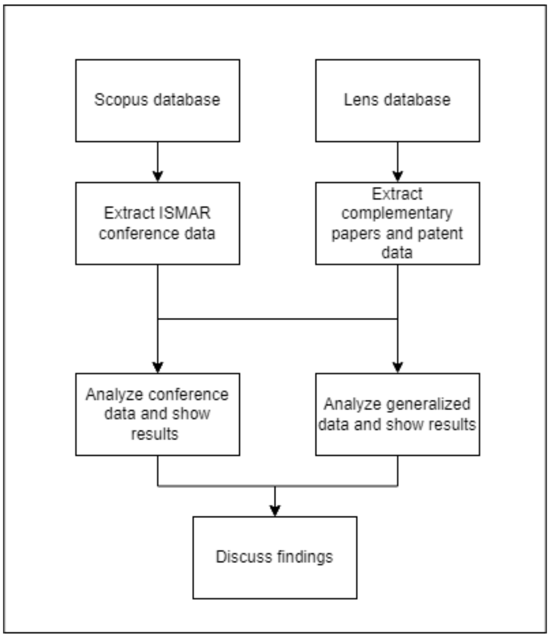


Figure 3.4: Visual representation of the implemented solution

Gathering Academic Literature: We implemented an architecture design that involved gathering academic literature related to augmented reality. We utilized Scopus, a comprehensive database, to obtain all the data related to the ISMAR conference. This allowed us to gather a significant amount of academic literature specifically from this conference.

Analyzing Paper-Patent Relationship: From the ISMAR articles, we can already make a relation to patents by analysing the bibliometric data of the patents (retrieved via Lens) and subset of papers that have been cited.

To further explore the connection between papers and patents, recurring to the Lens database we adopted for a keyword-based approach. Our goal was to identify AR papers that had been referenced by patents within the same time frame as the ISMAR conference. By meticulously filtering and refining our article collection using specific keywords associated with augmented reality we were able to gather papers during the same time interval as the ISMAR conference and their citing patents.

Table 3.2: Key terms used to gather AR data

Keywords employed
Augmented reality (AR)
Virtual Reality (VR)
Mixed Reality (MR)
Wearable AR devices
Head Mounted Display (HMD)
AR applications

Bibliometric Review: In the end, we conducted a bibliometric review of both the patents and the cited references. The aim was to identify any patterns or correlations between the scientific aspects represented by the papers and the industrial aspects represented by the patents. This analysis aimed to uncover connections and insights at the intersection of academia and industry within the augmented reality field.

4

Results and Discussion

Contents

This section will start with an analysis of the academic papers in ISMAR, followed by an examination of the academic literature gathered with the defined keywords that have been referenced by patent data. Subsequently, we will discuss the relationship between the data from papers and patents.

4.1 Results

4.1.1 ISMAR Data

Upon initial examination of the ISMAR conference over the past decade, our choice to focus on this conference proves to be substantiated. As depicted in Figure 4.1, AR emerges as the predominant field of study, encompassing the broader realm of computer science.

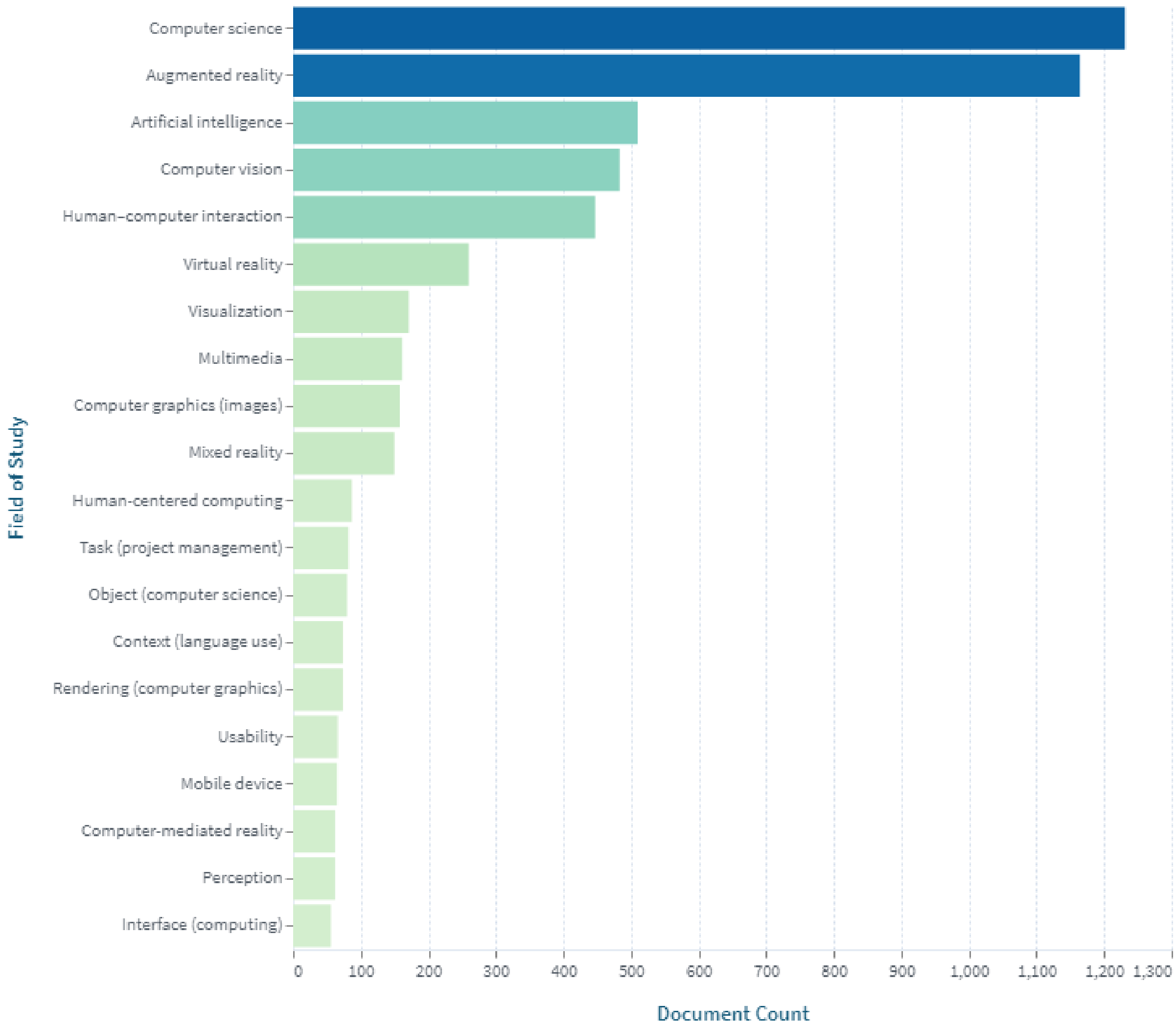


Figure 4.1: Study fields present in the last decade of ISMAR conferences, from a total of 1232 articles

Analysing the amount and field of study by year we can also observe that the field of study has been stable and the number of publications in this conference has exhibited a steady growth.

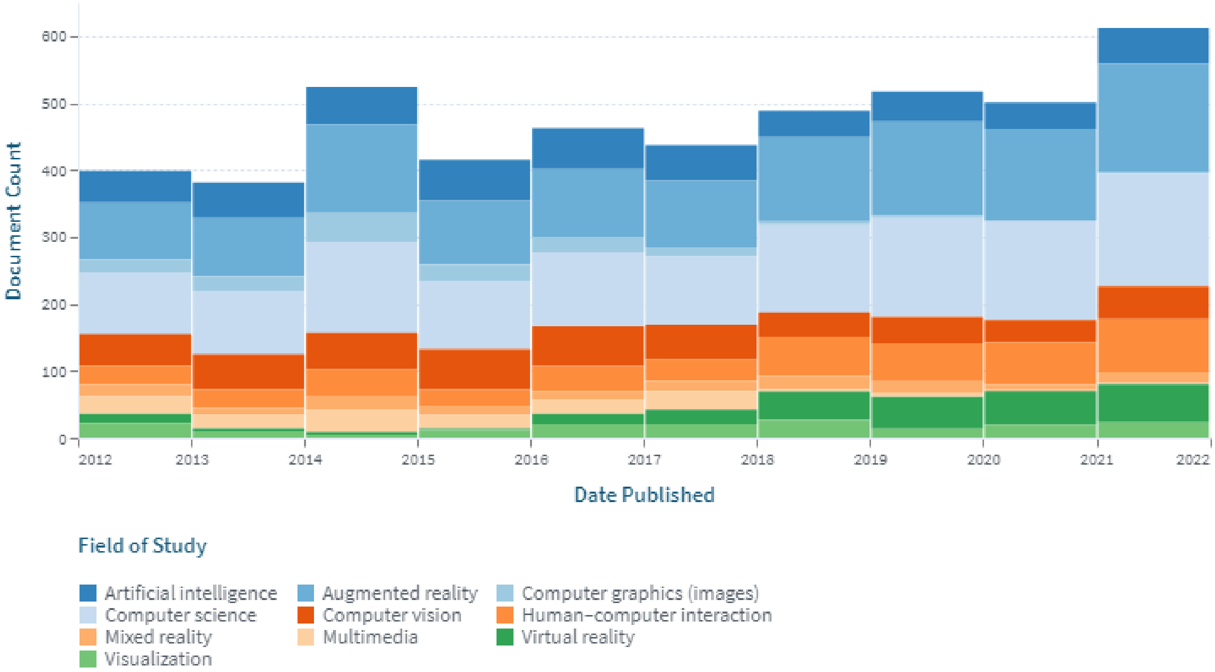
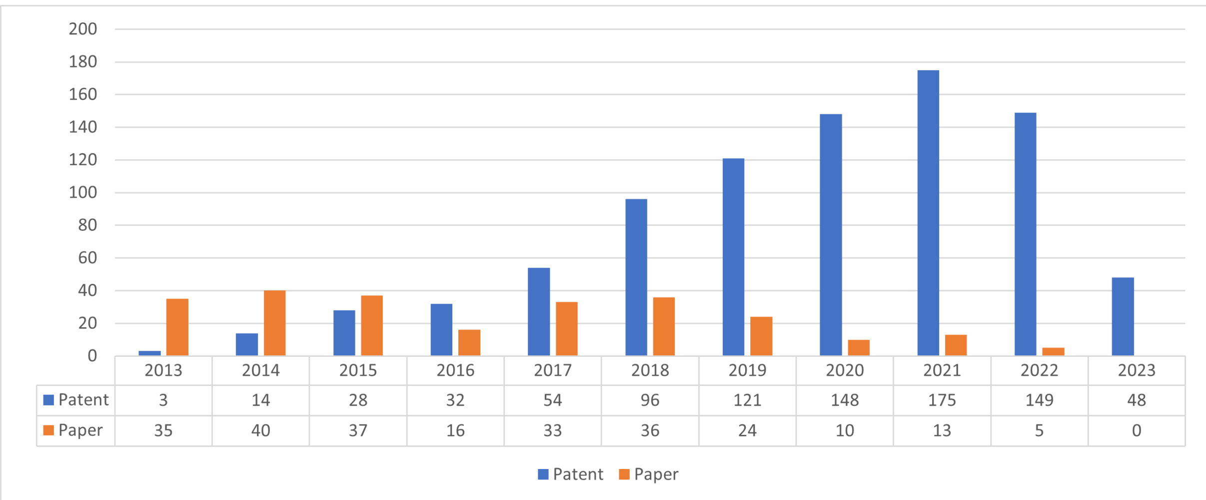


Figure 4.2: Number of articles and field of study per year at ISMAR

Upon further analysis of the patent data specifically from the ISMAR conference, we observe that there are a total of 249 works that have been cited by 869 unique patents. Interestingly, when comparing the publication dates of the cited works and patents, we can clearly see a time discrepancy as shown in Figure 4.3.



	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Patent	3	14	28	32	54	96	121	148	175	149	48
Paper	35	40	37	16	33	36	24	10	13	5	0

Figure 4.3: Side-by-side view of number of publications per year

The publication dates of the cited works tend to be much earlier compared to the patents. This finding suggests that the works being referenced by patents in the augmented reality domain are often from earlier periods, highlighting a temporal disparity between the two.

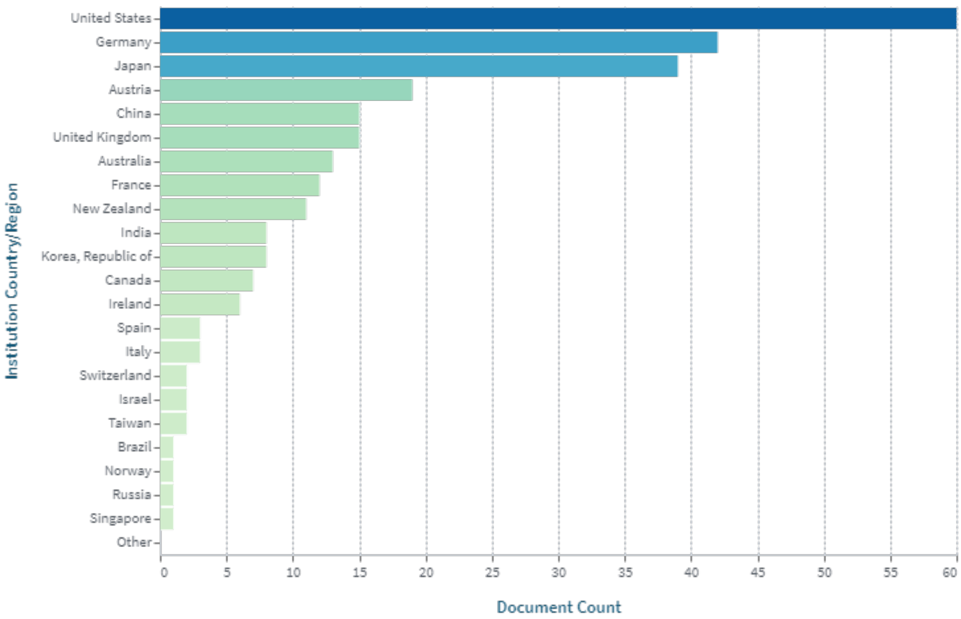


Figure 4.4: Number of publications per country

Another noteworthy observation we made, which we will further investigate with the expanded dataset, is the predominant contribution of research from the United States. As depicted in Figure 4.4, a significant portion of the cited papers originate from America.

Likewise, the analysis of patents reveals a notable concentration of patent filings originating from the United States (Figure 4.5). This finding indicates that a significant portion of the foundational research, which serves as the basis for patent applications, is conducted and utilized mostly for American patents.

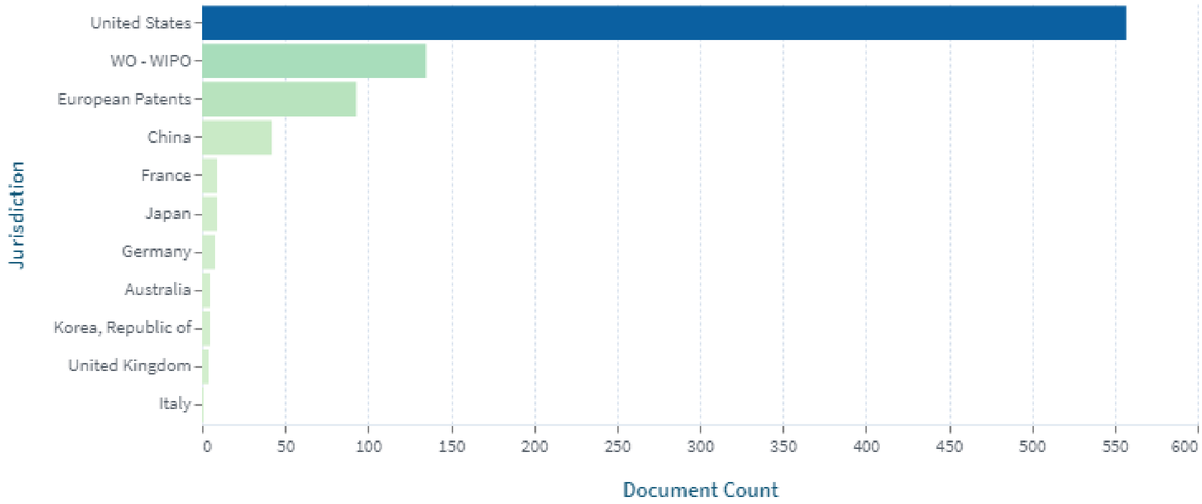


Figure 4.5: Number of publications per jurisdiction

In order to strengthen this observation, we focused on three specific countries which are the top publishers of articles in ISMAR: the United States, Germany, and Japan. We narrowed down the dataset to papers originating from each of these countries and examined which patent jurisdictions cited them the most. The results reaffirmed that the United States is the primary consumer of citations independently of the origin of the papers, as demonstrated in Table 4.1.

Table 4.1: Distribution of citing patents from the three major article contributors

Jurisdiction	United States	Germany	Japan
United States	245	60	67
WO - WIPO	41	17	12
European Patents	21	11	16
China	12	-	5
Japan	3	3	1
Australia	2	1	-
Germany	1	3	-
United Kingdom	1	-	1
Italy	1	-	-
Korea	1	-	-
France	2	-	-

Lastly, we believe it is noteworthy to mention the top applicants and owners of patents that cite the ISMAR conference. This information is presented in the tables 4.6

Applicant	Document Count
Microsoft Technology Licensing LLC	71
Qualcomm INC	30
Univ Arizona	28
Magic Leap INC	26
Apple INC	23
Adshir LTD	20
Snap INC	20
Ibm	18
Lang Philipp K	17
Lg Electronics INC	17

(a) Top Applicants

Owner	Document Count
Microsoft Technology Licensing LLC	64
Snap INC	34
Magic Leap INC	21
Snap Israel 2016 LTD	21
Adshir LTD	20
International Business Machines Corporation	20
Qualcomm Incorporated	19
Microsoft Corporation	16
The Arizona Board of Regents on Behalf of the University of Arizona	16
Apple INC	13

(b) Top Owners

Figure 4.6: Top Applicants and Owners of Patents citing ISMAR

4.1.2 General data

After exploring the initial connection between patents and referenced papers, we recognized that the ISMAR conference had a limited number of articles accepted and published each year. In order to gain a more comprehensive understanding of the field of AR, we conducted a deeper analysis that extends beyond conference restrictions. By expanding our scope to encompass a wider array of sources, we achieved a more comprehensive perspective on the interplay between patents and articles in the field.

The following graph, Figure 4.7, shows the distribution of articles from 2012 to 2022 that have cited by patents based on our keywords, for a grand total of 10 533 papers.

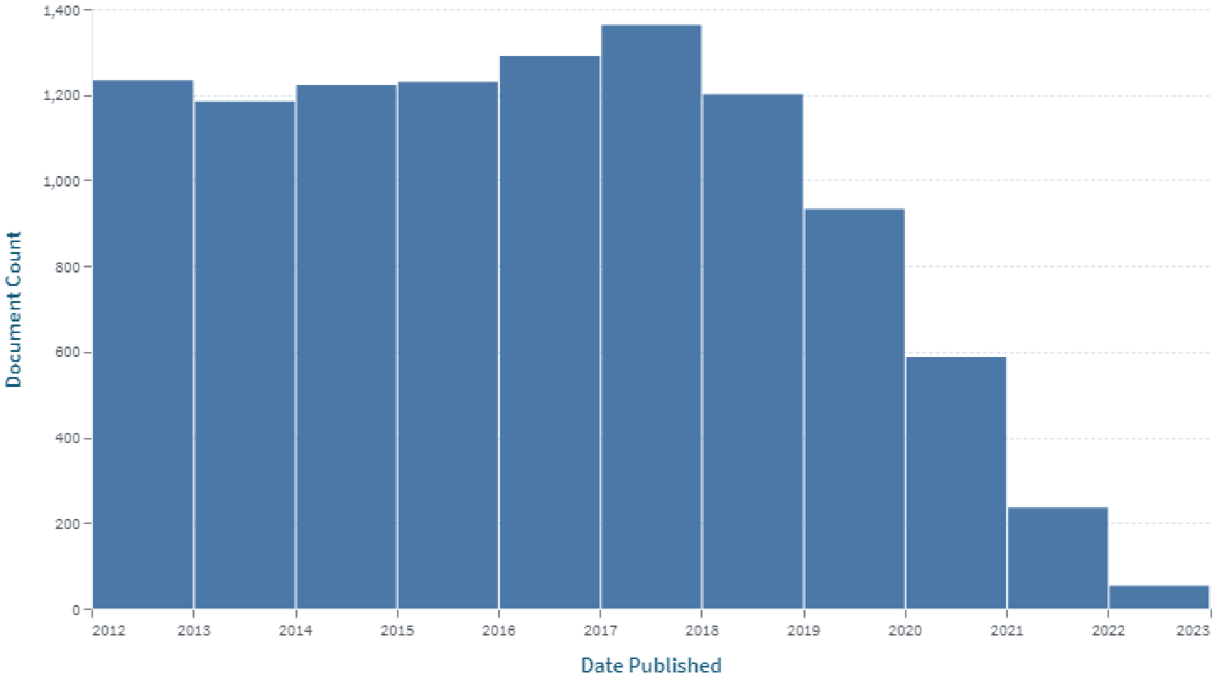


Figure 4.7: Number of publications per year

The number of citing patents however, amounts to 25 451 total. For which we also have the distribution along the years, as seen in Figure 4.8

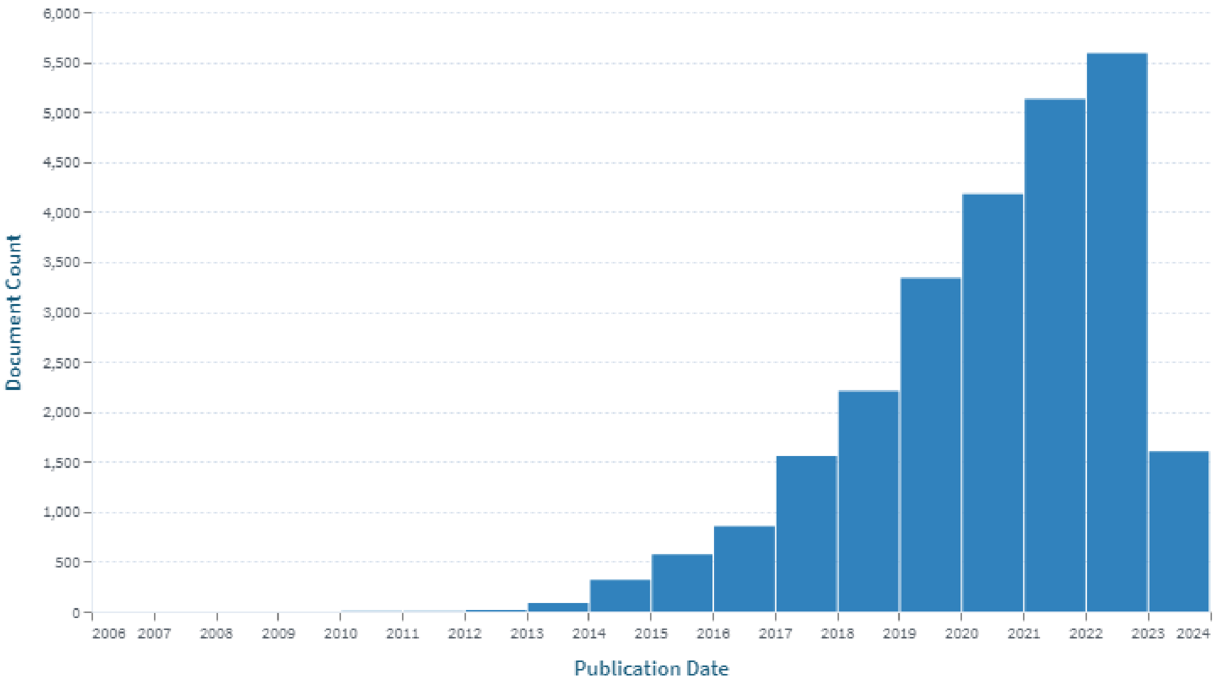


Figure 4.8: Number of publications per year

As with the data from ISMAR we found an interesting pattern: as papers become more recent, there is a decline in the number of citations they receive from patents. Conversely, the number of patent filings shows an upward trend, increasing over time.

To determine the exact duration of the time discrepancy, a more detailed analysis would be required, including examining the average time between article publication and patent filing in specific industries or conducting a longitudinal study tracking the timeline of knowledge transfer from research to patenting.

Publication Year	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
2012	16	2	0	0	0	0	0	0	0	0	0
2013	69	10	4	2	0	1	0	0	0	0	0
2014	225	72	14	4	1	1	0	0	0	0	0
2015	298	186	75	20	2	0	0	0	0	0	0
2016	342	249	197	97	16	2	0	0	0	0	0
2017	511	380	340	272	121	22	2	0	0	0	0
2018	561	455	509	383	324	165	30	6	0	0	0
2019	680	637	627	650	520	430	188	41	7	1	1
2020	702	674	667	791	608	655	514	184	33	5	6
2021	676	724	691	810	716	883	701	530	213	48	7
2022	609	822	615	808	755	1003	828	687	459	147	33
2023	185	204	180	226	193	285	238	225	153	78	17

Table 4.2: Distribution of Patents Citing Articles by Publication Year

Looking into the countries with the most patents, similarly to ISMAR, we found that the biggest producer of patents in once again the United States as we can see in Figure 4.9, followed by World Intellectual Property Organization (WIPO), China and European Patents

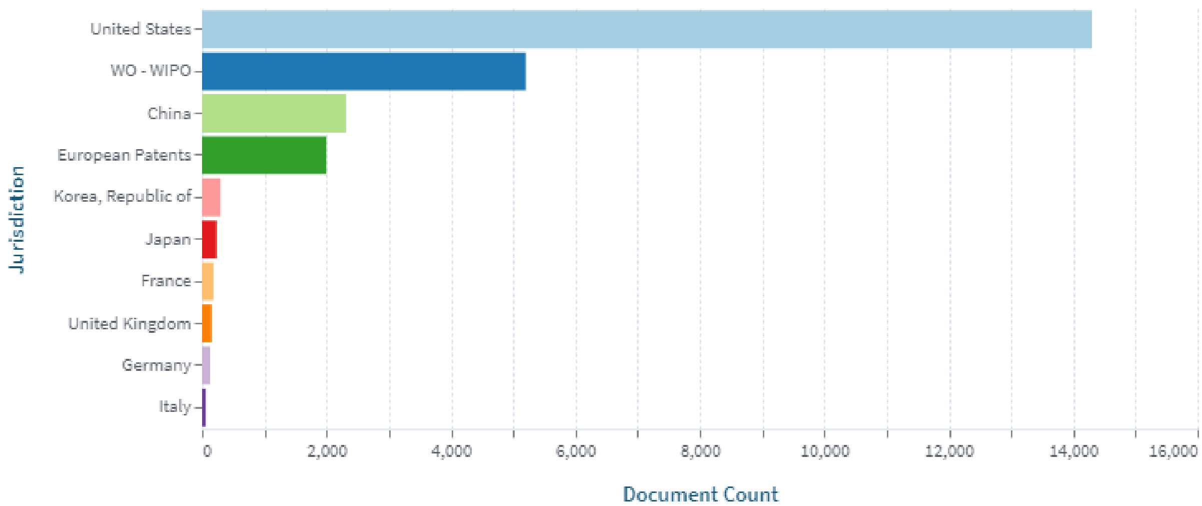


Figure 4.9: Number of patent publications by Jurisdiction

From the cited papers point of view, as with ISMAR, the top publishing country is the United States as we can see in Figure 4.10, followed by China, Germany and United Kingdom.

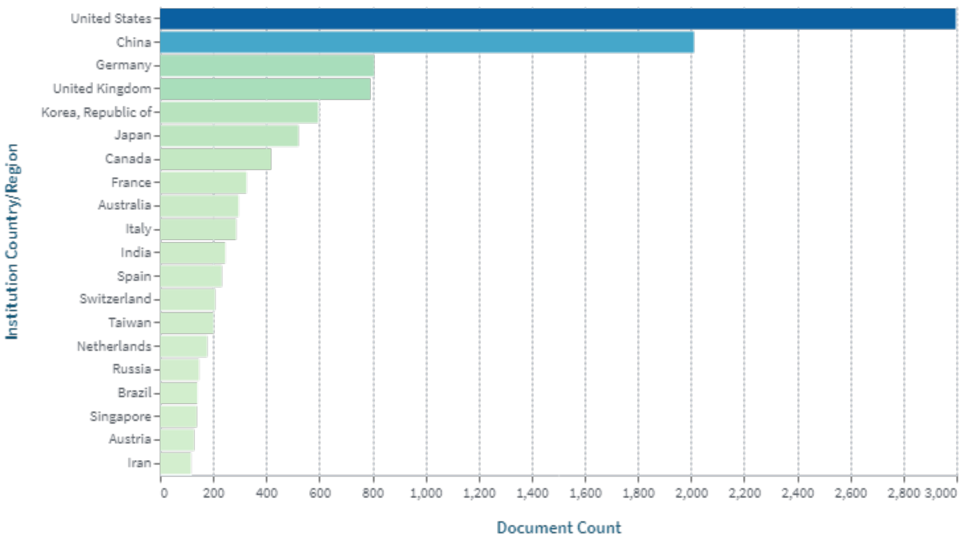


Figure 4.10: Number of paper publications by Country

The Table 4.3 allows us to confirm that the majority of patents from the United States are not biased towards the origin of the articles, being the predominant jurisdiction citing them across all major contributing countries.

Table 4.3: Distribution of citing patents from the major article contributors

Jurisdiction	United States	China	Germany	United Kingdom
United States	6687	1049	1803	2182
WO - WIPO	2270	662	611	662
European Patents	685	286	170	286
China	466	100	117	-
Korea, Republic of	90	15	18	-
Japan	73	25	14	25
United Kingdom	60	8	-	60
Germany	51	-	1803	14
France	37	16	8	34
Australia	26	7	4	7
Italy	15	10	2	7
Russia	8	3	3	3
Spain	7	1	2	1
Netherlands	7	2	1	7
Sweden	7	-	2	2
Taiwan	5	2	-	2
Luxembourg	3	-	1	2
Poland	3	1	1	1
Israel	2	1	-	1
Lithuania	1	-	-	-
Belgium	-	-	-	3
Austria	-	2	-	-
Norway	-	-	-	1
Switzerland	-	-	1	-
Eurasian Patents	-	-	1	-

Lens [1] itself also provided us with the corresponding fields of study for each article. Consequently, we examined the fields of study associated with the cited papers over the years and presented this data in Figure 4.11.

Next, combining the total amount of publications for each year with the number of publications per fields of study we created the Table 4.2 that displays the percentage of that a field of study represents in the total amount of papers for the 10 most popular fields per year.

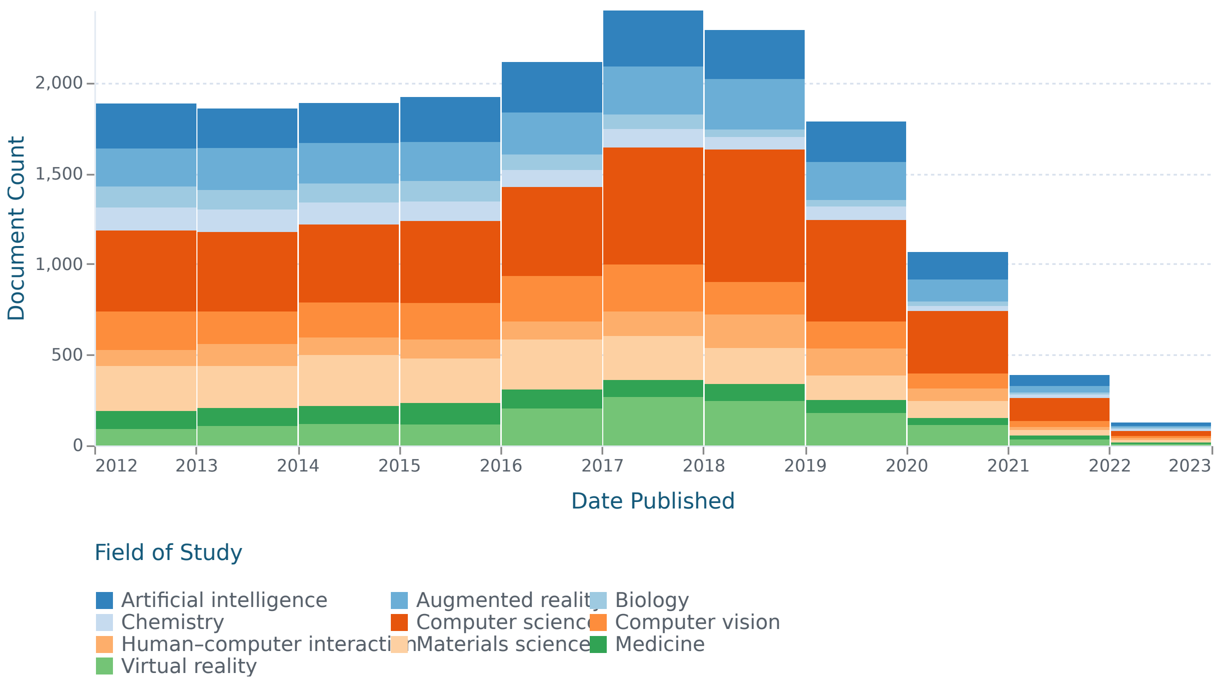


Figure 4.11: Number of paper publications, by Field of Study, per Year

From the Figure 4.12, we have also a view of the main applicants and owners of the most recent patents, which seems to share some of the big corporations that are also predominant in the ISMAR conference.

Table 4.4: Percentage of the top 10 fields of study per Year

Year	Artificial Intelligence	Augmented Reality	Biology	Chemistry	Computer Science	Computer Vision	Human-Computer Interaction	Materials Science	Medicine	Virtual Reality
2012	20%	17%	9%	10%	36%	17%	7%	20%	8%	7%
2013	18%	20%	9%	11%	37%	15%	10%	20%	8%	9%
2014	18%	18%	9%	10%	35%	16%	8%	23%	8%	10%
2015	20%	18%	9%	9%	37%	17%	8%	20%	9%	9%
2016	22%	18%	6%	7%	38%	19%	8%	21%	8%	16%
2017	23%	19%	6%	8%	47%	19%	10%	18%	7%	20%
2018	22%	23%	3%	6%	61%	15%	15%	17%	8%	20%
2019	24%	23%	4%	8%	60%	16%	16%	15%	8%	19%
2020	25%	21%	4%	5%	58%	14%	12%	16%	6%	19%
2021	25%	16%	5%	8%	54%	14%	7%	12%	9%	14%
2022	40%	13%	17%	19%	55%	23%	17%	28%	15%	11%

Applicant	Document Count
Microsoft Technology Licensing LLC	556
IBM	444
Samsung Electronics Co LTD	308
Massachusetts Inst Technology	292
Magic Leap INC	243
Apple INC	235
Univ California	234
Asm Ip Holding Bv	207
Facebook Tech LLC	200
At & T Ip I Lp	179

(a) Top Applicants

Owner	Document Count
Microsoft Technology Licensing LLC	503
International Business Machines Corporation	444
Meta Platforms Technologies LLC	219
Google LLC	199
Asm Ip Holding Bv	197
Magic Leap INC	196
Massachusetts Institute of Technology	196
Samsung Electronics Co LTD	183
At&t Intellectual Property I Lp	178
The Regents of the University of California	171

(b) Top Owners

Figure 4.12: Top Applicants and Owners of Patents citing current academic literature

4.2 Discussion

The presence of top industry players and technology giants among the applicants and owners of patents that have cited the ISMAR conference indicates the significance and impact of the conference in the field of Augmented Reality. Their involvement suggests that the research and advancements presented at the ISMAR conference hold value and contribute to the development of cutting-edge technologies in the industry.

The fact that these prominent companies are citing the ISMAR conference in their patents demonstrates the recognition and influence of the conference within the Augmented Reality community. It signifies that the research and findings presented at ISMAR are considered valuable and relevant for the advancement of the field, solidifying the conference's role as a platform for sharing groundbreaking research, fostering collaboration, and driving innovation in AR.

The involvement of such renowned companies also highlights the potential commercialization of research presented at the conference. We can see the presence of major corporations among the patent applicants and owners as an indicator of their the interest in translating research outcomes into real-world applications and products.

Regarding the time discrepancies between the published papers and citing patents we have delved a bit deeper into this, by segmenting the dataset by publication year, resulting in a distribution of patents corresponding to each year. The Table 4.2 provides a visual representation of this distribution, allowing us to examine the time discrepancy between papers and patents. This sheds light on the timing of citing scientific knowledge in the patenting process. The observed time discrepancy between papers and patents then suggests once more that there is typically a delay between the publication of scientific articles and their utilization in patent applications. This time lag highlights the gap between generating knowledge through research and its practical implementation in patented inventions.

Looking at the fields of study of the cited articles, and by analysing Table 4.2 it reveals to us several trends and patterns. As expected, the fields of Artificial Intelligence (AI) and Computer Science have consistently dominated the research landscape throughout the years. These fields show the highest percentages of documents published, indicating their sustained growth and significance in academic research. We can interpret the consistent high percentages as a continued interest and focus on advancing these fields. In contrast, fields such as Biology, Chemistry, and Medicine generally demonstrate lower percentages compared to the computer-related disciplines. It is also worth noting that the fields of AR and VR exhibit variations in their percentages across different years. AR shows higher percentages in the earlier years followed by a gradual descent, which could be reflective of the initial glow-up and exploration of Augmented Reality technology, followed by a stabilization or shift in research focus to other emerging fields. VR, on the other hand, demonstrates a relatively stable presence throughout the years, suggesting a sustained interest and research in this area.

The field of Materials Science showcases an interesting pattern with its percentage distribution. It displays an initial increase, potentially indicating growing attention towards material advancements and innovations, but stabilizes which suggests a continued interest in Materials Science research, although with a relatively steady growth rate.

The fields of Computer Vision and HCI demonstrate relatively consistent percentages over the years, with minor variations. These fields are closely related to AI and Computer Science, and given their steady presence we could interpret it as ongoing research and development in areas such as image processing, computer graphics or user interface design. To finish the analysis of the data, we can see that Computer Science witnesses a significant increase in percentage from 2012 to 2018. In a similar fashion, the field of AI exhibits a steady growth in percentage from 2012 to 2022, highlighting the increasing importance and proliferation of AI research.

Lastly, the high concentration of patents and citations from the United States indicates the country's strong research and development capabilities, robust intellectual property protection, and thriving innovation ecosystem. However, it also raises questions about the global distribution of resources and expertise in augmented reality research, as well as the potential impact on the global structure of the field.

Understanding the reasons behind the predominance of patents and citations from the United States seems to be relevant. Factors such as substantial investment in research and development, a favorable regulatory environment, and the presence of leading technology companies and research institutions could justify the United States' strong position in augmented reality. However, this investigation could show us if the field is still inclusive in what concerns research and the development efforts to bring innovation in augmented reality.

4.3 Limitations

While the analysis of the academic-industry landscape in augmented reality provides valuable insights, it is important to acknowledge certain limitations inherent to the work we conducted.

The analysis heavily relies on the availability and reliability of the data sources used. The accuracy and completeness of the data, particularly the patent and citation databases, can vary, which may introduce biases or inaccuracies in the results.

The methodologies, criteria for data collection, filtering, and analysis may also introduce subjectivity and potential limitations. Alternative methods or criteria could yield different results and interpretations.

Lastly, the interpretation of the findings is subject to the researcher's perspective and expertise. Different interpretations or alternative analyses may result in different conclusions or emphasize different aspects.

5

Conclusion and Future Work

Contents

5.1 Conclusions

Our dissertation initially aimed to explore the connection between academia and industry, specifically focusing on identifying factors that contribute to successful products. However, due to various constraints, our research direction shifted towards analyzing patent data and it restricted us into conducting a bibliometric review of academic literature referenced in patents.

Through our analysis, we have arrived at several findings. We provided an up-to-date review of the ISMAR conference, and how the patents in the last decade have been referencing the academic literature, demonstrated the link between academic papers and industry simply because the patents can be considered largely based on the referenced scientific papers, highlighting the influence of research on real-world applications. We gave insights into the trends and patterns observed in the distribution of documents per field of study over the years, which can be utilized to inform discussions on the research trends, priorities, and potential areas of future exploration within different fields of study. Furthermore, we have identified a time discrepancy between scientific research and its practical implementation in products. This time lag signifies the inherent delay between the generation of knowledge through research and its subsequent application in patented inventions. Additionally, our research sheds light on the companies that heavily invest in patents, indicating their commitment to translating scientific knowledge into tangible products, and revealed the countries that are actively engaged in publishing academic research, as well as industrial innovation.

While our work deviated from the original goal, taking a more surface-level approach, it still holds value. Our research provides an updated perspective on the relationship between academia and industry, highlighting the existing inter-dependency between the two worlds. By demonstrating the connection between papers, patents, companies, and countries, we contribute to a broader understanding of the knowledge transfer and the practical implications of scientific research. In conclusion, despite the adjustments made to our research approach, our dissertation insights into the intricate relationship between academia and industry.

5.2 Future work

The bibliometric review we conducted opens up opportunities to explore the connection between academia and industry, as well as address the time difference and its impact on transferring knowledge.

Based on the data that we showed we believe it is enough motivation for others to conduct a study to track the timeline of knowledge transfer from academic research to patenting. This would involve monitoring the progression of research findings to patents over an extended period, allowing for a more comprehensive understanding of the time discrepancy and its variations across different industries and scientific domains.

Lastly, it invites researchers to conduct more extensive analyses at a regional level to uncover geographical and industry-specific trends in the link between scientific research and industrial innovation. Such research could provide valuable insights and help identify strengths and weaknesses in the collaboration between academia and industry.

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