8. oktober 2025 | 8 October 2025
Koper, Slovenia

INFORMACIJSKA DRUŽBA

INFORMATION SOCIETY

18. Mednarodna konferenca o prenosu tehnologij

18th International Technology Transfer Conference

Uredniki | Editors:
Duško Odić, Terezija Poženel Kovačič, Robert Blatnik

Zbornik 28. mednarodne multikonference
Zvezek E

Proceedings of the 28th International Multiconference
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Oblikovanje naslovnice: Vesna Lasič

Dostop do e-publikacije:
http://library.ijs.si/Stacks/Proceedings/InformationSociety

Ljubljana, oktober 2025

Informacijska družba
ISSN 2630-371X
DOI: https://doi.org/10.70314/is.2025.ittc

Kataložni zapis o publikaciji (CIP) pripravili v Narodni in univerzitetni knjižnici v Ljubljani
COBISS.SI-ID **255459587**
ISBN 978-961-264-324-9 (PDF)

PREDGOVOR MULTIKONFERENCI INFORMACIJSKA DRUŽBA 2025

28. mednarodna multikonferenca *Informacijska družba* se odvija v času izjemne rasti umetne inteligence, njenih aplikacij in vplivov na človeštvo. Vsako leto vstopamo v novo dobo, v kateri generativna umetna inteligenca ter drugi inovativni pristopi oblikujejo poti k superinteligenci in singularnosti, ki bosta krojili prihodnost človeške civilizacije. Naša konferenca je tako hkrati tradicionalna znanstvena in akademsko odprta, pa tudi inkubator novih, pogumnih idej in pogledov.

Letošnja konferenca poleg umetne inteligence vključuje tudi razprave o perečih temah današnjega časa: ohranjanje okolja, demografski izzivi, zdravstvo in preobrazba družbenih struktur. Razvoj UI ponuja rešitve za številne sodobne izzive, kar poudarja pomen sodelovanja med raziskovalci, strokovnjaki in odločevalci pri oblikovanju trajnostnih strategij. Zavedamo se, da živimo v obdobju velikih sprememb, kjer je ključno, da z inovativnimi pristopi in poglobljenim znanjem ustvarimo informacijsko družbo, ki bo varna, vključujoča in trajnostna.

V okviru multikonference smo letos združili dvanajst vsebinsko raznolikih srečanj, ki odražajo širino in globino informacijskih ved: od umetne inteligence v zdravstvu, demografskih in družinskih analiz, digitalne preobrazbe zdravstvene nege ter digitalne vključenosti v informacijski družbi, do raziskav na področju kognitivne znanosti, zdrave dolgoživosti ter vzgoje in izobraževanja v informacijski družbi. Pridružujejo se konference o legendah računalništva in informatike, prenosu tehnologij, mitih in resnicah o varovanju okolja, odkrivanju znanja in podatkovnih skladiščih ter seveda Slovenska konferenca o umetni inteligenci.

Poleg referatov bodo okrogle mize in delavnice omogočile poglobljeno izmenjavo mnenj, ki bo pomembno prispevala k oblikovanju prihodnje informacijske družbe. »Legende računalništva in informatike« predstavljajo domači »Hall of Fame« za izjemne posameznike s tega področja. Še naprej bomo spodbujali raziskovanje in razvoj, odličnost in sodelovanje; razširjeni referati bodo objavljeni v reviji *Informatica,* s podporo dolgoletne tradicije in v sodelovanju z akademskimi institucijami ter strokovnimi združenji, kot so ACM Slovenija, SLAIS, Slovensko društvo Informatika in Inženirska akademija Slovenije.

Vsako leto izberemo najbolj izstopajoče dosežke. Letos je nagrado *Michie-Turing* za izjemen življenjski prispevek k razvoju in promociji informacijske družbe prejel **Niko Schlamberger**, priznanje za raziskovalni dosežek leta pa **Tome Eftimov**. »Informacijsko limono« za najmanj primerno informacijsko tematiko je prejela odsotnost obveznega pouka računalništva v osnovnih šolah. »Informacijsko jagodo« za najboljši sistem ali storitev v letih 2024/2025 pa so prejeli Marko Robnik Šikonja, Domen Vreš in Simon Krek s skupino za slovenski veliki jezikovni model GAMS. Iskrene čestitke vsem nagrajencem!

Naša vizija ostaja jasna: prepoznati, izkoristiti in oblikovati priložnosti, ki jih prinaša digitalna preobrazba, ter ustvariti informacijsko družbo, ki koristi vsem njenim članom. Vsem sodelujočim se zahvaljujemo za njihov prispevek — veseli nas, da bomo skupaj oblikovali prihodnje dosežke, ki jih bo soustvarjala ta konferenca.

Mojca Ciglarič, predsednica programskega odbora
Matjaž Gams, predsednik organizacijskega odbora

FOREWORD TO THE MULTICONFERENCE INFORMATION SOCIETY 2025

The 28th International Multiconference on the Information Society takes place at a time of remarkable growth in artificial intelligence, its applications, and its impact on humanity. Each year we enter a new era in which generative AI and other innovative approaches shape the path toward superintelligence and singularity — phenomena that will shape the future of human civilization. The conference is both a traditional scientific forum and an academically open incubator for new, bold ideas and perspectives.

In addition to artificial intelligence, this year's conference addresses other pressing issues of our time: environmental preservation, demographic challenges, healthcare, and the transformation of social structures. The rapid development of AI offers potential solutions to many of today's challenges and highlights the importance of collaboration among researchers, experts, and policymakers in designing sustainable strategies. We are acutely aware that we live in an era of profound change, where innovative approaches and deep knowledge are essential to creating an information society that is safe, inclusive, and sustainable.

This year's multiconference brings together twelve thematically diverse meetings reflecting the breadth and depth of the information sciences: from artificial intelligence in healthcare, demographic and family studies, and the digital transformation of nursing and digital inclusion, to research in cognitive science, healthy longevity, and education in the information society. Additional conferences include Legends of Computing and Informatics, Technology Transfer, Myths and Truths of Environmental Protection, Knowledge Discovery and Data Warehouses, and, of course, the Slovenian Conference on Artificial Intelligence.

Alongside scientific papers, round tables and workshops will provide opportunities for in-depth exchanges of views, making an important contribution to shaping the future information society. *Legends of Computing and Informatics* serves as a national »Hall of Fame« honoring outstanding individuals in the field. We will continue to promote research and development, excellence, and collaboration. Extended papers will be published in the journal *Informatica*, supported by a long-standing tradition and in cooperation with academic institutions and professional associations such as ACM Slovenia, SLAIS, the Slovenian Society Informatika, and the Slovenian Academy of Engineering.

Each year we recognize the most distinguished achievements. In 2025, the Michie-Turing Award for lifetime contribution to the development and promotion of the information society was awarded to **Niko Schlamberger**, while the Award for Research Achievement of the Year went to **Tome Eftimov**. The »Information Lemon« for the least appropriate information-related topic was awarded to the absence of compulsory computer science education in primary schools. The »Information Strawberry« for the best system or service in 2024/2025 was awarded to Marko Robnik Šikonja, Domen Vreš and Simon Krek together with their team, for developing the Slovenian large language model GAMS. We extend our warmest congratulations to all awardees.

Our vision remains clear: to identify, seize, and shape the opportunities offered by digital transformation, and to create an information society that benefits all its members. We sincerely thank all participants for their contributions and look forward to jointly shaping the future achievements that this conference will help bring about.

Mojca Ciglarič, Chair of the Program Committee
Matjaž Gams, Chair of the Organizing Committee

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FOREWORD

Dear guests, experts, panelists, and participants,
Welcome to the 18th International Technology Transfer Conference!

This year, the Conference takes place in the vibrant coastal city of Koper and is hosted by the University of Primorska, serving as the meeting point for visionaries from academia, industry, and policy, all united by a shared commitment to advancing innovation and deep tech across Europe. Since its inception, the Jožef Stefan Institute has proudly served as the initiator and main organizer of this esteemed event, advancing innovation and knowledge transfer in Slovenia. This year, we are honored to host the conference in collaboration with 13 public research organizations, representing two national consortia of knowledge transfer offices (KTOs). Collaboration among KTOs, both within and across the two consortia continues through joint activities aimed at promoting KTO initiatives, raising awareness, and encouraging networking and the exchange of best practices.

Over the years, this event has evolved beyond technology transfer alone. Today, it represents a broader vision of knowledge sharing, one that recognizes that innovation is not only about technology, tools, and systems that support creativity and progress, but above all, about people – people who listen, understand, and work together to meet one another's needs and aspirations.

Throughout the years, this conference has helped raise awareness, connect institutions, and co-create solutions that help researchers turn ideas into innovation. Our dialogue with ministries and research institutions has strengthened national consortia and laid the foundations for a lasting system of knowledge transfer. The conference has established itself as a crucial platform for exchanging ideas and fostering collaboration between domestic and international stakeholders, significantly contributing to the development of Slovenia's national innovation ecosystem.

As the International Technology Transfer Conference continues to gain recognition, the community of knowledge transfer professionals is likewise expanding. This growth reflects the ongoing strengthening and increasing importance of the Slovenian innovation ecosystem. We would like to express our sincere appreciation to the Ministry of Higher Education, Science and Innovation for its long-standing support of the conference and of knowledge transfer activities in general. The Ministry's commitment to fostering connections between science and the broader social and economic landscape plays a vital role in advancing innovation and collaboration in Slovenia.

This year's conference theme, "Strengthening Spin-Out Support Systems: Bridging Research, Innovation, and Policy for a Competitive Deep Tech Europe; Enabling Research Commercialization and Sustainable Innovation through Coordinated EU and National Strategies," aligns with our goal of bolstering the role of KTOs and improving the commercialization of intellectual property, as well as to promote the wider social relevance of knowledge transfer and the outputs and impacts of KTO work on the well-being of society as a whole.

At this conference, more than one hundred entrepreneurial-minded research teams have taken part in innovation competitions. Some now lead successful spin-off companies. This outcome captures our purpose - to bridge research and application, and to make science an active force in society. We therefore continue with the competition this year, presenting the Conference Prize for the Best Innovation in 2025, which aims to promote the commercialization of innovative technologies developed at public research organizations.

This year, we also highlight several key dimensions of our shared journey. The WIPO Awards honor inventors and enterprises that strengthen collaboration between research and industry through the effective use of intellectual property to drive innovation and societal progress. Our roundtable discussion explores how to better connect science, research, and innovation — and align national and European funding to support this goal. As the EU prepares for its next funding framework, the conversations we begin today, on spin-out support, strategic alignment, and mission-driven innovation, will help shape the future of research commercialization and economic resilience.

Meanwhile, the conference continues to grow as a platform for sharing peer-reviewed research on innovation and knowledge transfer, thanks to the dedication of our reviewers and contributors. We are excited to report that peer-reviewed contributions from researchers specializing in knowledge and technology transfer are now part of the conference for the sixth consecutive year.

We are proud to have hosted distinguished speakers from renowned institutions across Europe and beyond in previous editions of the conference. This year, we are especially honored to welcome Mr. Olav Carlsen from the German Federal Agency for Breakthrough Innovation, SPRIND GmbH, who will deliver the keynote lecture.

We extend our sincere gratitude to our host, the University of Primorska, as well as to all co-organizers and knowledge transfer offices for their support. Our special thanks go to the Ministry of Higher Education, Science and Innovation for co-financing the conference as part of the Science Month campaign and through the Public Call for Supporting the Activities of Knowledge Transfer Offices, co-financed by the Republic of Slovenia and the European Union via the European Regional Development Fund (ERDF).

Dear guests, may this conference inspire new ideas, curiosity, and collaboration, helping us move knowledge forward – for people, by people. Thank you for being part of this journey, and we look forward to an inspiring exchange of ideas at the 18ITTC.

Programme Committee of the 18ITTC

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Innovations in Patent Valuation: Testing SMART5 on Slovenian Spin-out and Start-up Companies

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Abstract

This study presents a brief review of patent valuation techniques, followed by a specific case study of SMART5, an online patent evaluation service. SMART5 was tested on U.S. and European patents of eight successful Slovenian firms that had previously been start-up companies, four of which originated as spin-outs from universities or public research institutes. The results show that SMART5 is a reliable and attractive tool; however, some improvements are needed, particularly regarding the transparency of its scoring methodology and the evaluation of patents belonging to the same family, where the system yields conflicting results for identical inventions.

Keywords

IP valuation, patent valuation, SMART5, quantitative valuation, spin-out/start-up enterprises

1 Introduction

The valuation of patents has become an increasingly important field of research and practice, as intellectual property (IP) is now widely recognized as a critical driver of innovation, competitiveness, and economic growth. Start-up companies and university spin-outs in particular rely heavily on patents not only to protect their technological advancements but also to attract investment, secure partnerships, and strengthen their market position. Yet, despite the growing strategic significance of patents, their valuation remains a complex task.

Universities or other public research institutions' (PROs) spin-out companies are typically formed to commercialize intellectual property (IP) generated within these academic institutions. Here patents often play a central role in this process. The creation and success of these spin-outs are closely linked to how universities and PROs manage and protect their IP, especially through formal mechanisms like patents and trademarks. However, research indicates that while formal IP protection (such as patents) is commonly used, it can sometimes negatively impact the competitiveness of spin-outs [9]. In contrast, informal protection strategies, like maintaining trade secrets, may be more beneficial for competitiveness in certain contexts [9].

This paper contributes to the ongoing debate on patent valuation methods by presenting an empirical test of SMART5 applied to the patents of eight Slovenian start-ups, four of which are university or PRO spin-outs. By combining a short review of existing valuation techniques with a critical assessment of SMART5's performance, the study highlights both the potential and the limitations of automated patent evaluation tools. In doing so, it provides insights into how such tools could be further improved to better serve the needs of innovative enterprises, IP practitioners and technology transfer staff.

2 Patent valuation techniques

Patent valuation techniques can broadly be grouped into qualitative and quantitative approaches. Qualitative methods have interpretative and subjective nature and they attempt to determine patent value by understanding the processes and the behavioural patterns [3]. They often include expert judgment [6]. Quantitative methods, on the other hand, attempt to measure patent value using economic frameworks. These include cost-based approaches, which estimate the resources required to develop and protect the invention; market-based approaches, which rely on comparable patent transactions or licensing deals; and income-based approaches, which calculate expected future cash flows derived from exploiting the patent [1, 12, 13].

A classification of methods for patent valuation as analysed by Munari and Oriani [7] is presented on Figure 1.

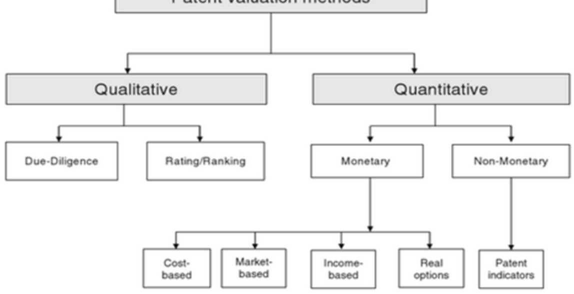

Figure 1: A classification of methods for patent valuation, source [7]

†Corresponding author

Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

We will focus only on quantitative non-monetary methods, i.e., patent indicators. Typical indicators are legal status, international and technological scope, number of forward citations and the existence of opposition and litigation [7]. Such valuation has many advantages: the method is fast, objective and inexpensive and can be fully automated once the valuation system is set up [7]. International scope (size of patent family) and forward citations (citations received from patents applied later) are probably the most frequent measures for assessing patent value. For example, patent valuation using forward citations has been increasingly used by practitioners when a patent's value has not been otherwise established [10]. Og et al. [8] divide patent value indicators into ex-ante indicators (family size, backward citations, backward references to non-patent literature, number of claims, and number of inventors) and ex-post indicators (forward citations). Such indicators can be further integrated into indexes, composite measures that can combine multiple indicators into a single value. Grimaldi and Cricelli [4] in their paper "Indexes of Patent Value: A Systematic Literature Review and Classification" identified even 37 different indexes.

Despite the variety of available methods, no single approach offers a universally accepted or comprehensive solution. Traditional valuation models often face limitations when applied to early-stage companies. Valuing patents in start-ups presents unique challenges due to limited financial history, uncertain market prospects, and evolving technologies. As a result, traditional valuation models often require adaptation or supplementation [2].

In response to various challenges connected to patent valuation – along with a lengthy and complex assessment – SMART5 was developed under the auspices of the Korea Invention Promotion Association (KIPA) and offers an online platform for patent evaluation where each patent can be evaluated in some seconds. The system claims to "objectively evaluate the superiority of a patent in different countries" by leveraging patent specifications, bibliographic information, and administrative data [14]. By transforming bibliometric indicators into comparative scores, SMART5 aims to provide accessible and standardized insights into patent quality across jurisdictions.

While such automated evaluation systems hold considerable promise for reducing information asymmetries and enhancing decision-making, they must be rigorously tested for reliability, transparency, and contextual relevance. This is particularly important for research-based spin-outs and start-ups, which often operate with limited resources and for whom misleading or inconsistent patent assessments may have serious strategic consequences.

3 About SMART5

To illustrate how patent evaluation systems can support innovation and technology transfer, this chapter introduces SMART5 with a brief overview of its purpose, methodology and application. SMART5 [14, 15] is an acronym for System to Measure, Analyse and Rate patent Technology. It is an online patent evaluation service in which the "superiority of a patent in different countries is objectively evaluated using patent information extracted from patent specification, bibliographic information, and administrative information", as claimed by owner and developer KIPA. It is not very clear, at least from the documents translated in English, what does the number "5" mean in the name. The "5" may refer to a software version (like the 5th release) or maybe to the five (broad) evaluation dimensions that the system applies when assessing patents.

The system is designed to objectively evaluate a patent across different countries using a combination of patent specifications, bibliographic information, application information, examination information, information about litigations, licences, changes of ownership, citations and patent family information. SMART5 emphasizes a data-driven scoring system grounded in patent documentation rather than subjective expert opinion alone. It supports evaluation for patents registered in China, Europe (European patent), Japan, Korea, and the United States.

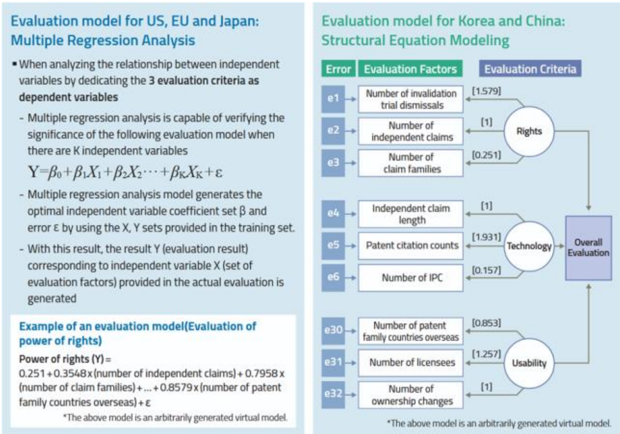

Figure 2: Patent evaluation model, source [15]

SMART5 was first launched already in 2010 and it has processed approximately 1.7 million evaluations (up to 2023) and has emerged as a leading patent evaluation system in South Korea, taking the forefront in popularizing patent assessment [16]. However, SMART5 is not known in Slovenia and it was first presented on the IP Valuation Workshop in Ljubljana in June 2025 [11] and it has received a lot of interest from technology transfer professionals. KIPA kindly provided us with possibility to test 10 patents free of charge.

4 Method

During August 2025 we tested SMART5 on ten patents from eight different patent families from eight Slovenian start-up or universities or other PROs spin-out companies. Start-up enterprises were selected from enterprises which received support of Slovenian Enterprise Fund – Tender P2 – which is a grant intended to co-finance the setting up of innovative enterprises [17]. PROs spin-outs were selected from the online news and university websites such as University of Ljubljana presentation of their spin outs [18].

The basic criteria for the selected patents were, that they are not "too young and too old". With not "too young" we mean patents which are more than five years old, and they are applied and already granted outside Slovenia. With not "too old" we mean that patens are still maintained.

Two patent families from our spin-outs were tested with different patents within the same family – one applied in Europe and the other in the U.S. Since a "patent family" presents the same patent, applied in different jurisdictions, we were interested, will SMART5 recognize the same patents and evaluate them equally.

SMART5 evaluates patents based on three core aspects: IP Rights valuation – legal strength and enforceability of the patent; Technology valuation – the technical sophistication and innovativeness of the invention; and Usability valuation – the potential for practical application and commercialization of the patent [15]. These grades are in the end summarized in one overall grade of a patent which can receive a hierarchical grade from AAA (the highest grade) to C (the lowest grade) as presented on the Figure 3.

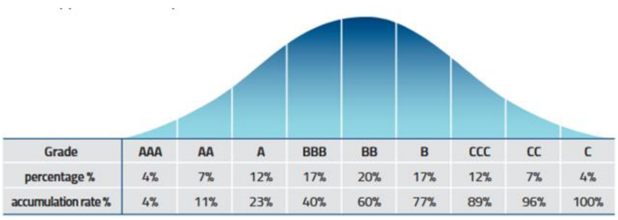

Figure 3: SMART5 evaluation grades, source [15]

5 Results

We can confirm that SMART5 offers several clear strengths that make it an attractive tool for patent evaluation. The results are presented in a clear and user-friendly way, with well-structured grades and visualizations that allow even non-specialists to quickly grasp the relative strength of a patent. The interface and design are intuitive, supporting ease of use even for small companies which may lack in-house IP expertise.

Our results are listed in the Table 1. It is also important to note that the patents were filed in the past, while the company size reflects the present data.

Table 1: Results of testing SMART5

Patent no.	Priority date	Company	Grade	Company size
US2016194054 (A1)	2013	Start-up	A	micro
US2020395832 (A1)	2017	Spin-out	CCC	medium
US2016134220 (A1)	2013	Start-up	AA	small
US2017100755 (A1)	2015	Spin-out	A	micro
US2021068752 (A1)	2019	Start-up	B	medium
EP2868662 (A1)	2013	Spin-out	A	medium
EP3197906 (A1)	2014	Spin-out	BBB	micro
EP3001203 (A1)	2014	Start-up	B	micro
EP3153246 (A1)	2015	Spin-out	AA	micro
EP3711147 (A1)	2017	Spin-out	BB	medium

Seven (five) patents received a grade of A, AA, BB, or BBB which is according to SMART5 above-average to strong quality. Only one patent received score CCC, standing out as significantly weaker. It should be noted that this patent belongs to an enterprise that already holds around 20 different patent families, and it may have been a coincidence that our sample included one of the weakest patents from its portfolio. By contrast, a micro start-up with only a single patent family received an A grade for its U.S. patent. It can therefore be argued that the overall quality of a company's patent portfolio cannot be inferred from a single evaluation result, especially when the portfolio is large and heterogeneous. Larger enterprises may hold a mix of both strong and weak patents, depending on the stage of development, research focus, and patenting strategy. Conversely, for very small firms or start-ups, even one patent can represent the core of their business model, and thus its evaluation result is highly consequential. This highlights the importance of interpreting SMART5 results not only at the level of individual patents but also within the broader context of portfolio structure and company strategy.

Most importantly, the scores generally align with expectations based on the technological and legal aspects of these specific patents, which indicates that the tool captures meaningful aspects of patent quality. These features demonstrate that SMART5 has considerable value as a first-level screening and benchmarking instrument, capable of guiding companies and IP professionals toward more informed decision-making.

However, from the Table 1 we cannot see evidence of influence of quality of patent to the present size of enterprise. Micro firms have patents graded from AA (very strong) to B (solid) what shows that even the smallest firms can secure relatively strong patents. At the same time medium sized firms showed mixed performance, ranging from CCC (weak) to A (strong). Of course, this might be a consequence of a small sample size.

Among the tested cases, two patents (marked with blue and green colour) belong to the same patent family (parallel filings of the same invention in different jurisdictions). Ideally, such patents should receive identical grades, because their technical content, inventive step, and core claims are essentially the same. Minor differences may occur due to jurisdiction-specific citation practices, examiner reports, or legal events, but these should not result in substantial differences in the overall valuation.

6 Discussion and Conclusion

Some previous studies already tested SMART5. For example, study of Lee, Jeong, and Kong [5] examines determinants of successful technology commercialization. It focuses on 883 U.S. patents issued in 2020 that originated from government-funded R&D in South Korea. The key aim of the study was to understand which patent-related characteristics contribute to revenue generation through licensing and transfers. Among the variables analysed, the study highlights SMART5 scores as a central qualitative indicator. In statistical tests (linear and logistic regression), the SMART5 grade emerged as the only variable with a statistically significant positive impact on technology commercialization outcomes.

Of course, our sample was very small, therefore we found no evidence of correlation with commercialisation outcomes (translated into our study we may have predicted that start-ups which had more valuable patents in the past are now larger firms with more employees and more revenue). Because of small sample size, we cannot conclude anything except that SMART5 is an attractive tool for patent evaluation. For technology transfer professionals, the system may provide structured, evidence-based evaluations that support better patent portfolio management, stronger industry confidence, and higher commercialization potential.

However, SMART5 has two disturbing issues.

First, if a user of the system wants to find more information about how scores and how the final score are calculated, what specific indicators are taken and how are they weighted, there are not many available information – at least not in English. So, while SMART5 provides clear numerical indicators of patent quality and market relevance, the underlying algorithms and weightings used in the evaluation remain largely undisclosed. This lack of transparency can limit user trust and also raises questions about the value of SMART5 for technology transfer offices: if it is better at assessing the impact of a patent that is already well established and widely cited than at evaluating an initial patent application, then it is more useful as a tool for monitoring and demonstrating the value of mature patents rather than for making early-stage decisions about which patent applications to prioritize. However, it might also be reasonable that KIPA is keeping the methodology as a business secret.

Second, in the SMART5 evaluation, we observed inconsistent grading of patent family members. It seems from our two cases that European patents automatically get a higher grade than those from the U.S. This inconsistency can be interpreted in two ways: 1) Algorithmic sensitivity to jurisdictional data: SMART5 may weigh bibliographic and administrative data differently across jurisdictions (e.g., USPTO vs. EPO citation patterns, costs of patent or procedural timelines). This could lead to artificially divergent results for otherwise equivalent inventions. 2) Lack of family-level normalization: SMART5 appears to evaluate each filing in isolation, without consolidating information across the patent family. In practice, this risks misrepresenting the value of an invention, since a strong patent family can be unfairly weakened by one low score, or vice versa.

Despite these limitations, the application of SMART5 to Slovenian start-ups/spin-outs demonstrated its usefulness as a benchmarking tool. It allows companies to compare their patent portfolios against competitors across jurisdictions, identify relative strengths, and detect areas where additional IP strategy development might be necessary. With targeted improvements, SMART5 could evolve into a more robust and widely adopted instrument for patent evaluation in both academic and private-sector innovation ecosystems. With inclusion of artificial intelligence, occupations such as expert for patent valuation, may become obsolete. We believe that this can happen in the next three years.

Acknowledgments

Author acknowledges that this research was supported by the project KTO3 funded under the Call for Proposals to support the activities of Knowledge Transfer Offices (JR KTO).

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Academic Entrepreneurs in Slovenia: Entrepreneurial Competences, Intellectual Property, and Academic Culture

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Abstract

Academic entrepreneurship is a key channel for linking research and economic development, yet little is known about its dynamics in smaller national innovation systems. Based on in-depth interviews with the founders of three internationally successful Slovenian spin-out enterprises, we examine how do Slovenian academic entrepreneurs in the natural and technical sciences acquire entrepreneurial competences, use intellectual property, and perceive the entrepreneurial culture in their academic environment. Although their academic backgrounds are rooted in highly technical fields, our findings reveal that these founders have engaged extensively in entrepreneurial learning, management and intellectual property, acquiring knowledge and skills far beyond their original scientific expertise. They emphasise the importance of patents and intellectual property rights knowledge, however, intellectual property is not viewed merely as a legal safeguard but as a strategic resource for signalling credibility and positioning firms at different growth stages. At the same time, they express a critical perspective on the prevailing entrepreneurial culture within Slovenian academia, which they perceive as underdeveloped, contrasting it with more supportive environments abroad.

Keywords

Academic entrepreneurs, spin-outs, academic entrepreneurship, intellectual property, patents, entrepreneurial competences

1 Introduction

Academic entrepreneurship is often defined as the direct involvement of academicians in valorising research results in the market, often through the creation of new firms or academic spin-offs [14]. This process has gained increasing attention in recent decades, but in smaller countries such as Slovenia, where the institutional setting is less developed and the number of cases is limited, the dynamics of academic entrepreneurship are not yet well understood.

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Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

Our research question is: how do Slovenian academic entrepreneurs in the natural and technical sciences acquire entrepreneurial competences, use intellectual property, and perceive the entrepreneurial culture in their academic environment?

Previous studies on academic entrepreneurship have shown that institutional culture, resource availability, and the presence of role models play important roles in shaping academic entrepreneurship, but their influence can vary by context. For example, in Brazil, institutional initiatives had limited direct impact on academic entrepreneurship, suggesting some level of ineffectiveness in initiatives aiming at promoting academic entrepreneurship in Brazilian universities [6] while study in China highlights that supportive university environment and favourable government policies significantly enhance entrepreneurial intentions [1].

Academic entrepreneurs more likely engage in commercial activities such as founding or advising companies compared to their non-entrepreneurial peers. Ding and Choi [4] showed that founding activity occurred earlier during a scientist's career than advising and that factors such as gender, research productivity, social networks and employer characteristics also play important roles. Academic entrepreneurs often develop a dual identity, balancing their roles as scientists and entrepreneurs [3] and the interaction between scientific and entrepreneurial identities can strengthen the intention to engage in entrepreneurship: academic entrepreneurs who are also "hybrid scientists" can positively promote the development of the firms' knowledge breadth, and the "hybrid entrepreneurs" deepen the knowledge depth of academic start-ups. Academic entrepreneurs with prior business ownership experience had broader social networks and were more effective in developing network ties while less experienced entrepreneurs likely encounter structural holes between their scientific research networks and industry networks [11]. International mobility experiences further differentiate academic entrepreneurs, as returnees with international exposure are more than 50% more likely to become academic entrepreneurs than those who have not worked abroad [12].

Our study draws on in-depth interviews with the founders of three internationally successful Slovenian spin-out enterprises to examine how academic entrepreneurs from the natural and technical sciences acquire and integrate entrepreneurial competencies into their professional trajectories. We explore the ways in which they engage with entrepreneurial learning, management practices, and intellectual property rights, as well as their critical views on the prevailing entrepreneurial culture within Slovenian academia. By analysing these cases, we aim to contribute to four strands of literature: (1) the study of academic entrepreneurship in smaller, less-researched national systems; (2) the understanding of how technical and scientific expertise is complemented by non-technical competencies in successful spin-out ventures; and (3) the examination of the role of intellectual property for spin-out (start-up) enterprises.

2 Methodology

This study employs a qualitative research design. Given the complexity of individual decision-making processes, an in-depth interview approach is well-suited to uncover nuanced perspectives that may not be evident in quantitative studies. This approach enables us to delve into the participants' experiences, motivations, and perceptions regarding entrepreneurship, intellectual property and innovation management.

The study focuses on three top Slovenian spin-outs which successfully sell their products internationally, and they are also well known to the wider Slovenian public. Companies had to meet the following criteria:

- their founders were employed at universities/ PROs before they founded a start-up,
- they sell scientifically based product or services, i.e., they are deep tech companies,
- they are international companies: their market is extended outside Slovenia,
- they are older than five years.

Additional characteristics of companies are presented in Table 1.

Table 1: Properties of spin-out companies

	R1	R2	R3
Year of foundation	2006	2017	2005
Number of patent families	20	0 (owners of a patent are founders/ institute)	5
Number of trademarks	3	1	20
Number of employees	100 - 200	1 - 10	200 - 300
Company's size	Medium sized company	Micro company	Large company
Educational background of founder	Physics, electrotechnics	Physics, chemistry	Physics

Patents were obtained from Espacenet database, while trademarks from TM View database.

Interviews were held either face-to-face or online in June and July 2025, lasting between 60 and 90 minutes. All interviews were audio-recorded and subsequently transcribed verbatim for analysis.

We applied thematic analysis, which involved the following steps: transcription, independent coding by two researchers to ensure data validity, identification of recurring themes, and interpretation of findings.

3 Results

From Table 1 we can see that two companies are now 20 years old while one is more than 10 years younger. The two older spin-outs have significantly more registered industrial property as well as they have more employees.

It is very interesting that all our respondents have bachelor's degree from physics, however, two of them later specialized in another fields. For example, R1 graduated in astrophysics, but, as he explained, he had always wanted to do something more practical. This is why he decided to pursue a master's degree in electrical engineering.

One of the reasons of spin-out's success was founders' willingness to receive additional education in entrepreneurship and intellectual property, before and/or after founding the company. After finishing his PhD from physics, R3 also completed MBA study with the highest grades. R2 describes: *"When I started, I didn't have any knowledge about how to be a manager. Then I began educating myself a little, and I basically internalized that the most important thing is the team – how you hold the team together, what you have to do? /.../ How do you make sure that everyone is motivated, that you figure out what each person is best at, and place them exactly there so that they feel the most comfortable? These are the kinds of skills that are very important, especially in small companies."* R1 explains: *"Here, I would like to praise our supportive environment. The technology park organized a bunch of workshops, as did the business incubator, so I was somehow "infected" with these /entrepreneurial/ things, but I was also proactive. This also applies to my master's studies. I arranged my electrical engineering program in such a way that I also took the Innovation Management course at the Faculty of Economics /.../ So I switched from physics to electrical engineering, but I set it up in a rather interdisciplinary way."* R2 also attended several management and entrepreneurial lectures at the university incubator. R1 also took World Intellectual Property Organization's Distance Learning courses from intellectual property (IP): *"...so I would also advise all researchers interested in technology to simply be proactive and to also take advantage of online courses and various workshops and participate in them. It's not about how much they will gain from the content itself, but primarily it will stimulate their thinking and make it easier for them to understand something on their own later."*

IP is very important for our respondents, but not only in the "classical" sense, such as the legal protection of patents or trademarks as a means of achieving market exclusivity. Rather it is understood in a broader, more strategic sense. Respondents emphasized its role in shaping competitive advantage, facilitating collaboration with external partners, and signalling credibility to investors and stakeholders. In this perspective, IP functions less as an offensive mechanism and more as an active resource within innovation processes and organizational strategy. R1 claimed: *"We know for sure that some larger companies potentially infringe our patents. But that doesn't necessarily mean that we will react to it. This is because a patent has a specific purpose, and in the industry it has a certain value that you add. And it's not necessarily about wanting to block others who are doing something similar. So yes, a patent does not necessarily have an offensive role."* R3 explained: *"I would* *say that patent is one of the defensive mechanisms. Just like a trademark is a defensive mechanism against competition. We want to compete, we want to beat the competition. How will we beat them? With quality? Certainly. With price? No. /.../ We achieve that through other elements: quality, brand, reputation as such. If patents or regulatory protections are part of that brand, then yes. If we are producing medical products, they must be certified. That is quite demanding. But once we have certification, we know the competition will need two years, not only to copy us but also to go through that same process. In short, that's it. One of these defensive mechanisms."* R2 believes that patents may enhance the company's reputation and gain the trust of customers: *"Patents are very important because people ask you whether you have patented something. And if you say yes, then that's it. They feel safe, because someone has reviewed it and confirmed that it is truly an invention."* R1 emphasized that patents are very important for attracting investors: *"Without this, it is completely impossible to gain either a customer or an investor, because, of course, the customer needs to be protected in order to use your technology. The same goes for the investor."* How you use IP, also depends on the size of a company. R1 explained: *"For example, if you are a small company, you have a patent so that you can show others that you have it and that this makes you worth something. It also protects your customers, since someone bigger cannot just use protected technology. If you are a medium-sized company, say with a few hundred or thousand employees, then you have patents in order to defend yourself against the large players. When you step on their toes and capture a share of the market, they start putting pressure on you. And if you are a very large company, then you have patents to secure and prolong your monopolistic position for some time. So, it depends on the role you are in. But as a small company, of course, it is very useful to have patents. At the same time, I am aware that patents come with costs, which means you cannot have an unlimited number of them. Writing patents is also not easy. Obtaining them involves lengthy procedures, including abroad. You need a patent attorney to handle communication with patent examiners, and these are things that cost money."* R3 concluded: *"I think we should patent more. We are still learning, and I am also to blame, so in a way I am criticizing myself. But I think that our culture is too scientific. We tend to believe that if we have done something, it is nothing special. I should have patented every little thing. When I look at American companies, they patent every little stupid thing."*

How supportive are Slovenian academic institutions toward entrepreneurship? R2 explained: *"Though I had very good experiences at my institute, and I think others do as well, there are also objective obstacles. For example, there is this new law – or rather, it's already a few years old. It does state that public institutions can be co-owners of spin-outs, but in reality this doesn't happen because there are no implementing regulations. /.../ For example, when I go abroad, I know some companies that are spin-outs (where public institution is a co-owner). Portugal is very good with these small companies and startups, and I asked them do they have to pay a rent when they had a sit at their institute, they were surprised: 'How do you pay rent, what kind of rent?'"*

R1 believes that *"in USA there is now significantly more (spin-out) tradition. This is something that is taken for granted. Does it give professors the highest rating? That means students go to the professor who is the most successful – not academically, but entrepreneurially. Because this way they ensure, let's say, good conditions for life and for interesting research. We don't have yet these traditions and experiences in Europe. But it's not forbidden. I believe the legislation is not particularly unfriendly to this. It's just that people need to start doing it. The more good stories are there, the more it will happen naturally on its own."* R2 agrees: *"The US has significantly more spin-outs than Europe. Europe is very diverse. In some countries, there is enough support and a lot of startups. In others, there is less – for example, in Croatia, there are already more startups than in Slovenia. We are very poor here."*

Our respondents were very critical to basic academic requirements, such as excessive publishing and metrics tracked by academic institutions. R2 said: *"What really annoys me are these articles with a huge number of authors, and in most cases, people are just listed there. I am not listed on any such article, because I don't want to be listed if I didn't read it and participate in it. No, this is pointless to me, because if someone tells me they have 50 articles per a year – I say, just don't try to fool me!"* To encourage more spin-outs, R3 believes, the achievements should be equivalently rewarded, both academic and entrepreneurial: *"The reward and reputation should be equivalent, or you do pure basic science and publish articles, or you start a company. /.../ I think I have enough knowledge, experience, and everything to be a professor and teach. However, the system does not allow me to be a university professor, because I do not meet the requirements for habilitation."* R3 concluded: *"Here in science, for example, where I am, the professors have a secure academic job and on top of that they also have some extra private business and have a good time. And this is fine. With that money they can buy a Mercedes, a yacht and a weekend house. And that's it. But wouldn't it be better if this professor would use this knowledge and created a company where he could employ 100 people, and they all would earn so much that each of them could buy a Mercedes, a yacht and a weekend house?"*

4 Discussion and Conclusion

Our study highlights the critical role of spin-out founders' proactive learning and entrepreneurial education in the success of spin-out companies. Our respondents consistently emphasized that formal and informal education in entrepreneurship, management, innovation, and IP provided them with essential skills to build and lead effective teams. For instance, R2 described the importance of understanding team dynamics, highlighting the significance of human capital management in small companies, while R1 and R3 actively sought interdisciplinary knowledge through structured courses, workshops, and online programs, demonstrating that continuous learning fosters both confidence and competence in entrepreneurial endeavours. These findings align with prior research emphasizing the value of absorptive capacity in entrepreneurial education [9] and continuous learning and skill development in technology-based entrepreneurship [2, 10]. Academic founders must acquire competencies in entrepreneurship, management, and IP that go far beyond their original disciplinary expertise. The ability to navigate these domains is particularly important in environments where the entrepreneurial culture within academia is underdeveloped or where institutional support for commercialization is limited.

Intellectual property emerged as a multifaceted strategic resource rather than merely a legal instrument for market exclusivity. Respondents consistently described patents and trademarks as defensive mechanisms, tools for signalling credibility to investors and safeguards for customer trust. Our respondents recognized that IP strategy is context-dependent, varying with company size and market position. Small firms use patents to establish legitimacy and protect customers, medium-sized firms use them defensively against larger competitors, and large firms leverage them to maintain monopolistic advantages. Some of these insights are supported by previous research: small firms often use patents to attract customers and venture capital, so patenting has an important role to play even in firms where the protective function of patents is secondary [7]. Huges and Mina [8] also showed that an increasingly important factor for high tech small firms is the role of patents in obtaining financial backing by venture capitalists.

However, respondents also highlighted cultural and structural challenges in patenting and entrepreneurship. R3 noted that European research culture tends to undervalue the commercialization of inventions, and that many innovations remain unpatented due to overly academic mindsets or other obstacles. R2 and R1 pointed to the uneven institutional support across European countries, contrasting the US and Portugal with Slovenia, where regulatory ambiguity hinder spin-out formation. These findings suggest that supportive policy frameworks and a culture that values entrepreneurship are critical for translating scientific research into commercial ventures.

The study also revealed tension between academic values and entrepreneurial incentives. Respondents criticized the overemphasis on publication metrics and authorship inflation, arguing that current academic reward systems insufficiently recognize entrepreneurial achievements. R3 emphasized the need for equivalently rewarding scientific and entrepreneurial paths. This echoes broader debates in higher education policy regarding the balance between research excellence and technology transfer [5]. Additionally, here we can add critics of higher educational system who claim that universities are too bureaucratic, they educate mainly 'job seekers', they suffer from decreasing number of science and technology students and are weak at technology transfer [13].

In conclusion, academic entrepreneurs who succeeded in Slovenia, demonstrate a greater willingness to step outside the boundaries of traditional research roles (shaped by discoveries and publications), proactively acquire managerial and legal knowledge, and engage with external stakeholders such as incubators, investors, patent attorneys and customers. They perceive intellectual property not only as a legal safeguard but as a strategic asset that enhances credibility, facilitates partnerships, and supports long-term competitiveness.

Acknowledgments

Hafner and Lamut gratefully acknowledge CRP - Podpora IL project (https://www.rudolfovo.eu/en/nacionalni-projekti/crp-il%3A-) co-funded by Ministry for Higher Education, Science and Innovation (MVZI) and Slovenian Research and Innovation Agency (ARIS).

Dobravc Škof and Kolar gratefully acknowledge the research was co-funded by the Slovenian Research and Innovation Agency (ARIS) through the annual work program of Rudolfovo.

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University - Business Cooperation in Slovakia

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Abstract

This paper contributes to our understanding of the university-business cooperation in Slovakia. We have assessed university-business cooperation activities on the example of the case studies of 2 Slovak universities – Pavol Jozef Šafárik University in Košice and Slovak University of Technology in Bratislava. The paper is based on the qualitative research provided in frame of the STEIDA project under the Erasmus+ program, with the aim to strengthen technology transfer ecosystem through an innovative and holistic approach. The output of this research was included as the “Best Practices in Technology Transfer Ecosystem in Slovakia.”

Keywords

Technology transfer, university, business, cooperation, innovation ecosystem

1 Introduction

University-Business Cooperation (UBC) is a relationship in flux, reflecting issues of transition from an industrial to a knowledge society. UBC links are no longer confined to a relatively small academic sector, leaving most of the academy untouched, but have expanded from engineering and medicine to the social sciences and the arts [1].

The aim of this paper is to get a more profound, comprehensive and up to date understanding of the state of UBC in Slovakia: what is the state of play of a wide range of UBC activities, what are the main drivers and barriers for the different stakeholders and at what levels; what is the regulatory framework and socio-economic conditions and what kind of measures/initiatives exist on a national level to support the development of UBC.

This paper compiles the best practices identified by Slovak Centre of Scientific and Technical Information after conducting desk and field research, carried out within the scope of STEIDA (Strengthening Technology Transfer Ecosystem through Innovative and Digital Approaches) project, ref. № 2023-1-TR01-KA220-HED-000157242.

The project, which is funded under the “ERASMUS + programme”, aims to strengthen the technology transfer ecosystem through an innovative and holistic approach which will foster national and international collaboration among HEIs, academics, businesses, students, entrepreneurs and other stakeholders by developing/using digital platforms and networks. This objective will be achieved through the implementation of the following main activities:

- Conducting a comprehensive study on the technology transfer ecosystem;
- Compilation of a report on best practices in technology transfer;
- Development of a curriculum for higher education institutions and students;
- Development of training modules for technology transfer professionals and newcomers;
- Conducting pilot training for building the capacity of technology transfer professionals/newcomers/students;
- Development of digital platform for cooperation between actors in the technology transfer ecosystem.

The present paper of 2 best practices from Slovakia has been developed in parallel with the Research on Best Practices in Technology Transfer, carried out within the scope of Activity 5, with both outputs to be used as a basis in the implementation of the other foreseen project activities.

This paper is structured within five main sections. Section 1 sets out the introduction. Section 2 discusses methodology of the research. Section 3 provides an overview of the 2 best practices within Pavol Jozef Šafárik University in Košice and , Slovak University of Technology in Bratislava. Section 4 provides conclusions, stemming from the analysis of the case studies.

2 Methodology

The process of collection of best practices included the following 4 stages: Initial Desk Research, Internal Review and Selection of preliminary identified best practices, Field research, Involvement of Stakeholders. Data was gathered through two-step qualitative research with the use of

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templates for both the review of secondary sources and the field survey. This approach ensured the collection of identical information and significant level of trustworthy and reliable results. Similarly, the assessment of the collected data was held at two levels – internally by partners and externally by stakeholders. This double check led to improvement of the produced materials and ensured that the expertise and contribution of the organisations involved in the assessment has been reflected in the final collection of best practices. The research focused on answering the following main questions:

- WHAT? (What is the best practice about? What have been the main factors contributing for its success? What challenges have been faced and what actions have been taken to address them? To what extent is the best practice applicable in another setting? What has been the main impact of the best practice?)
- WHO? (Who is involved in the implementation of the best practice?)
- WHEN? (Since when the best practice has been in existence?)
- WHERE? (Where is the best practice located?)
- WHY? (Why is it important to study this best practice?)
- HOW? (How can certain aspects of the best practice be further improved?) [2].

2.1 Initial desk research

Initial desk research involved the study of secondary sources, i.e. through searching information available on the Internet or in relevant literature. The most relevant results were then carefully reviewed and additional information was collected about each best practice identified [2].
Within desk research in cooperation with The Technology Transfer Center (CTT) at Slovak Centre of Scientific and Technical Information (CVTI SR), we have reviewed institutions that had successfully implemented technology transfer with good practice strategies in the sector. This was followed by another session to present examples of good practice that best fit the STEIDA project priorities.

2.2 Field research

Field research involved the collection of data from primary sources, i.e. from the organizations responsible for the best practices. Each organization, which had been identified during the initial desk research as responsible for a best practice, was contacted by the CVTI SR as a project partner and requested to complete the questionnaire for field research. The interviews with the organisations providing the best practices were conducted face-to-face in Košice and Bratislava. The information obtained from the field research complemented and expanded the data gathered during the desk research [2].

3 Best practices from Slovakia

3.1 Transfer of rights carried out by Technology and Innovation Park of the Pavol Jozef Šafárik University in Košice and its TTC

The first best practice presented Academy-Industry Collaboration between the Pavol Jozef Šafárik University in Košice (Technology and Innovation Park of the Pavol Jozef Šafárik University in Košice), Comenius University in Bratislava, Masaryk University in Brno and the Czech holding group FABA Capital.
The cross-border cooperation between three universities and one start-up has brought significant success in the field of technology transfer to the Pavol Jozef Šafárik University in Košice at the end of 2022. The concluded intellectual property transfer agreement will bring a new technology closer to practice.
Successful technology transfer of the MicroRNA test of the success of the IVF (in vitro fertilization) process and diagnostics of a quality embryo for IVF. Technology transfer that can contribute to the success of assisted reproduction by the IVF method. Innovative technology consists in the non-invasive collection of biological material without any damage to the embryo, by analyzing isolated miRNA molecules from the culture medium as new biomarkers. Molecules are thus able to help in personalized medicine in predicting the success of IVF through the selection of a suitable embryo.
Duration of best practice is since 2019. The Technology Transfer Center at CVTI SR entered the process in the fall of 2019, when it delivered an evaluation report and research on the state of the art to the Pavol Jozef Šafárik University in Košice. The Slovak patent application was submitted to the Industrial Property Office in March 2020. In 2021 the patent attorney filed an international PCT application (on the basis of the Patent Cooperation Treaty). The sign of the contract on the transfer of IP to the start-up FETUS, IVF occurred on December 20, 2022 between the four contracting parties.
The best practice is about successful technological transfer and close cooperation with the commercial and legal department at the Technology and Innovation Park of the Pavol Jozef Šafárik University in Košice. Professionally provided commercialization process.
The new technology, protected by a patent application, identifies new microRNA (miRNA) molecules that can be used in prediction. Simply put, the identified molecules predict the women's current readiness and the quality of the embryo suitable for the artificial insemination process.
The importance of the invention is underlined by its nomination for the Technology Transfer Award in Slovakia in 2021, in the Innovation category, and finally, the transformation of the nomination into the victory of the MicroRNA test for the success of the IVF process and diagnostics in its category.
As part of the commercialization of academic and university projects, a new fabaincube incubator was created for other similar projects.

Three universities, one investor, services and coordination from the CTT CVTI SR are behind the success in the field of technology transfer.

CTT CVTI SR entered the process in the fall of 2019, when it delivered an evaluation report and state-of-the-art research to Pavol Jozef Šafárik University in Košice. The next step in the process of successful technology transfer was the filing of a patent application. The concluded intellectual property transfer agreement will bring a new technology closer to practice.

The research of two Slovak and one Czech university and the subsequent entry of the holding company FABA Capital bring into practice a new technology that can contribute to the success of assisted reproduction by the IVF method. The task of the start-up, which is part of the FABA Capital group, is now the commercialization of the IVF embryo transfer project. FABA invested 441 000 EUR in the startup. The investment includes the transfer of intellectual property rights to the newly established startup Fetus with scientific teams from universities in Bratislava, Košice and Brno.

The challenge is in combination of molecular methods with the use of artificial intelligence in biomedicine, to bring better healthcare as well as a higher quality of life for everyone, not just infertile couples.

The challenge was determining the value of this solution for the purposes of concluding the contract. An expert determined the general value of the invention. This was then used to determine the value of the final contract between the universities and the financial holding.

Certain aspects of the best practice can be improved by inviting other specialists to the research group with experience in the field of study and high-capacity analyzes of miRNA molecules in clinical material.

It is important to study this best practice because it's a breakthrough in the field of intellectual property commercialization. This is the first ever successful transfer of intellectual property within Slovak universities that we have information about, and CTT CVTI SR significantly contributed to its implementation.

The professional technology transfer departments of all three universities involved played an irreplaceable role in the entire process.

Based on a detailed assessment of the invention and its potential for commercial use by experts from CTT CVTI SR, was recommended offering a license to use the invention to reproductive centers. They also provided support to Slovak universities in obtaining patent protection with the aim of subsequently selling the invention in question."

This best practice is highly applicable in other academic and institutional settings, especially where there is a need to strengthen the cooperation between the research and industry.

The main impact of this best practice is in bringing into practice a new technology that can contribute to the success of assisted reproduction using the IVF method.

3.2 Technology transfer implemented at the Slovak University of Technology in Bratislava

The second best practice presented Academy-Industry collaboration between Faculty of Chemical and Food Technology (FCHTP) of the Slovak University of Technology in Bratislava (STU), Polymer Institute of the Slovak Academy of Science and the commercial company PANARA. It concerns first Slovak bioplastic Nonoilen, which represents a 100% ecological solution in the field of biodegradable plastics. Nonoilen was created by Slovak scientists as part of PANARA cooperation with the scientific team from the Faculty of Chemical and Food Technology of STU in Bratislava and is protected by Slovak and international patent protection. The material was not only created, but is also commercially used. The best practice is about the PANARA cooperation with the scientific team from the Faculty of Chemical and Food Technology of STU in Bratislava

Nonoilen is the result of R&D collaboration between scientists from the Slovak Technical University in Bratislava (Faculty of Chemical and Food Technology) and private company PANARA. The goal of both parties is to produce bioplastics with a wide range of practical uses.

Contractually sealed long-term cooperation between FCHPT and the commercial company PANARA is an example of "the best practice". In the field of bioplastics, the faculty used its scientific potential, in which it is supported technically and economically by PANARA, which, on the other hand, as a representative of the business sphere, knows how to create suitable conditions for applied development supported by the faculty and the implementation of research into the industrial production.

Thanks to mutual support, not only was it created, but it is also used commercially. Nonoilen was tested and was put into practice on a pilot basis in several Slovak and foreign companies.

The idea of entering the market with a material that would have the properties of Nonoilen was introduced to academia by Pavol Alexy, a young engineer in the 1990s. Later, the knowledge and experience of a by then professor Alexy were combined with the risk tolerance of PANARA, which provided the university research with necessary conditions, and also actively took part in a significant portion of the research. Their synergy and enthusiasm for finding the possibilities to create and especially bring to market a truly ecological bioplastic have united into the Nonoilen granulate we have today.

The main factors that have contributed for the success of the best practice are: long-term cooperation between academic sector (FCHPT) and commercial sector (PANARA). The Slovak University of Technology is collaborating with the Brno University of Technology in Czechia. The scientists there, together with a commercial company, have developed a technology specifically for processing waste oils into polyhydroxybutyrate. In the field of bioplastics FCHTP use its scientific potential, in which it is technically and economically supported by PANARA, which, on the other hand, as a representative of the business sphere, is able to create suitable conditions for applied development supported by the faculty and the implementation of research into industrial production.

The authors of this invention gave a license to the Nitra-based company PANARA, which focuses on the development and production of ecological plastics.

From the point of view of the application use of Nonoilen, the faculty (FCHTP) has definitively developed recipes for packaging films from the first generation, and the second generation is practically complete, where only is needed to verify production under industrial conditions.

The STU team is also working intensively with companies and universities to find ways to use the invention in practice. One way is through mass commercial use in cooperation with manufacturers of plastic containers, cutlery, packaging films, or mulch films, which are used in agriculture to maintain moisture and prevent weed growth. The second path is original applications in the field of design and fashion. Here, chemists collaborate with designers from the crafting plastics studio. The third way for use is medical applications. Here, the STU team is collaborating with the Faculty of Medicine of Comenius University in Bratislava and top implant development experts from the Technical University of Košice. Bioplastics can be used as temporary implants for treating complicated fractures.

On the open market, 100% bioplastic cannot compete with the production price of super-cheap plastic made from petroleum today.

Certain aspects of the best practice can be improved by enforcing the preference for the production of 100% bioplastics over classic plastics made from oil through clear legislative rules.

It is important to study this best practice because it is important to work systematically on the most ecological solutions in the field of polymers and thus improve the ecological situation and the environment.

This best practice is highly applicable in other academic and private sector settings, especially where there is a need to strengthen the cooperation between research and industry. It creates opportunities for introduction of new progressive materials that are environmentally more sustainable.

The main impact of the best practice is that research activities, predominantly carried out by the team of FCHTP, were completed by submitting an application for an invention, which was awarded at the prestigious international fair of inventions and technologies.

4 Conclusions

The paper provides information about best practices in the field of technology transfer, identified in the STEIDA project by the Slovak Centre of Scientific and Technical Information. The best practices have been collected and elaborated through desk and field research and encompass different sub-categories of technology transfer ranging from management of technology transfer processes (digital services, innovative approaches, project support services), commercialization of patents, university-industry cooperation to promoting entrepreneurship and creation of spin-offs. Each best practice begins with a brief description, information about the providing organisation, duration of its existence, and continues with more insights related to the main success factors, challenges faced, mitigation actions, possible improvements, applicability and impact. The paper has been developed by the CVTI SR with the involvement of the organisations responsible for providing the best practices and target the main stakeholders of the project, which include higher education institutions, business support organisations, current and newcoming professionals in technology transfer offices, students, academics, entrepreneurs and companies. The paper will serve as one of the foreseen project outputs for dissemination of the STEIDA project results.

Acknowledgments

This paper was supported by project STEIDA (Strengthening Technology Transfer Ecosystem through Innovative and Digital Approaches), program Erasmus+, project ref. № 2023-1-TR01-KA220-HED-000157242.

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Developing University Industry Collaboration through Liaison Offices in Organized Industrial Zones: The KTU TTC Example

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Abstract

This study investigates how establishing Technology Transfer Office (TTO) liaison offices within Organized Industrial Zones (OIZs) can overcome structural and communicational barriers in university–industry cooperation. The research adopts a qualitative case study methodology, drawing on longitudinal data (2018–2024) from the Karadeniz Technical University Technology Transfer Application and Research Center (KTU TTC). Data sources include institutional records, project databases, company visit logs, and academic–industry matchmaking records, complemented by qualitative feedback from stakeholders.

Findings demonstrate that the OIZ-based liaison model substantially increased firm engagement (from 15 firms in 2019 to 76 in 2024), facilitated 43 academic–industry pairings leading to 20 publicly funded projects, and supported the establishment of two certified R&D Centers and one accredited test center. Moreover, the initiative enhanced firms' awareness of R&D incentives and fostered a shift from intermediary-based interactions to direct cooperation, indicating the formation of a sustainable trust-based collaboration culture. The added value of this study lies in providing empirical evidence on a place-based interface model for technology transfer, an area largely

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Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

overlooked in prior literature. While most research focuses on university- or technopark-embedded TTOs, this paper shows that relocating interface structures directly into industrial zones accelerates collaboration, enhances accessibility, and strengthens regional innovation ecosystems. The findings contribute a transferable model for policymakers and practitioners seeking to bridge structural gaps between academia and industry and to design more inclusive innovation policies.

Keywords
Technology transfer office, organized industrial zones, university industry collaboration

1. Introduction
University industry cooperation (UIC) has long been recognized as a cornerstone for fostering innovation, driving regional economic growth, and enhancing national competitiveness [1]. Technology Transfer Offices (TTOs) play a pivotal role in this process by acting as intermediary structures that facilitate the commercialization of research outputs, support intellectual property management, and promote collaborative R&D activities between academia and industry. However, despite the strategic importance of TTOs, structural and spatial barriers often limit their effectiveness, particularly in regions where industrial actors are physically distant from universities or technoparks.
In many cases, industrial firms especially those located in Organized Industrial Zones (OIZs) face challenges in accessing TTO services due to geographical separation, limited awareness of university capabilities, and the absence of sustained communication channels. Conversely, universities and TTOs encounter difficulties in understanding and responding to the evolving technological needs of the industry. This gap reduces the potential for joint innovation, delays the transfer of knowledge, and hinders the establishment of a collaborative culture. The literature on technology transfer has largely focused on models situated within university campuses or science parks, with relatively little empirical research examining place-based interface structures embedded directly within industrial zones[2].

To address this challenge, Karadeniz Technical University Technology Transfer Application and Research Center (KTU TTC) implemented an innovative interface model by establishing liaison offices within OIZs in Trabzon of Türkiye. Launched in 2018, this initiative aimed to strengthen university industry ties by physically embedding TTO representatives in industrial clusters, thus enabling direct, regular, and trust-based interactions with companies. These offices served as access points for firms to receive tailored guidance on R&D incentives, engage in academic matchmaking, and initiate collaborative projects, while also allowing TTO staff to observe industrial needs on-site and respond more rapidly.
The central research question guiding this study is: How can the physical presence of TTO liaison offices within OIZs enhance collaboration, technology transfer, and innovation outcomes in regional ecosystems? By examining six years of operational data from KTU TTC's OIZ liaison offices, this paper evaluates the impact of the model on cooperation frequency, project generation, and R&D capacity building. In doing so, it contributes to filling a gap in the literature by providing empirical evidence on the effectiveness of field-embedded TTOs as a scalable strategy for fostering regional innovation ecosystems.

1.1. Theoretical Background
The theoretical foundation of this study builds on the literature concerning university–industry collaboration (UIC) and the role of intermediary structures in fostering innovation. Prior research has highlighted Technology Transfer Offices (TTOs) as crucial mechanisms for bridging academic knowledge and industrial application, yet their effectiveness is often shaped by spatial proximity, institutional capacity, and relational trust (Perkmann et al., 2013; Bozeman et al., 2015). While traditional models emphasize campus-based or technopark-based structures, emerging perspectives in innovation policy underline the importance of place-based interface models that embed transfer mechanisms directly within industrial clusters. This conceptual lens frames the present study, situating Organized Industrial Zones (OIZs) not only as production sites but also as potential innovation hubs where localized interaction can reduce barriers, accelerate technology transfer, and cultivate trust-based ecosystems.

2. Methodology
This study adopts a qualitative case study approach to examine the outcomes and impact of establishing Technology Transfer Office (TTO) liaison offices within Organized Industrial Zones (OIZs), focusing on the model implemented by Karadeniz Technical University Technology Transfer Application and Research Center (KTU TTC) in Türkiye. The case study method is considered appropriate for in-depth analysis of real-life interventions where the boundaries between phenomenon and context are not clearly defined [3].

2.1. Data Collection
Primary data were collected through institutional records, project databases, and semi-structured observations maintained by KTU TTC between 2018 and 2024. These records included:

- Annual reports and internal monitoring documents,
- Company visit logs and academic-industry matchmaking records,
- Publicly funded project data (e.g., TÜBİTAK, KOSGEB, DOKA),
- R&D Center application files and outcomes,
- Training and awareness session participation data.

Additionally, informal interviews and feedback were gathered from TTO staff members and OIZ representatives involved in the implementation and follow-up processes. These provided contextual insights into challenges, adaptations, and perceptions of stakeholders regarding the liaison office model.

2.2. Evaluation Framework
The collected data were analyzed using a descriptive and impact-focused framework. Key performance indicators (KPIs) were

identified to assess the effectiveness of the liaison offices, including:

- Number of companies reached per year,
- Number of academic–industry pairings facilitated,
- Number of publicly funded projects initiated,
- Number of R&D Centers established,
- Level of firm engagement with R&D incentives before and after implementation,
- Qualitative feedback on trust, accessibility, and cooperation dynamics.

The evolution of these indicators over time allowed for a longitudinal analysis of the model's effectiveness in strengthening university industry collaboration and fostering an innovation-driven culture in the region. Comparative data from pre-implementation years (before 2018) were also used as a baseline to assess progress.

2.3. Limitations

As a single-case study, this research does not seek to generalize findings statistically but to provide transferable insights that may inform similar practices in other institutional or regional contexts. While the qualitative nature of the study captures the depth of implementation processes and outcomes, further research incorporating surveys or interviews with company representatives could enrich the analysis with more user-centered perspectives.

2.4. Data Analysis Procedure

The qualitative data analysis was conducted in a sequential process designed to capture both descriptive patterns and impact-oriented outcomes. First, all institutional records, project databases, visit logs, and matchmaking reports were compiled and organized chronologically. Second, the data were systematically coded to identify recurring themes related to firm engagement, academic collaboration, and R&D capacity building. Third, a descriptive analysis was performed to summarize observable trends across the six-year period, highlighting changes in the number of firms reached, partnerships established, and projects generated. Fourth, an impact-focused analysis was carried out using the previously defined KPIs (e.g., number of R&D Centers established, uptake of incentive programs, and shifts in communication dynamics) to evaluate the broader significance of the liaison office model. Finally, the results of both analyses were triangulated with qualitative feedback from TTO staff and OIZ representatives to ensure contextual validity and to capture nuanced stakeholder perspectives. This step-by-step approach ensured that the findings reflect not only quantitative improvements but also qualitative transformations in trust, accessibility, and cooperation culture.

3. Findings and Discussion

The establishment of TTO liaison offices within Organized Industrial Zones (OIZs) by Karadeniz Technical University Technology Transfer Application and Research Center (KTU TTC) has yielded significant outcomes in fostering university industry collaboration. The analysis of institutional records from 2018 to 2024 reveals substantial improvements in key indicators related to R&D engagement, academic industry matchmaking, and innovation driven project development.

➢ Increased Industry Engagement

The number of companies contacted annually through liaison offices increased markedly from 15 in 2019 to 76 in 2024. This upward trend demonstrates the growing awareness of and trust in TTO services among industrial actors. Initial skepticism regarding collaboration with universities was gradually overcome through face-to-face interactions and trust-building visits. This aligns with previous literature emphasizing the importance of proximity and sustained contact in university industry partnerships [4].

➢ Enhanced Academic Industry Matchmaking

One of the most critical outcomes has been the increase in academic industry pairings. A total of 43 academic matchings were facilitated through liaison offices, leading to 20 publicly funded R&D projects. These projects received support from national programs such as TÜBİTAK, KOSGEB, and DOKA. The pairing process, based on companies' identified R&D needs and academic expertise areas, has proven effective in translating industrial problems into collaborative solutions a key function of successful technology transfer [5].

➢ Institutional Outcomes and R&D Capacity

The model directly contributed to the establishment of two formal R&D Centers Çolakoğlu Makina (2018) and TİSAŞ (2019) which gained official recognition from the Ministry of Industry and Technology. Moreover, Mekap Deri ve Ayakkabı opened an accredited Test Center within Trabzon Technopark in 2020, expanding the innovation infrastructure of the region. These institutional outcomes are indicators of long-term capacity building and a shift from one-off collaborations to structured R&D engagement.

➢ Shift in Interaction Dynamics

Over time, the communication pattern between industry and TTO transformed significantly. While the initial contact relied heavily on intermediary based liaison office visits, many firms began to approach KTU TTC directly. This behavioral change indicates increased confidence, reduced informational asymmetry, and institutionalization of trust a cornerstone of sustainable university industry relations [6].

➢ Broader Impacts on Regional Innovation Ecosystem

The liaison offices served not only as connectors but also as disseminators of knowledge. Awareness-raising activities and on-site visits led to a more widespread understanding of R&D incentives and innovation processes. The number of firms benefiting from TÜBİTAK's industrial R&D supports increased from only 2 before 2018 to 6 by 2024. These results indicate a more innovation literate and incentive-oriented industrial base in the region.

3.1. Contribution to Literature

This case contributes to the literature by operationalizing a place-based interface model for technology transfer an under-researched area in TTO studies. Most existing models situate TTOs within universities or technoparks; however, this study shows that embedding liaison offices directly within industrial clusters yields faster, more targeted, and trust-enhanced interactions. These findings are consistent with evolving perspectives in innovation policy that emphasize spatial proximity, context-sensitivity, and relational trust [7]. The model appears transferable to other regions with similar structural gaps between academia and industry, provided that administrative support, qualified human resources, and sector-sensitive approaches are in place.

4. Conclusion and Policy Implications

This study examined the impact of establishing Technology Transfer Office (TTO) liaison offices within Organized Industrial Zones (OIZs) as a strategy to strengthen university industry collaboration and stimulate regional innovation. Drawing on the case of Karadeniz Technical University Technology Transfer Application and Research Center (KTU TTC), the findings clearly demonstrate that embedding TTO services within industrial zones significantly improves access, communication, and trust between academic institutions and industrial firms.

Over a six-year period, the liaison offices contributed to measurable outcomes, including a substantial increase in firm engagement, academic industry partnerships, publicly funded R&D projects, and institutional advancements such as the establishment of R&D Centers. Furthermore, the model facilitated a behavioral transformation to direct collaboration signifying a positive cultural shift in how firms approach innovation and research partnerships.

By physically positioning TTO representatives in proximity to industrial actors, this place-based model overcame spatial and perceptual barriers that often limit effective technology transfer. In doing so, it addressed a key gap in the literature, which has largely overlooked the potential of interface structures located outside of universities or technoparks. This research offers empirical evidence that such structures can catalyze not only transactional outcomes (e.g., projects, incentives, certifications) but also relational outcomes (e.g., trust, communication habits, innovation culture).

4.1 Policy Implications

The results of this study offer several important implications for policymakers, regional planners, and university administrators:
Support for Field-Based TTO Models: National and regional innovation policies should support the expansion of liaison office models in industrial zones, particularly in regions with weak university industry ties or limited technopark access.
Institutional Incentives and Funding: Dedicated funding mechanisms can be developed to support the operational costs of liaison offices, including staffing, mobility, and digital tools for academic industry matchmaking.
Integration into Smart Specialization Strategies: Regional development agencies should integrate liaison-based TTO models into smart specialization and cluster development strategies to ensure that knowledge flows and innovation incentives reach local firms effectively.
In conclusion, the liaison office model implemented by KTU TTC represents a replicable and scalable good practice for strengthening innovation ecosystems in industrial regions. It not only increases the operational reach of TTOs but also contributes to a more balanced, inclusive, and responsive innovation infrastructure at the regional level.

4.2. Transferability and Future Research

The OIZ-based TTO liaison office model presented in this study is not limited to the specific context of the Black Sea region but can also be applied to comparable environments with similar structural conditions. In particular, regions where university–industry interaction is weak, access to technoparks is limited, or firms have low awareness of R&D incentives present high potential for transferability. However, the successful implementation of the model requires the establishment of supportive administrative mechanisms, the provision of qualified human resources, and the development of strategies sensitive to regional sectoral dynamics.
For future research, comparative case studies across different universities and industrial zones would provide opportunities to test the scalability of the model. Moreover, surveys and in-depth interviews with firm representatives could offer richer insights into the effects of the model from the industry perspective. Multi-case analyses and international comparisons would further validate the applicability of this approach in diverse contexts, thereby contributing more comprehensively to the literature on university–industry collaboration.

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Knowledge Sharing, Protection of Trade Secrets, and Sensitive Practices in the Circular Economy

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Abstract

The paper addresses the research problem of how companies in the circular economy reconcile open knowledge sharing with the protection of trade secrets and other sensitive practices. A secondary analysis was conducted on the basis of relevant articles from the WoS and Scopus databases, which were published internationally in the last decade. Knowledge sharing and protection approaches that appear in the business environment at the content, organizational, technological, cultural and strategic levels are identified. The findings show that companies use combinations of selective, phased, organizational and digitally enabled knowledge sharing. The mentioned sharing is often coordinated with protection approaches: through restricted access, trust and technological security measures. Added value leads to an understanding of how to establish a balance between collaboration and protection of knowledge in the transition to a circular economy, which is often overlooked in companies, primarily due to market existence and achieving of competitive advantage.

Keywords

Sharing knowledge, trade secrets, sensitive practices, knowledge protection, circular economy

1 Introduction

Companies today operate in a competitive global environment, facing ever-increasing customer demands and at the same time pursuing rapidly evolving technological progress. To overcome these challenges, innovative and strategic actions need to be oriented towards sustainability. Knowledge sharing refers to the intentional exchange of information, experiences, ideas and skills among stakeholders, which contributes to knowledge application, innovation and optimization of the organization [22]. Companies are increasingly dependent on knowledge sharing in all aspects of their business if they want to operate in a circular, innovative and sustainable manner. The growing need for collaboration accompanies them and presents them with the challenge of how to share knowledge without jeopardizing their own trade secrets or other sensitive practices that are a competitive advantage for their business. Trade secrets are information with economic value that is not publicly available and is subject to protective measures as defined by the EU Directive [7]. Often in practice, companies consider as trade secrets even their own knowledge that is not formally protected by legal means. Nevertheless, knowledge is strategically important and therefore they do not want to disclose it to external partners. In this paper, we therefore provide a perspective on the sharing and protection of knowledge and the inclusion of formally protected information and informal forms of protecting sensitive content that companies (do not) want to disclose to partners. In this paper, we follow the research question of how companies in the circular economy reconcile open exchange and sharing of knowledge with the protection of trade secrets and other sensitive practices.

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2 Theoretical Background

An economic system that aims to eliminate waste and continuously use resources through reuse, recovery and recycling can be understood as a circular economy [11]. There are numerous definitions of the circular economy in literature. The transition of companies to a circular economy creates a need for collaboration within and outside the industry. The challenge for organizations is to overcome organizational, technological, financial and regulatory barriers [12]. Companies are under pressure to maintain a competitive advantage, and this poses the challenge of how to share knowledge without compromising sensitive information and trade secrets. Interorganizational relationships and exploiting different aspects of collaboration in line with company goals and with partners and geographical proximity are crucial for maintaining competitive advantage [6, 15].

A successful transition to a circular economy requires an understanding of knowledge, which is a key source of competitiveness. It can be documented or possessed by individuals in experience and in competence [16]. Its sharing involves a process for innovation and learning [22]. Often, the knowledge to be shared is limited and protected. A trade secret is information that (1) is secret in the sense that it is not generally known or readily accessible, (2) has commercial value because it is secret, and (3) has been subject to reasonable steps to keep it confidential [7]. In addition to legally protected secrets, organizations manage sensitive practices. Their disclosure could threaten competitiveness and therefore they use formal or informal protection approaches [6, 21].

Knowledge sharing is crucial for successful collaboration in circular models. Selective sharing [14, 21], modular sharing [3] and phased sharing [10, 13] are practices that allow companies to decide what knowledge to share and when. Often, knowledge is shared in an abstract or generalized form [21] to avoid revealing technical details. Organizational filtering or sharing is implemented within the company through organizational roles depending on the context of collaboration [13].

Contemporary digital platforms and technologies (open data channels, digital twins, IoT, AR glasses and other smart devices) [10, 12] enable structured, personalized and controlled knowledge sharing. Platforms (e.g. Circular Living Lab) are a space for knowledge and information sharing between companies, consultants and research institutions [2, 19]. The collaborative system is strengthened through the aforementioned platforms, which enable two-way learning and structured and transparent communication between stakeholders [2, 20].

Due to the sharing of knowledge, information, content, sensitive practices and trade secrets, companies develop protective approaches or strategies. Selective disclosure, where only part of the knowledge is shared, is based on mapping and classifying competencies, sensitive information and roles in the collaboration [2, 3, 10]. Informal protective practices are used, when stakeholders share information only with a sufficiently high level of trust and predictable behavior. In the form of informal conversations or psychological contracts and relational trust, they regulate information sharing if stable partnership relationships are present [6, 21]. Organizations reduce risk through controlled partner selection, often using intermediaries who act as filters that determine what knowledge enters the network and what remains protected. [19]. Access to knowledge is regulated by technological solutions for filtering and control through roles and competencies. [12]

Coordinated strategies have been reported when companies combine sharing and protection, through digital sharing controls, [3, 4] through gradual knowledge disclosure [13, 20] and when sharing is tailored to the user according to their competency profile [10].

Most research addresses knowledge sharing and knowledge protection separately. In a circular economy, collaboration and competitiveness are intertwined and comprehensive approaches that include both aspects need to be explored. This paper then addresses this gap by identifying approaches used to implement a circular economy.

3 Methods

To prepare the paper, a systematic literature review was conducted in June and July 2025, in accordance with the PRISMA guidelines [17]. The aim was to identify knowledge sharing and exchanges and the protection of sensitive content and trade secrets within the circular economy. The analysis included scientific articles, regardless of the research methodology used (e.g. qualitative, quantitative, mixed), as the inclusion criterion focused on the relevance of the findings to the research question. The literature was selected from the extensive WoS and Scopus databases, and selective filtering was used on keywords. A single search string was used for the WoS and Scopus databases: “exchange of knowledge”, “knowledge sharing”, “trade secrets”, “confidential information”, “circular economy”, “circular business models”. The circular economy is present in all aspects of business, so we did not exclude any area. We limited ourselves to papers that were published internationally in the last ten years. 99 records were identified in Scopus and 59 records in WoS. After removing 46 duplicates, 112 documents remained, which were reviewed based on title and abstract. After the first reading, 95 were eliminated as irrelevant documents. 17 articles were submitted for assessment of relevance and included in the final analysis. (Figure 1).

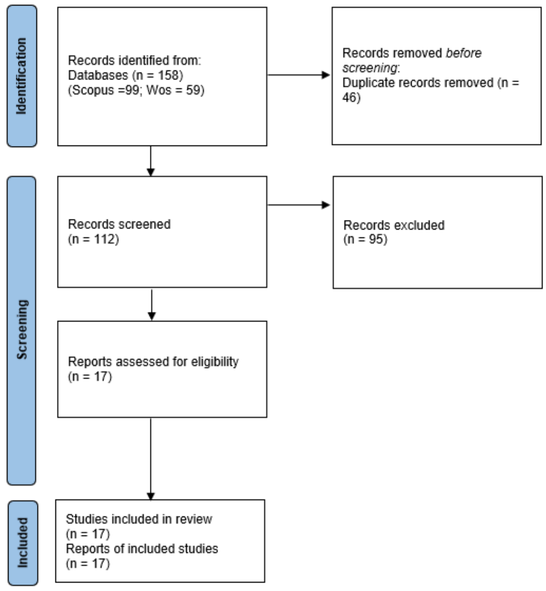

Figure 1: **PRISMA 2020 flow diagram of the study selection process**

4 Results and Discussion

The review of the contributions allowed for the definition and interpretation of perspectives that enable companies in the circular economy to share knowledge in a coordinated manner while protecting sensitive practices, information and trade secrets. Approaches occur at the content, organizational, technological, cultural and strategic levels. Opportunities were identified that reflect the coordinated use of approaches.

At the content level, companies implement selective and modular knowledge sharing. They selectively filter knowledge content within “safe” topics and share only non-sensitive information. Sensitive information, such as detailed processes, is protected [2, 14, 21]. Organizations implement knowledge and competence mapping to coordinate collaborations [3]. If goals are aligned, companies share information about production processes between partners, but under conditions of relational trust [6]. Phased knowledge selection means more protection in development, more openness in implementation, sharing is in steps [10, 13, 20]. Modular content distribution allows controlled access only to individual content sets. Knowledge is pre-classified and only what is safe or necessary for the process is shared. Partial internalization is present, when appropriate external knowledge is accepted from a security perspective and internal resources are protected. External competencies are converted into potential internal resources [3].

At the organizational level, knowledge is shared through organizational roles (project manager, manager, consulting organizations), which filter the content and level of shared knowledge and prevent uncontrolled disclosure of knowledge by experts. They determine which knowledge enters the network and which remains protected [2, 13, 19]. In addition, partners are carefully selected based on the level of trust and previous experience, which enables effective collaborative relationships [6, 14]. At the same time, research and design teams are established to promote knowledge sharing [8].

At the technological level, digital technologies provide central support, which are the central tools for secure, personalized and continuous knowledge exchange [3, 4, 10, 18]. They use technological tools (open data channels, visualization support with smart devices, decision-support technologies) that enable the transfer of complex knowledge through graphic or data displays. Technological solutions enable traceability and access restrictions [1, 12]. Communication is adapted to the user profile through digital interfaces. [10] Researchers, consultants and companies develop and test solutions and collaborate in innovation laboratories (Circular Living Lab) [19]. Organizations collaborate in circular ecosystems with industry, researchers and governments to find solutions and share knowledge [5, 11, 20].

At the cultural level, the aspect of trust proves to be an essential component of successful knowledge sharing and protection. Mentoring and informal conversations enable the exchange of employee experiences and knowledge transfer [4]. Informal conversations are based on mutual expectations and trust of the process stakeholders and predictable behavior [21]. Partners share information only when there is a sufficiently high level of trust, which indicates controlled disclosure of information [6]. In proactive collaboration, business ethics and transparency are of great importance in addition to trust [9].

At the strategic level, sharing and protection are aligned with the long-term goals of the company [4, 6, 20]. External stakeholders are involved gradually, depending on the nature and phase of the project. Depending on the level of involvement, the level of protection of disclosed information and sensitive practices changes [12, 19, 20]. Knowledge sharing serves as a mediator in the relationship between intermediaries and organizations. [23]

The findings of the reviewed literature indicate that in the circular economy, companies use different approaches to balance open knowledge sharing and protection of sensitive practices and trade secrets. The identified approaches are: content selectivity, organizational mechanisms, digital technologies, culture of trust, strategic orientation, personalization and collaboration in networks. The listed approaches occur at the content, organizational, technological, cultural and strategic levels. Companies often combine knowledge sharing and protection approaches, rarely using only one strategy. This confirms that openness to sharing and protection are processes through which collaboration is possible without jeopardizing key resources for competitive business. Balance is achieved through targeted control and shared content.

A selective and modular view of knowledge sharing is essential, where companies filter content according to its sensitivity (more or less important information) and the phase of the project. Only non-sensitive or secure content (non-confidential information) is shared, while measuring (mapping) competencies to align collaboration. In this approach, competitive advantages are not revealed during sharing [3, 6, 10, 14, 21]. Partners are provided with enough data to be able to collaborate effectively. The alignment between capabilities and needs is important, so companies create an overview of existing knowledge and skills and identify what, how much and how to include in the collaboration.

At the organizational level, knowledge sharing is controlled by intermediaries who take on certain roles between experts and external partners. At the same time, companies carefully select partners based on trust and previous experience [6, 13, 19]. This approach reduces the risk of uncontrolled disclosure of key information with partners. Intermediaries act as a filter to control the dynamics and content of the exchange. Careful selection of partners further reduces the risk, but also narrows the network of potential collaborations and wider openness.

Secure, structured and flexible sharing and exchange of knowledge is enabled by digital platforms and technologies. Blockchain, IoT, digital identity, AR technologies are advanced solutions that provide traceability and access control and increase the transparency of processes [3, 4, 10, 12]. The findings show that digital technologies are becoming an important element in addressing the challenges of sharing and protecting key content. Complex information and knowledge can be reliably and securely transferred through controlled mechanisms.

Long-term successful cooperation is also based on softer, human factors. A culture of trust stands out, which strengthens work in the process with experience, mentoring and psychological contracts between stakeholders. It is precisely a high level of trust that enables the secure exchange of sensitive information and long-term cooperation, which are key to the functioning of the circular economy. Mutual trust creates the foundations on which a company can more easily build long-term practices.

The approaches are aligned with the broader strategic goals of the companies, gradually involving stakeholders in the project phases. In doing so, they take into account the levels of information protection or sensitivity of the collaboration [4, 12, 19, 20].

Companies develop the ability to internalize external competencies and personalized knowledge transfer based on user competencies. Effective and targeted learning of employees and stakeholders in the process and support in the introduction of plate practices [3, 4, 8, 10].

Within the framework of the collaborative approach in networks and incubators, companies, researchers and other stakeholders jointly develop innovations and solutions. In the organizational and socio-technological framework for collaboration (Circular Living Labs), companies, consultants and users can come together to collaborate and develop solutions [5, 12, 19].

The combination of approaches allows organizations to simultaneously seize the opportunity of open innovation and reduce the risk of losing competitive advantage. This is important for governance in the circular economy and for cooperation between stakeholders in the process involved in sharing, using and protecting knowledge, sensitive practices and trade secrets.

5 Conclussion

The paper identifies and formulates key approaches that companies in the circular economy use to balance open knowledge sharing with the protection of sensitive practices and trade secrets. The findings show that selective, phased, organizationally and digitally supported combinations are used for knowledge sharing. These are often aligned with access restriction strategies, relational trust and technological safeguards. Coordination is considered in companies with regard to technological infrastructure, strategic goals, level of trust and context of collaboration. Creating a balance is a response to risks and at the same time part of the process in an open innovation environment. Sharing, simultaneous openness and protection are necessary and necessary for long-term competitive advantage in the circular economy. This research opens new research questions, namely, it should be examined which strategies or approaches are more effective depending on the industry or the size of the company. The nature of knowledge, sensitivity of information and the possibilities of its protection vary depending on the industry and the size of the company. Knowing these differences allows them to design appropriately tailored approaches in the process that encourage collaboration while maintaining the security of key content. It would also be necessary to analyze how the institutional environment influences the formation of a balance between openness and knowledge protection. An in-depth analysis of various combinations would provide a view of how different approaches to sharing and protecting knowledge change throughout the life cycle of project collaboration. The levels of sharing and protecting knowledge show that companies in the circular economy use comprehensive approaches where the elements are not exclusive, but rather complementary. The main challenge is to establish a balance between open access to knowledge and security and protection. Companies solve the challenges at the content (filtering), organizational (roles), technological (platforms), cultural (trust) and strategic (alignment with goals) levels. A coordinated balance between sharing and protecting knowledge is a dynamic process that must constantly adapt to market changes, technological changes and changes in relationships between partners in the circular economy.

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Self-evaluation of Research Organizations in the Field of Knowledge Transfer

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Abstract

Knowledge transfer plays a central role in transforming research outcomes into social and economic value, addressing both technological progress and societal challenges. The European Council Recommendation 2022/2415 calls for systematic approaches to knowledge transfer, supported by clear metrics, appropriate policies, and stakeholder collaboration. This work examines self-evaluation in research organisations, highlighting its potential to improve performance, align activities with long-term vision, and identify both strengths and gaps. It includes international comparison and prevalence of quantitative indicators as well as stresses the importance of combining them with qualitative indicators such as case studies, narratives, and relationship assessments. The SCOPE methodology is presented as a practical, values-based framework for responsible research evaluation. By integrating both quantitative and qualitative indicators, organisations can achieve fairer, more transparent, and more effective evaluations that foster societal impact and sustainable growth. The paper explores the existing approaches for self-evaluation in the field of knowledge transfer and gives recommendations for those being responsible for self-evaluations at research organisations as well for policy makers, setting the frame for performing evaluations.

Keywords

knowledge transfer, self-evaluation, indicators, SCOPE methodology

1 INTRODUCTION

Knowledge transfer (KT) is key to transforming research and innovation into social and economic value, as it enables technological progress and addresses societal challenges. In its Recommendation 2022/2415, the EU Council stresses that knowledge transfer must be systematic and supported by appropriate measures. Its effective implementation requires good management of intellectual property, including protection and transfer into practice. The cooperation of various stakeholders, from researchers and entrepreneurs to decision-makers and civil society, is crucial. The Recommendation calls on Member States to provide financial and political support that will enable better integration of research with industry and society. Only in this way will knowledge transfer have the greatest possible impact on sustainable development and economic growth [1].

The Council of the EU encourages joint efforts to develop and adopt definitions, metrics and indicators covering the different channels of valorisation, with the aim of improving its performance in the EU. Monitoring and evaluation practices should be aligned with the broader framework for monitoring the European Research Area. [1].

Across the EU, systematic self-evaluation of knowledge transfer in research organizations remains uneven and often limited in scope. While many organizations collect quantitative indicators, fewer engage in structured, organisation-wide self-evaluation that also captures informal, collaborative, and societal dimensions of knowledge transfer. The European Commission has acknowledged these gaps and is developing common frameworks and self-assessment tools, but uptake is still at an early and variable stage [2].

2 Methodology

In the period between November 2024 and August 2025 we reviewed the relative literature. We were interested to know which are relevant guidelines for self-evaluation in the field of KT as well as which are most relevant quantitative indicators and how to balance them with the qualitative assessment. We are members of The Coalition for Advancing Research Assessment (COARA), European Association of Research Managers and Administrators (EARMA), Association of European Science and Technology Transfer Professionals (ASTP) and other relevant organizations, relevant for self-evaluation of KT and have thus insight in most relevant literature. Internal documents of relevant working groups not cited here as well as our experience as technology transfer officers have been used to elaborate our recommendations.

3 Guidelines for self-evaluation of knowledge transfer

3.1 Monitoring and evaluating research organizations is reasonable and necessary

The reasons behind implementation of evaluating research organisations (RO) are not only accountability for public funding, improvement of research quality and international

Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

competitiveness but they focus on broader impact reflecting the growing expectation that science should benefit society, not only the academic community. Thus, the evaluation of RO in the field of knowledge transfer has several positive effects. One of them is to shed light on those research organisations that have a high potential for economic impact. The Redstone Venture Capital Fund recently carried out a study of 457 research organisations from 34 European countries. The study showed differences in the effectiveness of research organisations in creating companies. Some organisations achieve the same economic impact with €2 million as others with €200 million. The study highlights the importance of (self)evaluation in the field of knowledge transfer [3].

3.2 A research organization must establish a vision

Vision is crucial to the long-term success of an organization, setting its direction, inspiring employees, and aligning decisions with its overarching goals. A good vision goes beyond ambitious goals—it must be meaningful, inspiring, and easily understood. When effectively crafted, it acts as a compass that guides the organization through change and challenges. In addition to providing internal direction, a good vision also communicates externally the organization's values and commitment to a larger purpose, which can build trust with customers, partners, and communities. Without a clear vision, organizations can get lost in the operational details and lose a sense of long-term perspective. Evaluation, metrics, and indicators are tools for measuring progress toward a specific vision. If indicators are not aligned with the vision, the organization may start optimizing the wrong things. Therefore, it is important that research organizations establish their vision. Measurements and evaluations must be meaningfully aligned with the long-term vision [4].

3.3 Potential negative impacts of evaluation

Evaluation can lead to potential negative effects. An example of this is the increased administrative burden for all involved, highlighted by the EU Council Recommendation 2022/2415 [1].

The process can even lead to an obsession with the quantitative measurement of human performance. In his book The Tyranny of Metrics, Jerry Z. Muller warns of the dangers of over-reliance on quantitative indicators in assessing performance in education, health, science, public administration and other fields. The author criticizes the idea that everything that matters can be measured, as such an approach often leads to distortion of behavior, manipulation of data and neglect of qualitative aspects of work. Metrics used without context can undermine the real goals of organizations. Muller therefore calls for a thoughtful and critical use of measurement, where numbers do not replace judgment and expertise [5].

3.4 Guidelines for the evaluation of scientific excellence

There are an increasing number of global and national initiatives focused on driving Responsible Research Assessment (RRA). Research organizations are typically evaluated in three categories: (1) scientific excellence (research quality), (2) viability and (2) societal relevance (impact). Guidelines for evaluating scientific excellence can also be useful in the field of evaluating knowledge transfer. The San Francisco Declaration on Research Evaluation (DORA) and Strategy Evaluation Protocol (SEP, Netherland) call for the elimination of the use of impact factor as the main measure of research quality. Instead, it encourages evaluation based on the content of the work and recognizes the diversity of research results and contributions. SEP in particular sets the organization's strategy as a key stone of evaluation. The Leiden Manifesto offers ten principles for the responsible use of metrics, emphasizing that quantitative metrics should complement, not replace, professional judgment. It advocates for transparent, inclusive, and tailored evaluation approaches that take into account context and differences between disciplines. The COARA agreement on research evaluation reform builds on similar foundations and brings together organizations committed to long-term changes in the evaluation of researchers, projects, and institutions. COARA set up WG Responsible Metrics and Indicators, to deliver critical evaluation of the indicators used for evaluation. All those initiatives and instruments warn of the dangers of over-reliance on simple metrics and advocate for a holistic, fair, and quality-oriented evaluation of research work in support of scientific excellence and societal relevance [6], [7], [8]

4 SCOPE Methodology

The SCOPE framework, developed by the International Network of Research Management Societies (INORMS), offers a values-based methodology to improve the fairness, transparency, and effectiveness of research evaluation. Traditional approaches often rely on citations, journal impact factors, or funding levels. While useful, these indicators can introduce bias, encourage quantity over quality, and increase pressure on researchers [9].

SCOPE provides a structured five-step process that helps research organisations, funders, and managers design evaluations that promote fairness, inclusion, and responsible use of indicators:

1. **Start with what you value** – Evaluation should reflect the true priorities of the organisation, not external pressures. For example, if open science is a key value, indicators might include open access, data sharing, or research transparency.
2. **Consider context** – Evaluation must be adapted to its purpose (understanding, self-praise, control, comparison, rewarding) and the unit of assessment (individuals, groups, or institutions). Since practices differ across disciplines, one-size-fits-all approaches are unfair.
3. **Options for evaluating** – Both qualitative and quantitative methods should be combined. Citation counts or other metrics should never stand alone; broader contributions such as mentoring, ethics, or societal impact should also be considered.
4. **Probe deeply** – Anticipate unintended consequences, such as bias, gaming, or harmful behaviours like over-publishing. Addressing risks ensures evaluations remain fair and effective.

5. **Evaluate your evaluation** – Reflect on whether the process met its goals, improved research culture, and what can be enhanced for the future.

SCOPE warns against unconscious bias and discriminatory effects in evaluation processes. It emphasizes that evaluations must be co-designed with the evaluated community, tested for discriminatory impact, and continuously checked for unintended consequences.

By following SCOPE, organisations can foster a more balanced, responsible, and values-driven research evaluation culture [9].

5 Indicators

Indicators are tools used to measure and track progress, performance, and impact in knowledge transfer and related activities. They provide valuable insights for policymakers, research organisations, and industry by capturing both inputs and outputs. A balanced approach combining quantitative metrics with qualitative evidence, such as case studies, is essential to reflect the complexity and societal value of KT processes. Quantitative indicators may also be useful to underpin the case studies as qualitative indicator.

The choice of indicators depends on the exact argument for which they should provide evidence [10]. Evaluated RO shall explain the choice of the indicators as well as their link to RO's aims and strategy.

5.1 Quantitative indicators

Joint Research Center of European Commission (JRC) has defined four groups of quantitative indicators: (1) KT Internal Context Indicators and (2) KT Environment Indicators represent inputs, while (3) KT Activity Indicators and (4) KT Impact Indicators represent outputs [2]. JRC also listed concrete indicators which we present here. We have reviewed three other sources and compared indicators that they use [11], [12], [13] and [14]. Indicators are presented in

Table 1, Table 2, Table 3 and Table 4. JRC excluded most of intellectual property indicators from their metrics. Although they are right that the number of patents are less relevant than license agreements and are according to our information even sometimes recognized by researchers as the end of their knowledge transfer journey, we believe they are nevertheless important intermediate indicators. Most common quantitative indicators are research expenditure in RO, licences & assignments — number and gross revenue to RO and spin–offs — number (identified by 4 sources) as well as age of KTO, number of FTE in KTO, invention disclosures — number, spin–offs — gross revenue to RO from equity sale, research collaboration agreements with non–academic third parties — number and gross revenue to RO, research contracts with non–academic third parties — number and gross revenue to RO, and consultancy agreements with non–academic third parties— number and gross revenue to RO (3 sources). The prevalence of these indicators should be a sign for RO when establishing a quantitative system for self-evaluation.

Table 1: KT Internal Context Indicators. JRC [2]; ASTP [11]; UK [12], [13]; US [14].

Indicator	JRC	ASTP	UK	US
Existence of RO KT & IP Policies	X			
RO KT Strategy	X			
Direct funding via the RO for KT e.g. to KTO	X			
Indirect funding via the RO for KT e.g. proof of concept	X			
Existence of KTO	X			
Age of KTO	X	X		X
Number of FTE in KTO	X	X		X
Research expenditure in RO	X	X	X	X
Number of researchers	X	X		

Table 2: KT Environment Indicators

Indicator	JRC	ASTP	UK	US
National R&D spend as % GDP	X			
National Higher Education Expenditure on R&D (HERD)	X			
National Business Expenditure on R&D (BERD)	X			
Availability of public funding programmes to support KT/Industry engagement	X			
Availability of investment capital	X			

Table 3: KT Activity Indicators

Indicator	JRC	ASTP	UK	US
Invention disclosures — number	X	X		X
Priority patent applications		X		X
First patents granted		X		X
Active patent families		X		X
% of Licensed or optioned active patent families		X		X
Licences & assignments — number	X	X	X	X
Licences & assignments — gross revenue to RO	X	X	X	X
Option agreement		X		X
Spin–offs — number	X	X	X	X
Spin–offs — gross revenue to RO from equity sale	X		X	X
Research collaboration agreements with non–academic third parties — number	X	X	X	

Research collaboration agreements with non–academic third parties — gross revenue to RO	X	X	X	
Research collaboration agreements with non–academic third parties — length of relationship			X	
Research contracts with non–academic third parties — number	X	X	X	
Research contracts with non–academic third parties — gross revenue to RO	X	X	X	
Research contracts with non–academic third parties — length of relationship			X	
Consultancy agreements with non–academic third parties — number	X	X	X	
Consultancy agreements with non–academic third parties — gross revenue to RO	X	X	X	
Consultancy agreements with non–academic third parties — length of relationship			X	
Income from courses			X	
Number of courses held			X	
Number of participants that attend courses			X	

Table 4: KT Impact Indicators

Indicator	JRC	ASTP	UK	US
Jobs created in spin–offs	X	X		
Aggregate investment in spin–offs	X		X	
Products on market	X		X	
Culture change in RO	X			
Societal benefits	X			
Economic Benefits	X			

5.2 Qualitative indicators

In line with many strategic directions, quantitative indicators need to be combined with qualitative ones. Examples include:

Case studies of successful collaborations (e.g. AUTM's Better World project, CURIE's "20 years KT success stories", or Knowledge Transfer Ireland's impact cases)

Narrative assessments of how KT contributed to outcomes like health, civil society engagement, or policy change.

Relationship quality between universities and industry, highlighted as a key driver of success beyond measurable outputs

Societal benefits such as improved well-being, new policies, or civil engagement [2].

6 Conclusions

Effective self-evaluation in knowledge transfer should rely on established global and national initiatives focused on driving Responsible Research Assessment (RRA) in combination with guidelines of respected organizations like JRC, ASTP, KT UK and AUTM. If not already in place, research organizations' managers should use most common quantitative indicators like research expenditure, licences, spin–offs and others in their self-evaluation system. While quantitative indicators remain useful, they provide only a partial view of performance. Research organizations' managers should integrate qualitative indicators - such as case studies, narrative assessments, and relationship quality - which offers a fuller understanding of KT outcomes and their societal relevance. Furthermore, they should follow the existing frameworks, which provide valuable guidance by emphasising values, context, and reflection in evaluation design. Ultimately, self-evaluation must align with the long-term vision of research organisations while supporting broader European goals of innovation, sustainability, and societal benefit. By embedding responsible and inclusive self-evaluation practices, KT can more effectively bridge research, industry, and society, strengthening its role as a driver of economic and social progress.

Acknowledgments

This project has received funding from the Slovenian Research and Innovation Agency and Ministry of Higher Education, Science and Innovation under grant agreement No. V5-24055, project ISERO.

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Strengthening Knowledge and Technology Transfer Ecosystems through Transnational Collaboration: The Case of the STEIDA Project

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ABSTRACT

This study, conducted within the scope of the STEIDA project, examines the technology transfer (TT) ecosystems of Bulgaria, Croatia, Slovakia, Slovenia, Spain, and Türkiye through a comparative and multidimensional analysis. Using a mixed-methods approach that integrates bibliographic reviews, stakeholder interviews, and data from the European Innovation Scoreboard (EIS 2024) and the Regional Innovation Scoreboard (RIS 2023), the study evaluates the institutional structures, key actors, legal frameworks, financing mechanisms, and the scope of services provided by technology transfer offices (TTOs) in these countries.

The findings reveal significant differences in TT practices in terms of innovation performance, TTO structures, stakeholder engagement, and service diversity. Slovenia and Spain demonstrate well-institutionalized TT systems characterized by strong public–private sector partnerships and diversified service structures, while Bulgaria, Croatia, and Slovakia show more project-based TT models with limited institutional capacity. Türkiye, on the other hand, is enhancing its capacity through industry-oriented policies, state incentives, and regional clusters, but still requires structural improvements in university–industry integration and the scaling-up of innovations.

Common challenges across the countries include limited commercialization capacity, entrepreneurship ecosystems that remain largely at the level of public entrepreneurship within universities, the lack of standardized curriculum in TT-related curriculum, and a dependency on project-based funding. The study emphasizes that TT is not merely a technical process but one that requires multi-actor, multi-layered, and structural transformation. Accordingly, it offers strategic recommendations focused on capacity building, strengthening stakeholder collaborations, and fostering cross-border learning mechanisms.

KEYWORDS

Technology Transfer, Innovation Ecosystems, Comparative Analysis, Technology Transfer Offices

1 Introduction

Knowledge and technology transfer (K&TT) is a collaborative process that allows scientific findings, knowledge and intellectual property to flow from creators, such as universities and research institutions, to public and private users [1]. Today, despite the rapid growth of research and development activities globally, the commercialization and social transfer of scientific knowledge and technological innovations has not yet reached the desired level. This situation not only limits the potential for economic growth but also hinders the effective use of resources within innovation ecosystems to create value. TT processes strengthen this interaction and vary significantly across countries due to differences in legal frameworks, institutional capacities, financial opportunities, institutional profiles, stakeholder relationships, and organizational dynamics.

This diversity makes it essential to share good practices, correctly identify shortcomings, and establish a common development perspective; therefore, a joint analysis and evaluation process has been carried out through a multi-stakeholder consortium composed of institutions with different regional, institutional, and capacity profiles. This process enabled the assessment of the status and comparative development of TT ecosystems across the consortium's member countries, as well as their strengths, weaknesses, and shared challenges.

In this context, the "Joint Comprehensive Study Report of TT Ecosystem," prepared within the scope of the STEIDA project that aims to strengthen technology transfer ecosystem through an innovative and holistic approach which will foster national and international collaboration among universities, academic staff, businesses, students, entrepreneurs and other stakeholders by developing/using digital platforms and networks. The project will alsocontribute to close the gap between academia and industry through providing students with new competencies [2], addresses the technology transfer ecosystems of Bulgaria, Croatia, Slovakia, Slovenia, Spain, and Türkiye with a detailed and comparative approach. The study not only focuses on identifying the current state but also comprehensively evaluates each country's institutional structure in the field of TT, its key actors, operational mechanisms, legal and regulatory frameworks, financial resources, and their accessibility. In addition, elements such as the organizational structures of technology transfer offices, the scope of services they provide, their level of interaction with the private sector, stakeholder motivations, and capacity-building activities are systematically examined [1].

Through this multidimensional analysis, the study clearly reveals the strengths of countries in the field of TT, good practice examples, as well as structural deficiencies, regional differences, and operational shortcomings in the processes. In this way, similarities and differences between countries are identified based on concrete data, and applicable, targeted, and measurable recommendations are developed for policymakers, universities, research institutions, and industry representatives. The findings are also directly related to other components evaluated within the STEIDA project. In particular, the digital platforms, online training curriculum, and international cooperation networks to be developed within the project are designed to respond to the needs identified in the report. Thus, the report outputs go beyond a purely theoretical assessment of the current situation and contribute directly to strengthening the TT ecosystem in practice, establishing lasting collaborations among stakeholders, and enhancing the capacity for technology-based economic value creation.

2 Methodology

The study was conducted within the scope of the STEIDA project to comparatively analyze the TT ecosystems of six countries (Bulgaria, Croatia, Slovakia, Slovenia, Spain, and Türkiye). The methodology is based on a multi-stage approach that combines both quantitative and qualitative data collection and analysis techniques [3]. To understand the national context for the TT system in all consortium member countries, it is important to analyze the governance, institutional, legislative, funding, and other relevant aspects related to R&D, technology transfer, and

*The findings are part of the ongoing research at STEIDA Project that funded by Erasmus+ Programme.

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Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

research infrastructure. All consortium members followed the way that 3 number of desk research, 2 number of map of main stakeholders, 6 number of Analysis of existing bibliography and references, 22 number of expert interviews, 65 number of surveys were conducted under the needs of methodology.

2.1. National Data Collection Process

In the first stage, each project partner country conducted a comprehensive study on its national TT ecosystem. These national reports elaborated in detail on the current state of TT processes, key actors, legal and regulatory frameworks, financing mechanisms, the role and interest of stakeholders, capacity-building activities, as well as the capacity and services provided by TTOs. Two main data sources were used in this process:

- **Bibliographic review:** National and regional policy documents, strategy reports, legal regulations, statistical data, and reference reports published by the European Commission were examined. In particular, the European Innovation Scoreboard (EIS 2024) and the Regional Innovation Scoreboard (RIS 2023) served as key sources to assess and compare countries' innovation performances [4,5].
- **Stakeholder interviews:** Semi-structured interviews were conducted with universities, research centers, industry organizations, public institutions, entrepreneurship support structures, and other relevant actors. These interviews provided insights into the strengths and weaknesses of TT processes, opportunities, and challenges directly from the stakeholder perspective.

2.2. Comparative Analysis Process

In the second stage, the findings of the national reports were consolidated within a common methodological framework [3]. Using shared indicators and evaluation criteria, the maturity level, institutional capacity, regulatory compliance, financing structure, and stakeholder engagement level of each country's TT ecosystem were comparatively analyzed. In conducting this comparison, indicators such as innovation performance, regional differences, strong sectors, research intensity, public–private cooperation, and the legal/institutional infrastructure for TT—drawn from EIS 2024 and RIS 2023 data—were used as key references.

In this analysis, EIS data revealed the overall innovation capacity of the countries and their position relative to the European average, while RIS data were used to assess the impact of regional disparities within countries on TT processes [4,5]. Thus, the strengths and weaknesses of innovation ecosystems were identified not only at the national level but also at the regional level.

2.3. Consolidation of Findings

In the final stage, all national reports and EIS/RIS data were integrated into a common evaluation matrix. During this process, the strengths, weaknesses, opportunities, and threats (SWOT analysis approach) for each country were identified, and the findings were visualized through comparative analysis tables, charts, and thematic assessments.

Through this holistic method, the study not only provided a snapshot of the current state but also laid the groundwork for developing evidence-based policy recommendations. These were strengthened by EIS/RIS data and enriched by the experiences of institutions from different regions, profiles, and capacities.

3 Results

The multi-level comparative analyses carried out within the scope of the STEIDA project have clearly revealed the structural diversity and regional differences of the technology transfer (TT) ecosystems in Bulgaria, Croatia, Slovakia, Slovenia, Spain, and Türkiye. The findings demonstrate significant variations not only in terms of innovation performance but also in key areas such as TTO structures, legal/institutional frameworks, financial sustainability, stakeholder motivation, and the scope of services.

3.1. Innovation Performance and TT Capacity

EIS 2024 and RIS 2023 data provide a fundamental reference for identifying the maturity levels of the innovation systems of the six countries. Slovenia and Spain fall into the category of "moderate innovator countries," while the other four countries possess "emerging innovation systems." However, cluster formations in regional hubs create more rapidly developing TT areas in certain countries. The sectoral focus of TT practices also differs from country to country: in Türkiye and Slovakia, the defense, automotive, and electronics sectors are more prominent, whereas in Slovenia and Spain, green technology, pharmaceuticals, and information technologies stand out more clearly [4,5].

3.2. Institutionalization Level of TT Structures

The prevalence of TTOs, their network structures, and the diversity of services they provide emerge as key determinants of countries' TT capacities. In countries such as Slovenia, Spain, and Türkiye, TTOs are reinforced by public support structures and, in most cases, operate as visible and accessible institutional entities with clearly defined service catalogues. In contrast, in countries such as Bulgaria, Slovakia, and Croatia, TTOs are predominantly project-based structures, with management capacities that vary in terms of institutional development [6,7,8,9,10,11]. The scope of TTO services is generally limited to administratively oriented activities such as "funding search," "intellectual property management," and "EU project support," while commercialization and sectoral collaborations remain secondary.

3.3. Strengths and Challenges in TT Processes

The table summarized below presents, in a comparative manner, the strengths and structural limitations of the countries with regard to technology transfer:

Table 1: Strengths and Challenges in TT Ecosystems of Consortium Countries

Country	Technology Transfer Strengths	Challenges in Technology Transfer
Bulgaria	Progress through EU-funded programs. Emerging tech hubs in Sofia and Plovdiv; increasing international partnerships.	Weak research commercialization infrastructure, limited funding, and fragmented TT policies.
Croatia	Increasing focus on green tech and tourism. EU funding programs boosting TT and knowledge exchange	Low private sector involvement in TT, underdeveloped university-industry links, and insufficient R&D funding, insufficient academic-industry connection.
Slovakia	Strong in automotive and electronics sector. EU funding driving technology park development and	Limited domestic investment in R&D and low integration of academic research into commercial sectors.

	research collaboration.	
Slovenia	Robust TT in pharmaceuticals and green technologies. Strong public-private partnerships and active innovation hubs.	Challenges in scaling up TT activities due to limited domestic market size and funding.
Spain	Strong research outputs and innovation linkages. Significant academic-industry collaborations, especially in ICT and renewable energy sectors.	Gaps in scaling up innovations; regional disparities in TT effectiveness.
Türkiye	Industry-driven TT with growing tech parks and regional clusters, especially in defense and aerospace.	Insufficient academic-industry integration, challenges in scaling innovation beyond large companies.

3.4. Stakeholder Engagement and Capacity Building

The report highlights that a common challenge across all countries is the low motivation of academic staff to participate in TT activities, with TT generally not being integrated into institutional performance indicators. In addition, the support for fostering students' entrepreneurial potential remains limited in all countries; only a few universities (e.g., Zagreb, Istanbul) have established structural support models.

From a capacity-building perspective, a formal TT curriculum is largely lacking for both TTO personnel and researchers. Expertise in areas such as intellectual property management, patent portfolio strategy, or licensing is mostly outsourced, which limits the sustainable development of the TT process.

3.5. Additional Observations and Trends

Although the maturity levels of the ecosystems vary, EU programs in the consortium countries serve as key drivers of structural transformation. However, the project-based nature of these supports creates gaps in the development of sustainable strategies. Strengthening institutional network structures relative to their current status would enhance knowledge sharing and promote joint learning among TTOs.

4 Discussion

The findings of this study clearly demonstrate that TT systems in Europe show varying levels of structural and functional maturity. TT processes are not limited solely to institutional capacity or regulatory adequacy; they are also directly related to cultural norms, financial sustainability, academic motivation, and private sector expectations. In this context, both common trends and country-specific dynamics are noteworthy among the countries examined within the STEIDA project.

In countries with relatively more advanced innovation systems, such as Spain and Slovenia, the institutionalization level of TT structures, the prevalence of public–private sector partnerships, and the diversity of TTO services are higher. In these countries, TT activities are conducted through an integrated approach that goes beyond mere project management and also encompasses intellectual property protection, spin-off support, and licensing processes. In contrast, TT systems in Bulgaria, Slovakia, and Croatia remain largely project-oriented and lack institutional sustainability. Türkiye, while striving to increase TT capacity through industry-focused policies and public support mechanisms, has not yet reached a stage of systematic and deep-rooted transformation due to the limited institutional depth of university–industry collaborations and restricted researcher motivation.

The findings also reveal structural barriers commonly observed across the consortium countries. These include the weight of Procedural processes, insufficient incentives for TT within performance systems, limited engagement with the private sector, shortages in expert human resources within TTOs, and a service focus that is oriented more toward project execution than commercialization. At this point, for TT processes to succeed, it is necessary to address not only infrastructural but also institutional and organizational transformation needs.

Furthermore, programs and reports led by the European Commission, such as Horizon Europe, Erasmus+, EIS, RIS play a significant role in the development of TT ecosystems. However, due to the project-based nature of these supports, they are insufficient for creating lasting capacity. While national strategies are partially aligned with EU frameworks, in practice, regional inequalities, challenges in accessing funding, and deficiencies in institutional coordination emerge as the main factors limiting the effectiveness of TT systems.

In conclusion, technology transfer should not be regarded solely as a technical process but as a multi-actor, multi-layered mechanism requiring cultural transformation. In addition to structural reforms, building trust among actors, restructuring incentive systems, and strengthening cross-border learning mechanisms are critical for the development of TT ecosystems.

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Evaluating Skill Development and Collaboration Outcomes in the INDUSAC Project

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Abstract

The INDUSAC project, launched in 2022 under the Horizon Europe framework, innovatively brought together industry and academia by engaging students in solving real-world industry problems. Coordinated by the Jožef Stefan Institute, INDUSAC connected companies with international and interdisciplinary teams of students and researchers for co-creation projects lasting 4 to 8 weeks and executed as several consecutive calls for students and researchers to apply. This article evaluates student engagement during the first two calls (February 2024 and June 2024) through surveys conducted before and after the co-creation projects. Results show high initial student confidence and measurable improvements in professional skills such as negotiation and international teamwork. Satisfaction with the process and the online platform among both students and companies increased between the first and second call, indicating effective project adaptation based on student / researcher and company feedback. Companies valued student contributions for creativity but noted a need for more market viability. These findings confirm the effectiveness of INDUSAC's co-creation model and highlight areas for future improvement, ultimately preparing students for global careers.

Keywords

INDUSAC project, Industry-academia collaboration, Student engagement, Skill development

1 Introduction

Industry–academia collaboration is widely recognised as a driver of innovation, knowledge transfer, and competitiveness in Europe. Initiatives such as the EIT Knowledge and Innovation Communities (KICs) and Erasmus+ demonstrate the value of integrating academic expertise with industrial practice. Research highlights both enabling factors and barriers, particularly the need for student integration and for overcoming cultural and organisational challenges [1,2].

Conventional collaboration models are often lengthy, resource-intensive, and less accessible to widening countries. Evidence on short, challenge-driven projects is limited, even though transversal skills such as negotiation, teamwork, and conflict management are crucial for employability and often difficult to develop in classroom settings [3]. Moreover, evaluation practices in such short-term collaborations remain underdeveloped, particularly in terms of capturing engagement and response rates [4].

Alongside skills, collaboration also contributes to knowledge transfer by facilitating knowledge exchange, collaborative problem-solving, and cross-border learning. Previous research shows that while universities and companies recognise the importance of collaboration, students are often only indirectly involved, through workshops or mediated research projects, with limited access to real-world industrial problems [5,6]. INDUSAC explicitly addresses this gap by integrating students directly into co-creation with industry, enabling not only skill acquisition but also meaningful knowledge transfer [7].

This study evaluates INDUSAC, launched in 2022 under Horizon Europe, and argues that short, human-centred projects both enhance student skills and generate innovative solutions for companies. Our contribution is twofold: (1) we assess student skill development and company satisfaction through pre- and post-project surveys; and (2) we situate INDUSAC within broader debates on effective collaboration and knowledge transfer.

1.1 Project Context

Funded by Horizon Europe (Grant Agreement No. 101070297), INDUSAC fosters rapid, challenge-driven collaboration between academia and industry [8-10]. Coordinated by the Jožef Stefan Institute, the consortium includes universities, research institutes, clusters, and companies. International, interdisciplinary teams of 3–6 students and researchers addressed company challenges over 4–8 weeks, gaining practical experience while promoting cross-border cooperation. Attention was given to inclusiveness, gender balance, and the participation of both EU member states and associated countries, with a focus on EU widening countries. Financial support was provided for students who completed projects.

In the first two calls (February and June 2024), companies published 131 challenges. Student and researcher teams

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Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

submitted 64 motivation letters, 37 were approved, and 25 projects were completed. This combination of student development and industrial collaboration highlights INDUSAC's dual contribution to employability and knowledge transfer.

2 Methods

The evaluation of the INDUSAC project utilized surveys administered to students and researchers before and after each co-creation project, as well as to companies after each project. The aim was to capture changes in skills, satisfaction with the process, and company evaluations of the solutions produced.

Survey design. Before starting projects, all student and researcher team members completed an initial questionnaire to assess their baseline competencies, including communication, negotiation, conflict management, analytical and critical thinking, teamwork, creativity, time management, and international collaboration. After completing projects, participants filled in a follow-up survey to measure changes in these skills and to assess satisfaction with the INDUSAC process and platform (usability, clarity, support). Companies, after receiving final solutions, completed surveys evaluating creativity, innovativeness, market potential, quality of work, and satisfaction with the process and platform.

Participation and response rates. Across the first two calls (February and June 2024), more than 100 students and researchers participated. Students and researchers came from a diverse range of geographical locations, including Hungary, Slovenia, Croatia, Finland, Lithuania, Cyprus, Georgia, Serbia, Germany, Romania, North Macedonia, Tunisia, Bosnia and Herzegovina, Morocco, Poland, Türkiye, France, Moldova, Kosovo, and Bulgaria. In the first call, 71 valid pre-project and 56 post-project responses were received; in the second, 61 and 44, respectively. This corresponds to 86% pre-project and 73% post-project response rates, showing strong engagement at the outset and some attrition due to survey fatigue. Companies provided 9 valid responses in the first round and 8 in the second.

Data analysis. Survey responses were analysed with descriptive statistics. Improvements in competencies were calculated as percentage differences between average pre- and post-scores on a five-point Likert scale. Focus was placed on transversal skills with lower initial self-assessments (negotiation, conflict management, international teamwork), since these represent areas where knowledge transfer between students and companies is most visible. Company evaluations were aggregated across innovativeness, creativity, and market relevance.

This mixed-survey methodology enabled comparison of student self-assessments with company feedback, providing a holistic view of INDUSAC's effectiveness in fostering skill development and delivering useful outcomes.

3 Results and Discussion

The analysis of the INDUSAC project involved examining survey data gathered from participating students, researchers, and companies. This section details results related to participant engagement, skill enhancement, satisfaction with the INDUSAC platform and process, and company evaluations of delivered solutions. Together, these factors provide a comprehensive assessment of the INDUSAC project's effectiveness in achieving its goals of enhancing student capabilities, developing innovative solutions to industry challenges, and fostering robust collaborative relationships between academia and industry.

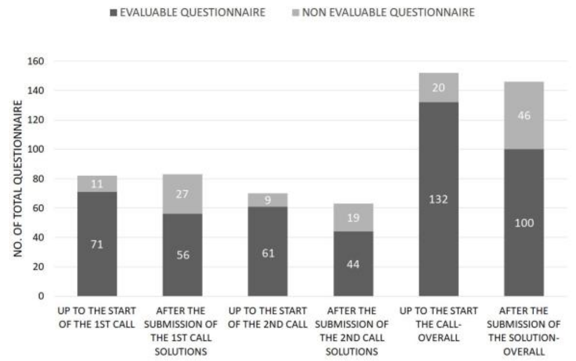

Figure 1: Evaluability of questionnaires after the cut-off date for students and researchers. The x-axis shows different stages of project participation (before and after each call, and overall), while the y-axis indicates the number of submitted questionnaires. Bars are split between evaluable (complete) and non-evaluable (incomplete) responses, measuring participant engagement and survey completion rate.

Participant engagement. Engagement was first assessed through the evaluability of completed questionnaires at the start and end of the co-creation projects. As shown in Figure 1, participation was strong: in the first call, 71 pre-project and 56 post-project responses were valid; in the second call, 61 pre-project and 44 post-project responses were valid. This corresponds to an overall response rate of 86% before projects began and 73% after completion. While the decline in post-project responses suggests survey fatigue, it nonetheless reflects a robust commitment, considering the short duration and intensity of the projects. This is consistent with findings in other challenge-driven initiatives, where sustaining engagement throughout the process remains a methodological challenge [2].

The presence of incomplete submissions post-project raises interpretive questions. Some students may have abandoned surveys due to waning motivation, while others may have struggled with clarity or usability. Preliminary qualitative feedback suggests both factors: some respondents found the platform navigation non-intuitive, while others noted a lack of clarity in survey expectations. Distinguishing between motivational and structural causes is crucial for improving future implementations.

Skill development. A central aim of INDUSAC was to enhance transversal skills. Students and researchers initially rated their skills highly, with an average of ~86%, reflecting strong self-confidence. Despite this high baseline, measurable improvements were observed, as shown in Figure 2. Overall, an average skill enhancement was ~4%. A more detailed analysis (Figure 3) highlights growth in negotiation (+7%), conflict management (+6%), and experience working with companies and international teams (+9–15%). These competencies are particularly relevant for employability and align with INDUSAC's goal of providing a practical, internationalized professional context. In some cases, self-assessments decreased slightly, which may indicate initial overestimation and subsequent recalibration when exposed to real-world challenges.

These results directly address the gap noted in the literature: while many collaboration models demonstrate learning benefits, few provide systematic evidence of skill development in short-term formats [1-3]. INDUSAC demonstrates that even brief interventions can yield tangible improvements, especially in international teamwork and company interaction. In addition, these skill gains form the basis for effective knowledge transfer, since negotiation, conflict resolution, and cross-cultural collaboration are essential for translating academic insights into industry practice [5-7].

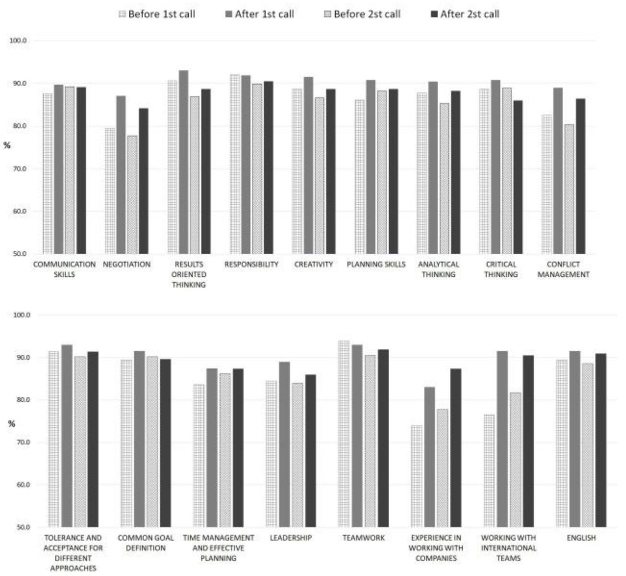

Figure 2: Skills of the co-creation team members before and after submitting the co-creation project solution. The x-axis lists specific soft skills, and the y-axis shows the average self-assessment scores on a standardized scale (a whole number out of 5, expressed as %). Two bars per skill represent student evaluations before and after project participation, measuring perceived skill development.

Satisfaction with process and platform. Students' and researchers' satisfaction with the INDUSAC process and platform increased between calls, as shown in Figure 4. Satisfaction with the process rose from 77% to 86%, while platform satisfaction increased from 81% to 87%. The positive change reflects successful adaptations based on first-round feedback, particularly improvements in usability and support materials. These outcomes reinforce the importance of iterative refinement [2]. They also underline how digital platforms can serve as enablers of knowledge transfer by keeping collaboration materials, feedback, and ideas accessible for later development.

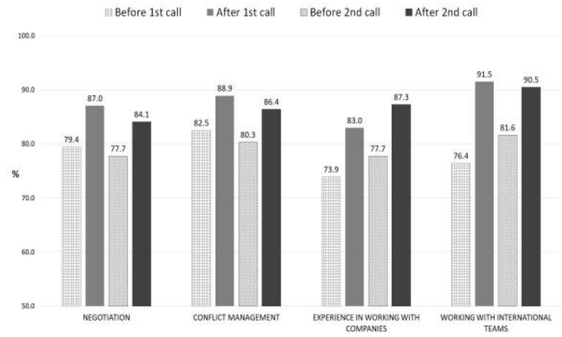

Figure 3: Enhanced skills in negotiation and conflict management, experience in collaborating with companies, and working with international teams of the co-creation team members (before and after the co-creation project). The x-axis identifies four skill categories (negotiation, conflict management, collaboration with companies, international teamwork), and the y-axis displays average skill scores before and after the project in percentage.

Company evaluations. Company satisfaction also improved notably. As shown in Figure 5, overall ratings increased from 77% in the first call to 87% in the second. Companies particularly valued creativity and innovativeness, while also calling for stronger market viability in delivered solutions. These observations confirm earlier feasibility analyses [11], which reported that while companies were enthusiastic about student creativity, they sought clearer communication and stronger connections to practical outcomes. The trend observed here, increased satisfaction after methodological refinements, indicates that INDUSAC has matured to better align with company expectations. Importantly, by providing innovative but not always fully market-ready solutions, INDUSAC lays the groundwork for knowledge transfer: student ideas and prototypes can be refined with company support into sustainable industrial outcomes.

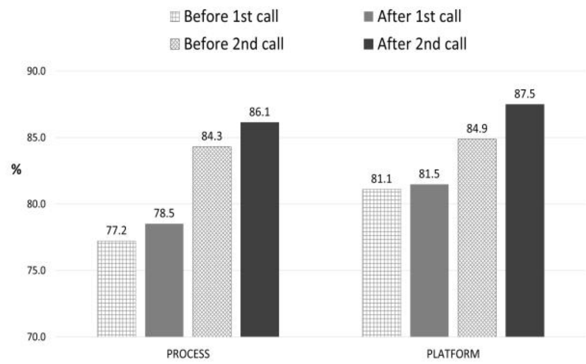

Figure 4: Satisfaction levels regarding the process and platform for co-creation teams. The x-axis distinguishes between satisfaction with the process and platform for each of the two calls, while the y-axis presents the percentage of students who reported satisfaction. Bars show the comparison between the first and second calls, highlighting overall improvements in participant experience.

Overall interpretation. The main insights demonstrate that the INDUSAC project has been successful in achieving its primary objectives. Despite high baseline self-assessments, students and researchers improved key transversal skills. Both students and companies expressed increasing satisfaction with the process and platform, reflecting the value of continuous improvement. Companies recognised the innovativeness of student contributions, though the call for stronger market viability suggests a need to integrate more structured support for business analysis in future rounds.

Taken together, these findings validate INDUSAC as a replicable and scalable co-creation model. Beyond skills and satisfaction, the project also strengthens knowledge transfer by linking collaborative problem-solving with structures for follow-up and application, ensuring that innovations generated within short-term projects can be sustained and further developed.

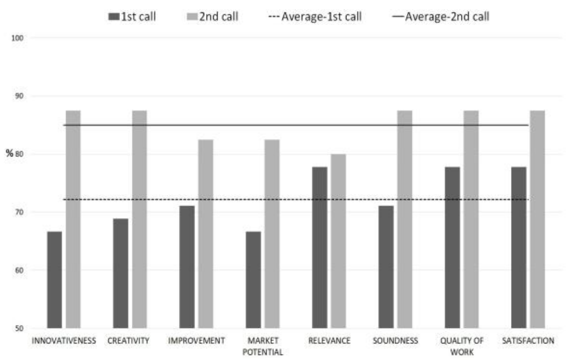

Figure 5: Companies' evaluation of solutions and the work of the co-creation teams. Of the categories surveyed, Innovativeness, Creativity, Improvement over existing solutions, Market Potential, and Relevance refer to the solution delivered by the co-creation team, whereas Soundness, Quality of Work, and Satisfaction refer to the work done by the co-creation team. The x-axis presents company evaluations from the first and second calls, while the y-axis indicates the percentage of company representatives who expressed satisfaction. The two lines represent average satisfaction scores for first and second calls, capturing industry perceptions of solution quality and teamwork.

4 Conclusions

The INDUSAC project presents a strong case for integrating students into co-creative processes that bridge academia and industry. Although students and researchers initially rated their skills highly, post-project evaluations revealed clear improvements in several competencies. Negotiation skills increased by 7%, conflict management by 6%, and international teamwork by up to 15%. These gains confirm the value of experiential, collaborative learning and show that short, focused project cycles can enhance professional readiness in areas often difficult to develop in traditional academic settings. Student reflections indicate that even confident participants recognised growth, underscoring INDUSAC's value as a developmental tool regardless of starting level. Companies likewise reported rising satisfaction with both the process and the solutions, appreciating creativity and innovation while calling for greater market orientation. This balance of skill enhancement and practical benefits illustrates how such collaborations provide value for all stakeholders. In addition to skills development and satisfaction, the project plays a significant role in knowledge transfer. By facilitating direct collaboration between students and companies on real-world challenges, INDUSAC promotes the exchange of knowledge, methodologies, and potential solutions that can be further refined and integrated into industrial practice. Direct student–company collaboration creates conditions for sustainable knowledge transfer, where ideas are co-created, critically tested, and adapted into practical industrial contexts. Overall, INDUSAC demonstrates effectiveness as a replicable model at the intersection of higher education, industry, and innovation. Key lessons include the importance of sustained engagement, feedback-driven refinement, and inclusive participation. Future work should strengthen market-oriented analysis and assess long-term impacts on student careers and company innovation.

Acknowledgments

Work described in this manuscript has received funding from the European Union's Horizon Europe Programme under grant agreement No 101070297.

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Digital Persona Generation:
Historical Figure Emulation in Learning

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Abstract

This Machine Learning paper presents an innovative pipeline for generating interactive digital personas of historical figures, aiming to enhance educational engagement. Our system leverages large language models (LLMs) and Retrieval-Augmented Generation (RAG) to ensure factual accuracy and employs sophisticated voice synthesis for authentic conversational experiences. A core aspect of our approach involves adaptive prompt engineering, which serves as a crucial feedback mechanism to continuously refine the historical figure's knowledge base and conversational tone, ensuring high fidelity to the original persona. This iterative adaptation enables personalized learning interactions, allowing users to deeply engage with historical context through emulated figures like Pliny the Elder.
Index Terms—Conversational AI, Historical Simulation, Retrieval-Augmented Generation (RAG), Educational Technology, Digital Humanities, Language Models, Virtual Persona, Interactive Learning, AI in Education, Prompt Engineering, Textto-Speech Synthesis, Knowledge Grounding, NLP for History, Whisper ASR, ElevenLabs TTS

Introduction

Traditional history education often relies on passive methods such as textbooks, lectures, and rote memorization, which can hinder engagement and knowledge retention, particularly in ancient history due to cultural and linguistic gaps. Students frequently struggle to connect meaningfully with historical content, reducing motivation and learning efficacy.

Advances in artificial intelligence (AI) offer new opportunities to transform history education. Conversational agents powered by large language models (LLMs) can bring historical figures ”to life” as interactive, personality-driven digital personas. These reconstructions simulate speech, behavior, and ideologies based on historical texts, enabling dynamic, dialogue-based learning experiences.

This paper presents a framework for reconstructing the persona of Pliny the Elder, a Roman author and naturalist, using a hybrid approach of Retrieval-Augmented Generation (RAG), prompt engineering, and voice synthesis. The system grounds responses in verified historical content and emulates Roman-era rhetorical style to provide an immersive, voice-interactive educational environment.

We investigate three core hypotheses:

1) H1: Historical Accuracy – Responses are factually accurate and temporally consistent with Pliny's writings.

2) H2: Engagement and Learning Efficacy – Dialogue-based learning enhances engagement and knowledge retention compared to traditional methods.

3) H3: Stylistic Authenticity – The system emulates Pliny's tone, language, and rhetorical style convincingly.

Initial evaluations indicate strong alignment with all hypotheses, including contextually grounded answers and engaging voice-based interaction. This approach transforms passive content consumption into interactive, personalized historical learning.

A. Relevance to Technology Transfer and Intellectual Property

The modular framework—comprising speech recognition, retrieval, prompting, and synthesis—is transferable to domains beyond history, such as healthcare training, cultural preservation, and corporate knowledge management. Additionally, creating historically grounded digital personas raises intellectual property considerations related to synthesized voices, digital likenesses, and curated corpora, connecting educational innovation with technology transfer and IP governance.

Related Work

AI-driven educational systems, including virtual tutors and conversational agents, enable dynamic, personalized learning and immediate feedback [1]–[4].

A. Conversational Agents and Digital Personas

Projects like SimSensei and New Dimensions in Testimony use AI avatars to simulate emotionally aware or historical interactions [2], [5], though often relying on firsthand recordings. Text-based approaches, such as Living Memories, generate digital representations from archival content [6]–[9].

B. Virtual Heritage and History Education

AI supports digital humanities by preserving historical narratives and enabling interactive learning [10]–[12]. Projects like REACH, Europeana, and Time Machine provide interactive timelines and story-driven modules [13]–[15]. LLMbased tutoring shows potential for higher-order reasoning and curriculum-specific contextualization [?], [16]–[20].

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C. Retrieval-Augmented Generation and Knowledge Grounding

RAG frameworks embed queries and source texts in a shared vector space to ground LLM responses in factual knowledge, reducing hallucination and maintaining style [21]–[26].

D. Gap in the Literature

Few studies integrate RAG, persona simulation, and interactive dialogue for ancient history. Most digital heritage work focuses on static visualization or archives [27]. Our approach uniquely combines semantically indexed historical texts, realtime voice synthesis, and prompt engineering to create an interactive, educational experience with a Roman scholar.

Methodology

A. Overview

The system enables immersive, historically grounded conversations with Pliny the Elder using four modules: Automatic Speech Recognition (ASR), Retrieval-Augmented Generation (RAG), Prompt-Conditioned Language Model, and Text-to-Speech (TTS) synthesis (Figure 1).

B. Data Collection and Preprocessing

Naturalis Historia [28] served as the primary knowledge source. Chapters were treated as atomic documents, cleaned, segmented, embedded with Sentence-BERT [29], and indexed in a FAISS vector database [30] for retrieval.

C. System Architecture

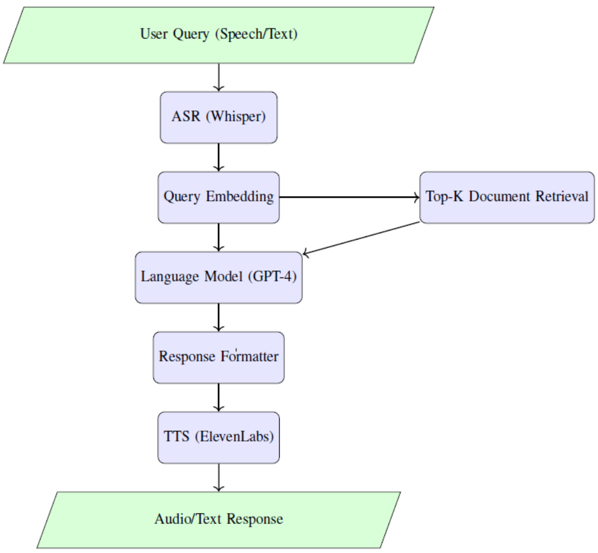

Figure 1. System architecture for Pliny the Elder simulation.

D. Persona Simulation Approaches

(1) Fine-Tuning: Supervised training on Q-A pairs from Naturalis Historia using cross-entropy loss, achieving tonal alignment but limited factual generalization.

(2) RAG: Integrates document retrieval into generation, grounding responses in top-k passages to reduce hallucination:

Context = TopK (sim(Embed(q),Embed(di)))

(3) Prompt Engineering: Few-shot examples and stylistic meta-instructions capture Pliny's tone but may struggle with complex queries.

E. Hybrid Strategy

Combining RAG + Prompting ensures factual accuracy via retrieval and stylistic authenticity via prompt templates [25]. Table I compares methods.

Table 1: Persona Simulation Methods Comparison

Method	Factual Accuracy	Stylistic Match	Flexibility
Fine-tuning	Medium	High	Low
Prompting	Low	High	High
RAG	High	Medium	High
RAG + Prompting	High	High	High

F. Illustrative Dialogue

Table 2: Sample Interaction with AI Pliny

User	What are the main uses of sand in construction?
Pliny (AI)	Sand mixed with lime strengthens mortar; river and sea sand require one-third lime, fossil sand one-fourth. Ground pottery fragments further reinforce structures, as observed in Rome.

Evaluation

A. Automated Evaluation

Using 200 in-domain and 100 out-of-scope questions [31], results were:

- In-domain accuracy: 194/200 (97%)
- Out-of-domain: 100% correctly declined

Table 3: Error Types in In-Domain Responses

Error Type	Count
Incorrectly Declared Unavailable	4
Misinformation from Same Chapter	2

B. Human Evaluation (Proposed)

Learning Efficacy: Pre- and post-tests comparing control (text) vs. test (AI dialogue) groups.
Engagement: Post-session Likert survey (1–5) on engagement, comprehension, and usability.
Stylistic Fidelity: Participants compare AI-generated vs. original excerpts on tone, language, and historical alignment.

C. Ethical Considerations

All synthetic content is clearly marked as artificial. The model supplements, but does not replace, scholarly sources.

Results and Discussion

A. In-Scope Knowledge Accuracy

The system correctly answered 194 of 200 in-domain questions from Naturalis Historia (97% accuracy), with errors limited to missed context (4) or minor factual inaccuracies (2) (Table IV). All 100 out-of-scope questions were correctly declined, demonstrating effective knowledge confinement.

Table 4: In-Scope Accuracy Evaluation

Result Type	Count	Percentage
Correct Responses	194	97%
Missed Context	4	2%
Misinformation	2	1%

B. Tone and Style

Generated responses maintained factual fidelity but used simplified modern English rather than Pliny's complex Roman sentence structures. This trade-off improved readability and engagement, although it slightly reduced stylistic authenticity.

C. System Responsiveness

Average response latency across 50 interactions was under 2.1 seconds, confirming near real-time performance suitable for interactive educational settings.

D. Insights and Implications

Accuracy vs. Style: High factual precision was balanced with simplified language for user comprehension. Informal testing suggested this trade-off enhanced engagement.

RAG Effectiveness: Retrieval-augmented generation reliably grounded responses in source texts and prevented hallucinations, preserving temporal and historical integrity.

Educational Potential: AI-driven historical personas can transform learning from passive text consumption to active, dialogic exploration, offering immersive experiences with figures like Pliny.

Limitations: Fine-grained control over rhetorical style, humor, and philosophical nuance remains limited. Formal human evaluations and broader demographic testing are planned for future work.

Conclusion

This work presents a framework for AI-powered historical personas using RAG, prompt engineering, and speech synthesis. The system successfully reconstructs Pliny the Elder's knowledge and voice, achieving 97% accuracy for in-domain queries and perfect rejection of out-of-scope questions, with sub-2.1s response latency.

By combining semantically indexed texts, context-aware language modeling, and voice synthesis, the approach ensures factual, temporally consistent, and stylistically guided interactions.

While modernized syntax slightly reduces historical authenticity, it enhances readability and learner engagement. Overall, the framework demonstrates the feasibility of immersive, interactive historical learning, opening avenues for AI-driven education in digital humanities, museums, and cultural heritage platforms. Future work will refine stylistic fidelity, extend to other historical figures, and incorporate comprehensive human-subject evaluations.

Future Work

While the current implementation successfully demonstrates the feasibility of recreating historically grounded conversational agents, there are several promising directions for future research and system development.

A. Expansion to Multiple Historical Figures

One of the most immediate opportunities lies in extending the system to support multiple historical personas. Expanding beyond Pliny the Elder to include figures such as Socrates, Cleopatra, Leonardo da Vinci, or Confucius would allow users to explore diverse viewpoints across different eras and civilizations. This would require the creation of distinct RAG pipelines, vector databases, and persona-specific prompt templates for each character. A central challenge in this expansion would be ensuring that each virtual figure maintains not only factual accuracy but also individual linguistic style, philosophical perspective, and cultural context.

B. Cross-Cultural and Multilingual Support

Another avenue of future work involves supporting interactions in multiple languages. For example, recreating conversations with Pliny in Latin, alongside translations in English, could enhance authenticity and facilitate language learning. This would necessitate incorporating multilingual language models and translating source corpora while preserving semantic integrity. Moreover, cultural nuance in translation and tone must be carefully handled to maintain the integrity of the historical persona.

C. Fine-Grained Stylistic Modeling

While current prompt engineering techniques allow for general stylistic tuning, more sophisticated methods could be developed to capture specific rhetorical patterns, humor, dialect, and tone unique to each persona. This could include training specialized adapters or using reinforcement learning from human feedback (RLHF) to better align generated outputs with ancient writing styles. Additionally, integrating large-scale corpora of classical literature could further improve stylistic realism.

D. Human Evaluation at Scale

A critical limitation of the present work is the lack of largescale user studies. Future work will involve conducting controlled experiments with learners across different educational levels, ranging from middle school to university. These studies will assess learning outcomes, engagement metrics, usability, and overall educational impact. In particular, comparisons between AI-based interaction and traditional textbook-based learning will provide quantitative insight into the system's pedagogical effectiveness.

E. Ethical Safeguards and Historical Fidelity

As the system is extended to simulate more figures, ensuring historical fidelity and ethical integrity becomes paramount. Mechanisms must be implemented to detect and prevent anachronistic statements, hallucinations, or culturally insensitive outputs. Additionally, the interface should clearly indicate that the persona is AI-generated and that any information provided should be cross-verified with scholarly resources when used for academic purposes.

F. Educational Integration and Deployment

Future work also includes integrating this system into learning management platforms, museum kiosks, and virtual reality environments. Instructors could use the AI personas to create curriculum-aligned conversations or simulate debates between historical figures. Moreover, real-time analytics could be used to monitor learner progress, adapt responses based on user history, and personalize educational journeys.

G. Model Optimization and Scalability

To support broader adoption, performance optimization will be necessary. Reducing latency while preserving response quality is crucial for scalability, especially in bandwidthconstrained environments. Research into model distillation, edge deployment of smaller LLMs, or serverless architectures could help bring such conversational agents to under-resourced regions and classrooms globally.

H. Simulation of Historical Ecosystems

In the long term, the framework could evolve into simulating entire historical ecosystems rather than individual personas. This would allow users to engage in conversations with multiple figures across time, participate in historical reenactments, or explore socio-political dynamics through AI-driven discourse. Such simulations could bring unparalleled depth to history education by enabling experiential, narrative-based exploration of the past.

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Trends in Brain-Computer Interface Technologies: Patent Analysis

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Abstract

Brain-Computer Interface (BCI) technologies are expanding rapidly across medical and commercial domains, yet little is known about their global innovation dynamics. This paper addresses this gap through a patent analysis of BCI-related filings in the World Intellectual Property Organisation (WIPO) Patentscope database from 1993 to mid-2025. The study examines filing and publication trends, geographical distribution, applicant types, and International Patent Classification (IPC) categories, supported by regression modelling. Results show 270 identified patents, with the United States and China leading (36% of filings). Nearly half were filed by individual inventors, reflecting vigorous entrepreneurial activity. The dominant technological areas are A61B (diagnostic and therapeutic instruments) and G06F (computing), confirming the convergence of biomedical and computational innovation. Projections suggest steady but modest growth through 2040. The paper presents one of the first longitudinal analyses of BCI patents, providing insights into technological progress, key actors, and application areas relevant to researchers, policymakers, and industry.

Keywords

Brain-Computer Interface (BCI), Neurotechnology, Patent analysis, WIPO, Innovation trends

1 Introduction

BCI technology establishes a direct communication pathway between neural activity and external devices, enabling the control of both hardware and software through brain signals. Initially conceived for medical purposes, such as supporting patients with paralysis or sensory impairments, BCIs are now rapidly expanding into domains including gaming, autonomous driving, mobile technology, and wellness [2, 5, 6]. This shift reflects the broader transformation of neurotechnology, which has moved from narrowly defined clinical applications to a multidisciplinary field with profound social, educational, and commercial implications [8, 15].

The innovative character of BCI lies in bridging neuroscience, engineering, and artificial intelligence (AI) while redefining human–machine interaction. BCIs enable the translation of neural activity into commands without physical movement, thereby creating opportunities for communication, rehabilitation, and human augmentation [1, 11]. Advances in neuroadaptive systems extend this potential by allowing technology to dynamically adapt to the user's mental state [3]. Beyond practical applications, creative experiments such as multi-brain cinema performances [18] highlight the cultural and artistic significance of BCIs.

Patent activity both reflects and accelerates these transformations. Authors [10] stress the importance of reliable signal processing, while others [14] underline the translation of neurotechnologies into everyday use. At the same time, ethical and regulatory challenges [5] emphasise the need for balanced progress.

This research was undertaken to address the lack of systematic evidence on how global BCI innovation is evolving, which actors are leading the development, and which technological areas are currently dominating. Patent analysis provides a suitable method, as patents are not only legal instruments but also early indicators of technological trends and commercialisation potential [9]. The added value of this article lies in offering one of the first comprehensive global overviews of BCI-related patents, mapping innovation pathways, and identifying key actors and applications. In doing so, it contributes to a deeper understanding of how BCIs are reshaping human–machine integration and informs the responsible development of these technologies.

2 BCI: Innovations Shaping the New Reality

With growing convergence between neuroscience, AI, and information technologies, neurotechnology has emerged as a central field of interdisciplinary research. Neurotechnology encompasses medicine, engineering, psychology, and computer science, enabling deeper connections between human cognition and technology [14].

Historically, neurotechnology was primarily associated with medicine. Today, however, it extends far beyond healthcare to include applications in education, workplace

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Information Society 2025, 6–10 October 2025, Ljubljana, Slovenia

productivity, gaming, sports, and everyday life [8, 15]. At the core of these developments are BCIs, which translate brain activity into commands without physical movement [1, 11].

BCIs are classified into two broad categories: non-invasive (wearable) and invasive (implanted). Non-invasive BCIs typically utilise EEG to monitor cortical activity, enabling real-time feedback and control of external devices [8]. Invasive BCIs, on the other hand, require surgical implantation to restore sensory or motor functions, particularly in patients with paralysis or amputations [4]. The civilian and military applications of BCI are wide-ranging, from communication and neurorehabilitation to drone control and stress monitoring [6].

The market outlook is promising. The global neurotechnology market is projected to reach $52.86 billion by 2034, with the BCI segment expected to grow to $6.2 billion by 2030 [7]. This growth highlights the importance of monitoring patent activity to identify the most significant areas of innovation.

3 Methodology

This research applies a patent analysis approach to examine innovation trends in BCI technologies. Patent data was retrieved from the World Intellectual Property Organisation (WIPO) Patentscope database, using advanced search filters, which covers filings across 193 member states, including international applications submitted under the Patent Cooperation Treaty (PCT) [16]. The WIPO database was selected because of its comprehensive and standardised global coverage, which enables comparative analysis across countries, institutions, and technological fields.

The dataset was collected on July 5, 2025, covering published patents filed between 1993 and mid-2025. Due to the confidentiality regulations stipulated by WIPO, patent applications remain undisclosed for 18 months after the filing date [9]. For this reason, applications filed in 2024 and 2025 are incomplete and were excluded from the analysis, as reliable conclusions about their content and trends cannot yet be drawn.

The search strategy was based on a combination of keywords, including BCI and "Brain-Machine Interface (BMI)." Although the keyword "BMI" was initially considered, it was excluded due to the high incidence of irrelevant matches, including terms such as Body Mass Index, Bio-renewable Carbon Index, and unrelated protein or networking concepts. Authors [12] highlight that such inconsistencies are typical when applying keyword-based searches across interdisciplinary fields, particularly when terminology overlaps across domains. To mitigate this, search results were carefully reviewed, though it is acknowledged that some relevant patents may have been inadvertently excluded or unrelated ones included.

The retrieved data were analysed by examining patent offices to map the geographical distribution of innovation, publication, and filing dates, tracking temporal trends. This analysis also included applicants, such as companies, universities, research institutes, individuals, and foundations, as well as technological classifications based on the IPC and CPC systems.

Patent classifications were particularly relevant for this study, as they indicate the technological areas in which innovation occurs. Since BCI research spans multiple scientific disciplines, including engineering, computer science, biology, and medicine, patents were often assigned to various IPC categories. That reflects the interdisciplinary character of BCI and its potential applications across healthcare, rehabilitation, human–computer interaction, and neuroadaptive technologies.

To identify long-term innovation patterns, both descriptive and inferential analyses were applied. Temporal patterns were examined using linear regression, with regression models estimating expected patent activity up to 2040. For instance, based on the regression equation ($y = 0.8203x - 1640.1$), projections suggest 25 BCI-related patents by 2030, 29 by 2035, and 33 by 2040. While these projections are indicative rather than definitive, they provide insight into the trajectory of technological growth.

The methodology builds on the understanding that patent data is not only a legal instrument for intellectual property protection but also a strategic resource for innovation analysis [9]. By systematically analysing patents, it is possible to trace the commercialisation potential of BCIs, monitor technological competition, and identify emerging areas of application. This approach complements existing literature on neurotechnology, which emphasises the translation of laboratory research into market-ready applications [14].

Several methodological limitations must be acknowledged. First, keyword-based searches cannot fully resolve issues of terminology, translation, or incomplete metadata [12]. Second, the exclusion of recent patents due to confidentiality rules creates a temporary data gap, which is unavoidable but limits conclusions about the very latest developments. Finally, patent activity does not necessarily equate to successful commercialisation, as many filings never result in market-ready products. Nonetheless, patents remain one of the most reliable indicators of early-stage innovation and competitive technological development.

4 Patent Analysis

4.1 Patents by PCT Offices

The search resulted in 270 BCI-related patent applications filed between 1993 and July 2025. These were examined along four main dimensions: PCT jurisdictions, publication and filing dates, applicants, and IPC classifications. Together, these categories provide a comprehensive picture of the state of innovation in BCI technologies and the trends shaping their evolution.

Patent Cooperation Treaty (PCT) filings reflect the global spread of innovation. The analysis indicates that the United States leads with 59 patents (22%), followed by China with 37 patents (14%). The European Patent Office, the Republic of Korea, and Canada each account for 7%, while India and Australia hold more minor but significant shares. Collectively, the United States and China account for 36% of global BCI patents, underscoring their dominant positions in neurotechnology innovation.

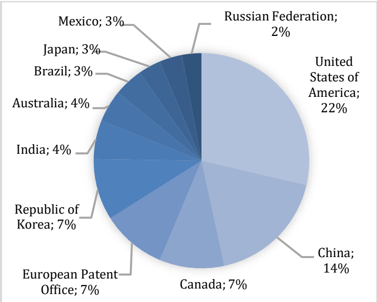

Figure 1: Patents by PCT offices (1993–2025)

These results align with broader innovation trends, where North America and East Asia remain central hubs of high-technology research. Notably, the diversity of contributing countries—including Brazil, Japan, Mexico, and the Russian Federation—demonstrates that BCI is not geographically confined but increasingly globalised [17].

4.2 Patents by Publication and Filing Dates

Figures 2 and 3 illustrate the temporal distribution of patents. The earliest patents appeared in the mid-1990s, but growth remained limited until 2008, when filings rose significantly, coinciding with broader advances in neuroscience and computing. Additional peaks occurred in 2019, 2021, and 2023, reflecting periods of intensified investment and technological breakthroughs.

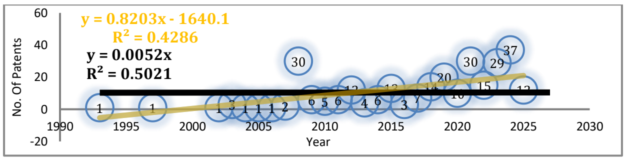

Figure 2: Number of patents by publication date (1993–2025)

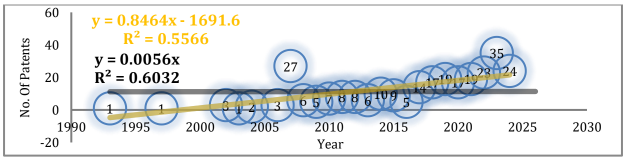

Figure 3: Number of patents by filing date (1993–2025)

Between 1993 and 2023, the annual growth rate of published patents averaged 12%, with an overall mean of 9.2 patents per year. Regression analysis ($R^2 = 0.4286$) reveals a moderate correlation between time and patent volume, indicating that external factors (including economic conditions, regulatory frameworks, and research funding) play a significant role in shaping innovation activity. This interpretation is consistent with literature on neurotechnology, which emphasises the impact of cross-disciplinary developments and funding dynamics [11, 13].

Based on the regression model ($y = 0.8203x - 1640.1$), patent activity is projected to continue rising modestly, with 25 patents expected by 2030, 29 by 2035, and 33 by 2040. These estimates highlight steady growth but also indicate that disruptive innovation cycles, rather than linear trends, may drive the field forward.

4.3 Patents by Applicants

Analysis of applicants shows that individual inventors play a disproportionately large role, representing 47% of all applicants and 61% of total patents (Table 1). That demonstrates the entrepreneurial and experimental character of BCI research, where small-scale innovators complement the efforts of companies and universities.

Companies account for 10 applicants with 61 patents, while universities contributed 39 patents from 11 applicants. Research institutes and foundations play minor roles but provide essential contributions to knowledge development. The distributed nature of patent activity suggests that a few large corporations do not monopolise BCI innovation but are instead characterised by pluralism and diversity of approaches.

Table 1: Patent applicants and number of patents (1993–2025)

Applicants	Total	No. of Patents
Company	10	61
Foundation	1	3
Research institutes	4	17
Individuals	23	186
University	11	39

4.4 Patents by IPC Classification

The International Patent Classification (IPC) system reveals which technological areas dominate BCI innovation. The most prevalent category is A61B (Diagnostic and Therapeutic Instruments), comprising 123 patents, and includes biomedical devices for brain signal processing, neurofeedback, rehabilitation, and the neural control of prosthetics.

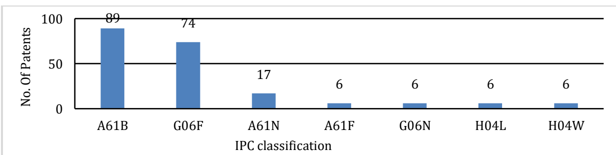

Figure 4: Number of published patents by IPC classification (1993–2025)

G06F (Computing/Calculation) accounts for 112 patents, reflecting the importance of software, signal processing, and human–computer interaction. Additional relevant categories include A61N (Electrotherapy, 29 patents), A61F (Medical devices, 29 patents), and G06N (Biological computing systems, 24 patents). Together, these highlight the interdisciplinary character of BCI technologies, which integrate hardware, software, and medical science [10].

Prominent companies include Neuralink, NeuroSky Inc., Neurable Inc., MindMaze SA, Precision Neuroscience, and MindPortal Inc. Their focus areas range from wearable EEG-based BCIs and neuroadaptive technologies to invasive implants and neuroprosthetics. Among individual innovators, Vijay VAD, Christoph Gugger, Günter Edlinger, Jose L. Contreras-Vidal, and Rodolfo Llinás have made notable contributions.

Figure 5: Word cloud based on BCI patent titles (1993–2025)

5 Conclusion

This study addresses a gap in the literature by examining BCI patents to map global innovation dynamics, an aspect that has been less explored compared to clinical or technical studies. The analysis shows rapid and diverse progress, led by the United States and China, with notable contributions from Europe, Korea, Canada, and India. Nearly half of all applicants are individual inventors, highlighting a broad, entrepreneurial ecosystem rather than dominance by large corporations. Patent classifications confirm the expansion of BCIs beyond medicine into education, entertainment, neurorehabilitation, and workplace productivity [3, 14], underlining their role both as assistive technologies and as tools for human augmentation.

Patent activity reflects funding cycles, regulatory changes, and disruptive advances, while the Geneva Academy [5] stresses that ethical and human rights considerations must guide development. Although patent data do not fully capture commercialisation, they remain a valuable tool for tracing innovation, anticipating applications, and assessing leadership. A logical next step is to complement patent analysis with evidence from clinical trials, investment flows, and governance studies, to track how AI-neuroscience convergence accelerates BCI integration into everyday life while ensuring responsible innovation.

6 Acknowledgments

The authors are deeply grateful to the PhD. Ana Hafner for her invaluable guidance, encouragement, and support.

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