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Interconnected Worlds: Human-AI Collaboration in International Technology Transfer for Industry 5.0

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A B S T R A C T

In the contemporary era marked by rapid technological advancements and intense competition across global markets, successful technology transfer has emerged as a strategic imperative for organizations. With the advent of the Industry 5.0 era, integrating cutting-edge artificial intelligence (AI) with human expertise and creativity unlocks new avenues for innovation and value creation. However, international technology transfer is fraught with numerous challenges, including cultural disparities, varying legal and regulatory frameworks, as well as technical and organizational complexities. This research endeavors to present an integrated model to facilitate seamless technology transfer within the Industry 5.0 framework, taking into account both human and technological factors. The research adopted a qualitative approach to data collection through the meta-synthesis method, encompassing a comprehensive review of the literature, analysis, and synthesis of existing findings. The validity of the research was affirmed based on established criteria, holding meetings with the research team members, leveraging expert insights, and conducting a thorough auditing process to achieve theoretical consensus, while its reliability was determined through the critical appraisal skills program. The findings identified 118 indicators and 31 components across 7 main dimensions: AI capabilities, human expertise, technology transfer processes, organizational factors, socio-cultural context, collaborative dynamics, and performance and impact. Based on these findings, it is proposed that organizations prioritize integrating AI and human expertise, fostering constructive interactions, developing an understanding of cultural contexts, nurturing an innovation-supportive environment, and embracing continuous learning to achieve successful technology transfer. Furthermore, continuous evaluation of the performance and impact of technology transfer is imperative for process optimization.

Keywords: *Human-AI Collaboration, International Technology Transfer, Human-Centered Approach*

1. Introduction

Industry 5.0 is an emerging concept that aims to address the challenges raised by the fourth industrial revolution and its focus is solely on technology advancement at the cost of human factors and environmental/social values (Irpan & Shaddiq, 2024). Unlike previous industrial revolutions that replaced human labor with machinery,

Industry 5.0 promotes synergy between new technologies like AI, the Internet of Things (IoT), robotics, and human capabilities like creativity, critical thinking, and problem-solving (Granata et al., 2024; Olsson et al., 2024). Humans and machines are viewed as complementary partners rather than rivals in this new industrial paradigm.

A key distinction of Industry 5.0 is its emphasis on human-centricity and the indispensable role of the workforce alongside advanced technologies. While machines powered by AI can automate repetitive computational tasks with high efficiency, creative, innovative, and value-adding activities remain the exclusive domain of humans (Pinto et al., 2024). Striking the right balance by integrating human factors like teamwork, communication, and decision-making with technologies like AI and robotics is crucial for realizing the full potential of Industry 5.0. This requires a strategic approach toward empowering the workforce through comprehensive technical training programs, enhancing digital literacy across all levels, and developing cognitive skills like adaptability, critical thinking, and problem-solving (Rožanec et al., 2023).

AI is undoubtedly one of the core driving technologies in Industry 5.0, enabling intelligent automation, large-scale data analysis, process optimization, and the development of new applications across diverse sectors like manufacturing, services, healthcare, and education (Leng et al., 2024). However, several challenges like cybersecurity risks, ethical concerns surrounding AI decision-making, the development of a specialized AI workforce, and legal issues related to accountability need to be addressed to successfully adopt and integrate AI systems (Ozmen Garibay et al., 2023).

In today's world of rapid technological advancements, the transfer of technology from one country, organization, or company to another plays a crucial and determining role in their development and progress (Siegel et al., 2023). Access to the latest scientific achievements and advanced technologies leads to increased productivity, enhanced competitive ability in global markets, and ultimately, economic growth and prosperity at national and international levels (Ravi & Janodia, 2022). Therefore, effective technology transfer mechanisms can help narrow the technological gap between developed and developing countries and regions, paving the way for a more level playing field for all (Simms & Frishammar, 2024).

International technology transfer is a vital process for achieving and sustaining competitiveness by providing access to advanced technologies, facilitating knowledge exchange, and bridging capability gaps between developed and developing nations (Ravi & Janodia, 2022). It can occur through various channels and modes like machinery and equipment purchases, licensing agreements, joint ventures, consultancy services, and human resource exchange programs. However, systematic planning considering technical, financial, legal, and cultural factors is key for ensuring an effective and successful technology transfer process (Simms & Frishammar, 2024).

With the emergence of the Industry 5.0 paradigm, traditional methods and technology transfer models have undergone a fundamental transformation (Olsson et al., 2024). The technology transfer process must evolve to incorporate and facilitate the seamless integration of cutting-edge and revolutionary technologies like AI, IoT, biotechnologies, and robotics with human capabilities, skills, and the central role of the human workforce (Leon-Roa et al., 2024). This requires a comprehensive framework that accounts for both the technical aspects of advanced technology adoption as well as the human and organizational factors necessary for effective implementation and use.

In the context of Industry 5.0, technology transfer models need to integrate human aspects like motivation, creativity, organizational culture, and behavior alongside technical frameworks for AI adoption, risk management, and strategic development (Jin et al., 2021; Pinto et al., 2024). The importance of examining technology transfer within this integrated Industry 5.0 framework is noteworthy from several perspectives (Sharabati et al., 2023). From a technical standpoint, the integration of AI and other advanced technologies in production and service processes will significantly enhance efficiency, productivity, and process optimization (Leng et al., 2024). However, leveraging unique human capabilities such as creativity, critical thinking, and problem-solving will ensure that these technologies are also considered from an ethical and social perspective, meeting the real needs of humans and society (Pinto et al., 2024).

However, there is a significant research gap in the field of international technology transfer within the integrated Industry 5.0 framework that combines advanced technologies like AI with human factors. Although numerous studies have been conducted on technology transfer mechanisms, the importance of AI adoption, and the role of human factors in production processes (Passalacqua et al., 2024), a comprehensive and integrated

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model that considers all these elements together has received less attention in academic literature.

The present research aims to bridge this gap and provide a comprehensive framework for international technology transfer in the era of Industry 5.0. By integrating the key aspects of AI adoption and human factors, this research seeks to present an integrated model that can serve as a practical guide for organizations and countries in planning and executing successful technology transfer initiatives. The novelty of this research lies in the fact that, unlike previous studies that focused solely on technology transfer mechanisms, the application of AI, or the role of human factors in isolation, this integrated model examines all these elements together in a holistic manner. This comprehensive approach can provide a new perspective on how to optimally combine advanced technologies like AI with human capabilities for the successful international transfer of technologies.

The main objective of the present research is to design an applied framework for leveraging the advantages of AI technologies and unique human capabilities for the optimal transfer of new technologies in the international arena. The results and insights derived from this study can be immensely useful for countries, organizations, and industries that intend to either transfer or receive cutting-edge technologies within the overarching framework of Industry 5.0 and its core principles.

To achieve its stated objectives, this research will propose a conceptual model after conducting a comprehensive review of existing literature and research background on technology transfer, AI applications, human factors in Industry 5.0, and their intersections. This conceptual model will encompass and synthesize the key factors influencing international technology transfer processes, the role and impact of AI integration, as well as the crucial human factors that need to be considered. In this regard, the main research question that will guide the study is: "How should an integrated framework for international technology transfer in the era of Industry 5.0, combining the functions of AI and human factors, be designed to assist countries and organizations in successfully transferring technology?"

2. Methods and Materials

This study is applied in terms of its objective and utilizes a systematic review methodology for collecting research data. The data analysis follows the meta-synthesis method (Sandelowski & Barroso, 2007). This method consists of seven stages: formulating research questions and objectives, systematically reviewing the literature, searching and selecting relevant articles, extracting information and results from articles, analyzing and synthesizing qualitative findings, quality control, and finally presenting the findings. In this research, a systematic search was conducted in the titles, abstracts, and keywords of published articles using the terms technology, technology transfer, international technology transfer, artificial intelligence, AI, human-centric, human-oriented, human-machine, and Industry 5.0. The selection of relevant articles and determination of the time range was based on the main objectives and issues of the research.

The inclusion criteria for the research were English qualitative articles related to the research question that was published in reputable publishers such as Elsevier, Wiley, Springer, Taylor and Francis, and Emerald over the past decade between 2017 and 2024, and were indexed in ISI-WOS, ISI-Listed, or Scopus. This time range was chosen because the term Industry 5.0 was first introduced in 2017 at the CeBIT trade fair in Hanover, Germany, by Japan when they announced their vision for the future of industrial automation, robotics, and smart manufacturing, which they termed Industry 5.0.

Through systematic searching across reputable publishers such as Elsevier, Wiley, Springer, Taylor and Francis, and Emerald, 203 articles were initially identified. After applying the inclusion criteria, 171 articles were excluded, leaving 32 relevant articles for analysis. The process of selecting the final articles is shown in Figure 1.

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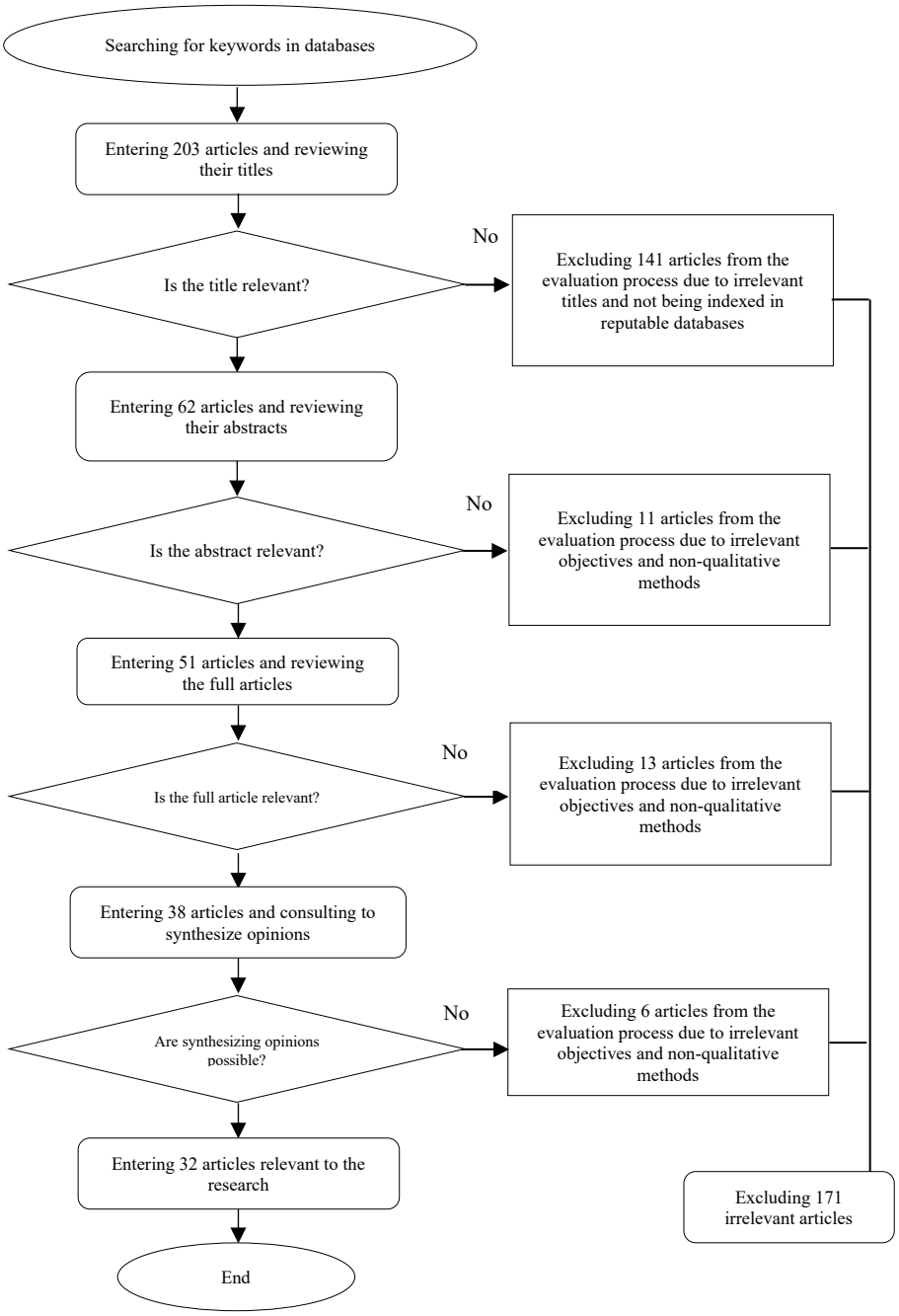
Figure 1

Algorithm for Selecting Final Articles (Sandelowski & Barroso, 2007)



For data analysis, we employed a qualitative content analysis approach. This involved coding and categorizing the extracted data from the selected articles to identify common themes, patterns, and insights related to human-AI collaboration in international technology transfer for Industry 5.0. The analysis process was iterative, involving constant comparison and refinement of codes and categories until theoretical saturation was reached.

The validity of this research has been confirmed using the Sandelowski and Barroso (2007) method (Sandelowski & Barroso, 2007). To increase descriptive validity, inclusion criteria were used. This involved holding weekly meetings to report on article searches and using the EndNote software to store and review articles. To increase interpretive validity, weekly meetings were held to evaluate team member reports. Additionally, an expert in the field of research was consulted to increase practical validity. The

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reliability of the research was also evaluated by the team members and experts using the Critical Appraisal Skills Program (2018). This evaluation consists of 10 questions addressing various aspects of the articles (including clarity of research objectives, logic of methodology, suitability of design to achieve objectives, suitability of sampling method, suitability of data collection method, quality of researcher-participant relationship, quality of ethical considerations, accuracy of data analysis, clear presentation of findings, and value of the research), to assess the quality, accuracy, validity, and importance of the final articles.

Following the comparative appraisals method (Sandelowski & Barroso, 2007), the final articles were evaluated based on multiple parameters, such as author characteristics, year of publication, title, objective, analysis method, and findings. Additionally, using the Critical Appraisal Skills Program (2018), the quality of the articles was evaluated and scored.

3. Findings and Results

To address the main research question, a taxonomic analysis approach has been utilized. In this method, expressions related to international technology transfer in the era of Industry 5.0 with the integration of AI and human factors were initially extracted as initial codes. Then, using the initial codes, concepts reflecting the existing patterns in the findings were identified through open coding. These concepts were further categorized into subcategories and main categories through axial coding. Table 1 shows the open and axial coding of the extracted data along with their sources.

Table 1

Open and Axial Coding of Key Factors Extracted from Literature Review on International Technology Transfer in Industry 5.0 Era, Integrating AI and Human Factors

Main Dimensions	Components	Indicators	Reference
Human Expertise	Knowledge and Skills	Depth of domain-specific knowledge	(Cunha et al., 2022; Pizoń & Gola, 2023; Rožanec et al., 2023)
		Breadth of technical proficiency	(Alves et al., 2023; Leng et al., 2024; Zhang et al., 2023)
		Ability to apply theoretical knowledge to practically	(Granata et al., 2024; Rauch et al., 2020; Stern & Freitag, 2022)
		Continuous learning and skill development	(Carayannis & Morawska, 2023; Cunha et al., 2022; Piller & Nitsch, 2022)
		Depth of expertise in emerging Industry 5.0 technologies	(Leng et al., 2024; Mourtzis et al., 2022; Zhang et al., 2023)
		Proficiency in advanced software tools for technology transfer	(Abrash, 2021; Ozmen Garibay et al., 2023; Passalacqua et al., 2024)
	Experience	Years of experience in technology transfer	(Hirsch-Kreinsen, 2023; Leng et al., 2024; Stern & Freitag, 2022)
		Exposure to diverse cultural contexts	(Calp & Bütüner, 2022; Murphy et al., 2023; Piller & Nitsch, 2022)
		Success stories and lessons learned	(Ciccarelli et al., 2023; Granata et al., 2024; Wang et al., 2022)
		Track record of successful technology transfer projects across diverse industries and geographical regions	(Hirsch-Kreinsen, 2023; Leng et al., 2024; Stern & Freitag, 2022)
		Exposure to various stages of the technology transfer lifecycle, from ideation to commercialization	(Granata et al., 2024; Wang et al., 2024)
	Problem-solving Abilities	Ability to identify and address complex challenges	(Bocklisch & Huchler, 2023; Ozmen Garibay et al., 2023; Ren et al., 2023)
		Creativity and innovation in problem-solving	(Carayannis et al., 2023; Piller & Nitsch, 2022; Zizic et al., 2022)
		Resilience in overcoming obstacles	(Murphy et al., 2023; Pizoń & Gola, 2023; Rauch et al., 2020)
	Communication Skills	Clarity and effectiveness in conveying ideas	(Abrash, 2021; Berretta et al., 2023; Ozmen Garibay et al., 2023)
		Active listening and empathy	(Berretta et al., 2023; Brückner et al., 2023; Lee et al., 2022)
		Language proficiency and cultural sensitivity	(Calp & Bütüner, 2022; Murphy et al., 2023; Piller & Nitsch, 2022)
	Adaptability	Flexibility in response to changing circumstances	(Leng et al., 2024; Ren et al., 2023; Wang et al., 2022)
		Willingness to learn and embrace new technologies	(Carayannis & Morawska, 2023; Piller

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			& Nitsch, 2022; Zizic et al., 2022)
		Ability to work effectively in diverse teams	(Brückner et al., 2023; Piller & Nitsch, 2022)
AI Capabilities	Algorithms and Models	Accuracy and precision of predictive models	(Alves et al., 2023; Leng et al., 2024; Zhang et al., 2023)
		Robustness and scalability of machine learning	(Leng et al., 2024; Ren et al., 2023; Wang et al., 2024)
		Interpretability and explainability of results	(Berretta et al., 2023; Ozmen Garibay et al., 2023)
	Automation and Autonomy	Degree of task automation and human intervention	(Leng et al., 2024; Ren et al., 2023; Wang et al., 2022)
		Autonomy in decision-making and problem-solving	(Bocklisch & Huchler, 2023; Leng et al., 2024; Ren et al., 2023)
		Adaptability to changing environments	(Leng et al., 2024; Ren et al., 2023; Wang et al., 2024)
		Degree of autonomy in decision-making processes without human intervention	(Bocklisch & Huchler, 2023; Leng et al., 2024; Zhang et al., 2023)
		Integration with IoT devices and sensors for real-time data processing and decision-making	(Leng et al., 2024; Passalacqua et al., 2024; Zhang et al., 2023)
	Data Processing Capabilities	Speed and efficiency of data processing	(Alves et al., 2023; Brückner et al., 2023; Pizoń & Gola, 2023)
		Handling of big data and real-time analytics	(Piller & Nitsch, 2022; Wang et al., 2022; Zizic et al., 2022)
		Integration with various data sources and formats	(Carayannis et al., 2023; Ozmen Garibay et al., 2023)
	Learning and Adaptation	Ability to learn from new data and experiences	(Granata et al., 2024; Hirsch-Kreinsen, 2023; Zhang et al., 2023)
		Incorporation of feedback for model improvement	(Murphy et al., 2023; Rauch et al., 2020; Stern & Freitag, 2022)
		Transfer learning and generalization capabilities	(Berretta et al., 2023; Bocklisch & Huchler, 2023; Mourtzis et al., 2022)
		Capacity to rapidly adapt to changes in market dynamics and technological advancements	(Abrash, 2021; Leng et al., 2024; Ren et al., 2023)
		Incorporation of feedback loops for continuous improvement and optimization of AI algorithms	(Calp & Bütüner, 2022; Passalacqua et al., 2024; Rožanec et al., 2023)
	Integration with Human Processes	Seamless integration with human workflows	(Cunha et al., 2022; Kazancoglu et al., 2023; Lee et al., 2022)
		Collaboration with human experts in decision-making	(Carayannis & Morawska, 2023; Ciccarelli et al., 2023; Ozmen Garibay et al., 2023)
		User-friendly interfaces and interaction designs	(Pizoń & Gola, 2023; Wang et al., 2024)
Collaborative Dynamics	Human-AI Interaction	Frequency and quality of communication	(Mourtzis et al., 2022; Piller & Nitsch, 2022)
		Trust and confidence in AI recommendations	(Granata et al., 2024; Ozmen Garibay et al., 2023; Stern & Freitag, 2022)
		Mutual understanding of roles and responsibilities	(Carayannis et al., 2023; Leng et al., 2024; Wang et al., 2022)
	Team Composition	Diversity of skills, backgrounds, and perspectives	(Carayannis et al., 2023; Ozmen Garibay et al., 2023; Zhang et al., 2023)
		Balance of technical and domain expertise	(Abrash, 2021; Ozmen Garibay et al., 2023; Passalacqua et al., 2024)
		Clear delineation of roles and responsibilities	(Granata et al., 2024; Wang et al., 2022)
		Diversity in perspectives and expertise within the technology transfer team, including interdisciplinary collaboration.	(Carayannis et al., 2023; Zhang et al., 2023)
		Balanced distribution of roles and responsibilities to leverage the strengths of each team member	(Hirsch-Kreinsen, 2023; Leng et al., 2024; Stern & Freitag, 2022)
	Communication Effectiveness	Openness and transparency in communication	(Granata et al., 2024; Mourtzis et al., 2022; Piller & Nitsch, 2022)
		Clarity of instructions and expectations	(Granata et al., 2024; Wang et al., 2022)
		Constructive feedback and conflict resolution	(Abrash, 2021; Ozmen Garibay et al., 2023; Passalacqua et al., 2024)
	Trust-building	Consistency and reliability of AI performance	(Leng et al., 2024; Ren et al., 2023)
		Transparency in decision-making processes	(Hirsch-Kreinsen, 2023; Leng et al., 2024; Stern & Freitag, 2022)
		Building rapport and establishing rapport	(Calp & Bütüner, 2022; Murphy et al.,

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			2023; Piller & Nitsch, 2022)
		Establishment of transparent communication channels to foster trust and confidence in AI recommendations	(Granata et al., 2024; Mourtzis et al., 2022; Piller & Nitsch, 2022)
		Consistent delivery of accurate and reliable results to build trust among stakeholders	(Abrash, 2021; Leng et al., 2024)
Technology Transfer Processes	Planning and Strategy	Clarity of objectives and priorities	(Brückner et al., 2023; Piller & Nitsch, 2022)
		Alignment with organizational goals	(Carayannis et al., 2023; Ozmen Garibay et al., 2023; Zhang et al., 2023)
		Risk assessment and mitigation strategies	(Ozmen Garibay et al., 2023; Zhang et al., 2023)
	Execution and Implementation	Timeliness and adherence to timelines	Carayannis et al. (2023); Piller & Nitsch (2022); Zhang et al. (2023)
		Resource utilization and optimization	(Leng et al., 2024; Piller & Nitsch, 2022; Wang et al., 2022)
		Monitoring progress and addressing deviations	(Piller & Nitsch, 2022; Wang et al., 2022)
	Knowledge Acquisition and Adaptation	Identification of relevant knowledge sources	(Mourtzis et al., 2022; Ozmen Garibay et al., 2023)
		Adaptation of technology to local contexts	(Brückner et al., 2023; Leng et al., 2024; Piller & Nitsch, 2022)
		Documentation and sharing of best practices	(Lee et al., 2022; Wang et al., 2024; Zizic et al., 2022)
		Ability to identify and leverage emerging trends and technologies relevant to specific industry domains.	(Carayannis et al., 2023; Mourtzis et al., 2022)
		Adaptation of acquired knowledge to address cultural and regulatory differences across international markets	(Calp & Bütüner, 2022; Piller & Nitsch, 2022)
	Dissemination and Integration	Accessibility of knowledge and resources	(Abrash, 2021; Carayannis & Morawska, 2023)
		Integration with existing systems and processes	(Leng et al., 2024; Wang et al., 2022)
		Training and support for end-users	(Ciccarelli et al., 2023; Lee et al., 2022; Ren et al., 2023)
	Evaluation and Monitoring	Use of performance metrics and KPIs	(Abrash, 2021; Ozmen Garibay et al., 2023; Piller & Nitsch, 2022)
		Continuous improvement and feedback mechanisms	(Granata et al., 2024; Ozmen Garibay et al., 2023)
		Impact assessment and value realization	(Granata et al., 2024; Murphy et al., 2023)
Socio-Cultural Context	Cultural Diversity	Respect for cultural norms and values	(Calp & Bütüner, 2022; Piller & Nitsch, 2022)
		Cross-cultural communication and collaboration	(Berretta et al., 2023; Kazancoglu et al., 2023; Murphy et al., 2023)
		Recognition and celebration of diversity	(Berretta et al., 2023; Carayannis et al., 2023)
		Integration of cultural sensitivity training into technology transfer processes to bridge cultural gaps and foster inclusivity	(Berretta et al., 2023; Calp & Bütüner, 2022; Murphy et al., 2023)
		Promotion of cross-cultural exchange programs to enhance understanding and appreciation of diverse perspectives	(Berretta et al., 2023; Carayannis & Morawska, 2023; Kazancoglu et al., 2023)
	Regulatory Environment	Compliance with intellectual property regulations	(Abrash, 2021; Carayannis & Morawska, 2023; Ozmen Garibay et al., 2023)
		Adherence to data privacy and security standards	(Ozmen Garibay et al., 2023)
		Understanding of export control regulations	(Berretta et al., 2023; Calp & Bütüner, 2022; Carayannis et al., 2023)
	Language and Communication	Multilingual communication and translation	(Abrash, 2021; Passalacqua et al., 2024; Piller & Nitsch, 2022)
		Use of common terminology and standards	(Calp & Bütüner, 2022; Carayannis et al., 2023)
		Clear communication of technical concepts	(Abrash, 2021; Ciccarelli et al., 2023; Passalacqua et al., 2024)
	Ethical Considerations	Protection of privacy and confidentiality	(Abrash, 2021; Ozmen Garibay et al., 2023)
		Ethical use of AI technologies	(Ozmen Garibay et al., 2023; Ren et al., 2023)
		Fair and unbiased decision-making	(Ozmen Garibay et al., 2023; Ren et al., 2023; Stern & Freitag, 2022)
		Implementation of robust data privacy and security measures	(Abrash, 2021; Ozmen Garibay et al.,

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		to protect sensitive information during technology transfer activities	2023)
		Adherence to ethical guidelines and standards governing the responsible use of AI technologies in decision-making processes	(Ozmen Garibay et al., 2023; Ren et al., 2023; Wang et al., 2022)
Organizational Factors	Leadership and Governance	Visionary leadership and strategic direction	(Carayannis et al., 2023; Ren et al., 2023; Wang et al., 2024)
		Support for innovation and risk-taking	(Carayannis et al., 2023; Ciccarelli et al., 2023; Ozmen Garibay et al., 2023)
		Establishment of clear policies and procedures	(Berretta et al., 2023; Carayannis et al., 2023; Mourtzis et al., 2022)
	Organizational Culture	Promotion of collaboration and knowledge-sharing	(Berretta et al., 2023; Carayannis et al., 2023; Cunha et al., 2022)
		Emphasis on continuous learning and improvement	(Berretta et al., 2023; Carayannis et al., 2023; Cunha et al., 2022)
		Recognition and reward for innovation	(Carayannis et al., 2023; Ciccarelli et al., 2023)
		Cultivation of a culture of innovation that encourages experimentation, risk-taking, and continuous learning	(Carayannis et al., 2023; Cunha et al., 2022)
		Emphasis on collaboration, knowledge-sharing, and interdisciplinary teamwork to drive technological advancements	(Carayannis et al., 2023; Cunha et al., 2022)
	Resource Allocation	Allocation of financial and human resources	(Carayannis et al., 2023; Mourtzis et al., 2022; Wang et al., 2022)
		Prioritization of technology transfer initiatives	(Mourtzis et al., 2022; Wang et al., 2022)
		Flexibility in resource allocation	(Mourtzis et al., 2022; Wang et al., 2022)
		Strategic allocation of resources based on thorough risk assessment and prioritization of technology transfer initiatives	(Carayannis et al., 2023; Mourtzis et al., 2022)
		Flexibility in resource allocation to adapt to changing market conditions and stakeholder priorities	(Carayannis et al., 2023; Wang et al., 2022)
	Innovation Culture	Encouragement of experimentation and creativity	(Ciccarelli et al., 2023; Mourtzis et al., 2022)
		Tolerance for failure and learning from mistakes	(Berretta et al., 2023; Carayannis et al., 2023; Ciccarelli et al., 2023)
		Support for cross-functional collaboration	(Carayannis et al., 2023; Ciccarelli et al., 2023)
Performance and Impact	Effectiveness and Efficiency	Achievement of technology transfer objectives	(Berretta et al., 2023; Cunha et al., 2022)
		Cost-effectiveness and resource utilization	(Berretta et al., 2023; Carayannis et al., 2023; Ozmen Garibay et al., 2023)
		Time-to-market and speed of innovation	(Ciccarelli et al., 2023; Mourtzis et al., 2022)
	Innovation and Value Creation	Development of new products, services, or processes	(Carayannis et al., 2023; Ciccarelli et al., 2023)
		Creation of intellectual property and patents	(Carayannis et al., 2023; Ciccarelli et al., 2023)
		Generation of revenue and market impact	(Abrash, 2021; Carayannis et al., 2023)
	Customer Satisfaction	Satisfaction with product performance and quality	(Ciccarelli et al., 2023; Granata et al., 2024)
		Responsiveness to customer needs and feedback	(Abrash, 2021; Ciccarelli et al., 2023)
		Loyalty and retention of customers	(Carayannis et al., 2023; Ciccarelli et al., 2023)
		Measurement of customer satisfaction through surveys, feedback mechanisms, and net promoter scores.	(Abrash, 2021; Carayannis et al., 2023)
		Responsiveness to customer needs and preferences, with a focus on delivering value-added solutions and services	(Abrash, 2021; Carayannis & Morawska, 2023; Ciccarelli et al., 2023)
	Return on Investment	Financial returns on technology transfer projects	(Abrash, 2021; Carayannis & Morawska, 2023; Ciccarelli et al., 2023)
		ROI compared to initial investment and costs	(Abrash, 2021; Carayannis & Morawska, 2023; Ciccarelli et al., 2023)
		Long-term sustainability and profitability	(Abrash, 2021; Carayannis & Morawska, 2023; Ciccarelli et al., 2023)

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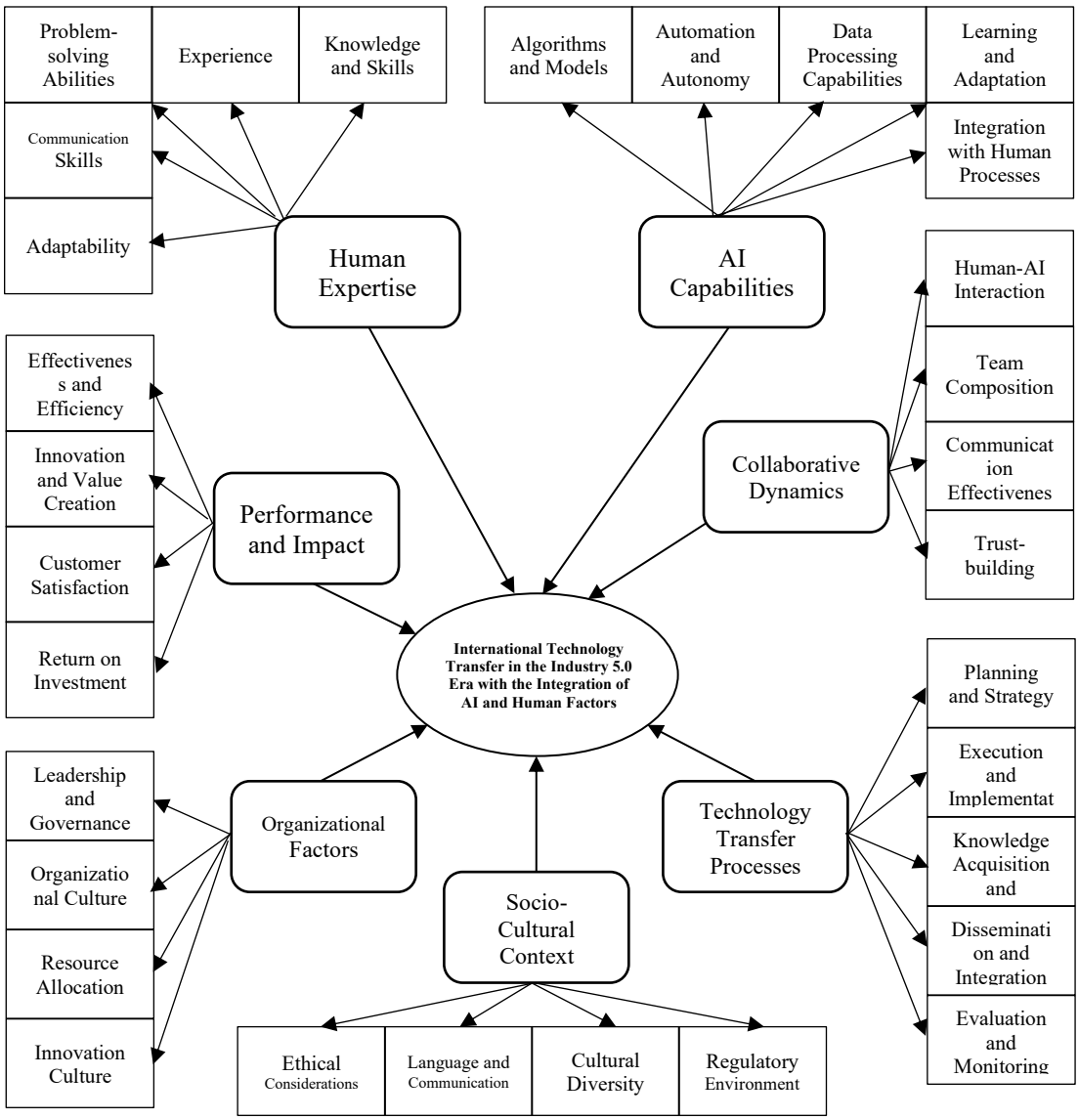
The findings of this research were categorized into seven main dimensions, as shown in Table 1: human expertise, AI capabilities, collaborative dynamics, technology transfer processes, socio-cultural context, organizational factors, and performance and impact. The dimensions, components, and indicators influencing international technology transfer in the era of Industry 5.0 by integrating AI and human factors are presented in Figure 2.

Figure 2

Conceptual Framework of Dimensions and Components Influencing International Technology Transfer in the Industry 5.0 Era with the Integration of AI and Human Factors



4. Discussion and Conclusion

In today's world, rapid technological advancements and increasing competition in global markets have made successful technology transfer a strategic necessity for organizations. With the emergence of the Industry 5.0 era, which emphasizes the integration of advanced AI and human expertise, new opportunities for innovation and value creation have arisen (Irpan & Shaddiq, 2024). However, international technology transfer faces challenges such as cultural differences, varying laws and regulations, and technical and organizational complexities (Ozmen Garibay et al., 2023). Therefore, researching to provide an

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integrated model that can facilitate successful technology transfer within the Industry 5.0 framework, while considering human factors and technology, seems necessary.

This research was conducted using a qualitative approach and the meta-synthesis method, which involves literature review, analysis, and synthesis of existing findings. The research findings identified 118 indicators and 31 components within 7 main dimensions in the field of international technology transfer in the Industry 5.0 era. These dimensions are human expertise, AI capabilities, collaborative dynamics, technology transfer processes, socio-cultural context, organizational factors, performance and impact.

The "human expertise" dimension is one of the key dimensions identified in this research, playing a crucial role in the successful transfer of technology in the Industry 5.0 era. This dimension includes components such as knowledge and skills, experience, problem-solving ability, communication skills, and adaptability. In the Industry 5.0 era, where advanced AI and humans work together, human expertise plays a central role in guiding and optimizing the use of new technologies. Deep specialized knowledge, practical experience, strong communication skills, adaptability, and the ability to solve complex problems are among the essential qualities for the successful transfer of technology in a multicultural setting. These findings align with previous research such as Rožanec et al. (2023), Murphy et al. (2023), Leng et al. (2024), and Pizoń & Gola (2023), emphasizing the importance of human expertise and its integration with technology in technology transfer processes (Leng et al., 2024; Murphy et al., 2023; Pizoń & Gola, 2023; Rožanec et al., 2023). However, this research provides a more comprehensive perspective by identifying more specific indicators.

In line with integrating humans and AI for technology transfer, "AI capabilities" is another prominent dimension. This dimension includes components such as algorithms and models, automation and autonomy, data processing capabilities, learning and adaptability, and integration with human processes. In the Industry 5.0 era, advanced AI is considered a fundamental pillar. The accuracy of predictive models, autonomy in decision-making, rapid and efficient processing of large datasets, and the ability to learn and adapt to changes are among the important capabilities of AI that play a vital role in technology transfer. Furthermore, the seamless integration and effective interaction of AI with human processes and experts are considered facilitating factors in this process. While previous studies such as Ren et al. (2023), Wang et al. (2024), and Berretta et al. (2023) have acknowledged the importance of AI capabilities in technology transfer, this research offers a more precise and comprehensive elaboration of these capabilities, providing a clearer understanding of the dimensions of AI in the Industry 5.0 era (Berretta et al., 2023; Ren et al., 2023; Wang et al., 2024). These findings indicate that for successful technology transfer in the Industry 5.0 era, attention to the various dimensions of AI capabilities and their integration with human expertise is essential.

"The dynamics of human-AI collaboration" is another crucial dimension that plays a pivotal role in the success of technology transfer. This dimension includes components such as human-AI interaction, team composition, communication effectiveness, and trust-building. Previous research such as Hirsch-Kreinsen (2023), Stern & Freitag (2022), and Piller & Nitsch (2022) has highlighted that constructive collaboration between humans and AI is key to success in technology transfer (Hirsch-Kreinsen, 2023; Piller & Nitsch, 2022; Stern & Freitag, 2022). However, this study provides deeper insights into the dynamics of collaboration within the framework of Industry 5.0 technology transfer by describing the components and relevant indicators in more detail. In the era of Industry 5.0, where AI and humans collaborate alongside each other, effective collaboration dynamics are highly important. Constructive interaction, mutual understanding of roles, diverse and balanced team composition, clear and effective communication, and building mutual trust are among the factors that facilitate technology transfer. These findings indicate that paying attention to the dynamics of human-AI collaboration is essential for successful technology transfer in the era of Industry 5.0. Organizations should focus on fostering constructive interaction, forming diverse and balanced teams, effective and transparent communication, and building mutual trust to benefit from the integration of humans and AI in technology transfer processes.

The "technology transfer processes" dimension is another important pillar that specifies how execution and implementation should take place. This dimension includes components such as planning and strategy, implementation, knowledge acquisition and adaptation, dissemination and integration, and evaluation and monitoring. Having coherent and structured processes for technology transfer is a determining factor in the success of this process. Strategic planning, timely and optimal implementation, acquisition and adaptation of relevant knowledge, dissemination and

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integration with existing systems, and continuous evaluation and monitoring are among the essential steps in this regard. In line with previous research (Brückner et al., 2023; Carayannis et al., 2023; Piller & Nitsch, 2022; Wang et al., 2022), the present study also attests to the importance of structured processes in technology transfer. These findings indicate that paying attention to technology transfer processes and all related components and indicators is essential for successful technology transfer in the era of Industry 5.0. Organizations should focus on strategic planning, optimal implementation, knowledge acquisition and adaptation, dissemination and integration, and continuous evaluation and monitoring to be able to benefit from the advantages of technology transfer in the Industry 5.0 era.

The "socio-cultural context" dimension is another important aspect identified in this research that plays a decisive role in the successful transfer of technology in the Industry 5.0 era. This dimension includes components such as cultural diversity, legal environment, language and communication, and ethical considerations. In the process of international technology transfer, paying attention to socio-cultural contexts is of particular importance. Respecting cultural values and norms, establishing intercultural communication and cooperation, adhering to intellectual property regulations and data privacy, and considering ethical implications in the use of AI are among the key considerations in this area. Previous research (Berretta et al., 2023; Calp & Bütüner, 2022; Murphy et al., 2023; Piller & Nitsch, 2022) has emphasized the importance of paying attention to socio-cultural contexts in technology transfer. However, the present study, by providing a more detailed elaboration of the components and indicators of this context, enables a deeper understanding of its various aspects within the framework of Industry 5.0 technology transfer. These findings indicate that for successful technology transfer in the Industry 5.0 era, special attention to socio-cultural contexts and related factors is essential. Organizations should focus on respecting cultural diversity, adhering to regulations and ethical considerations, and establishing effective intercultural communication to be able to properly manage the technology transfer process at an international level.

"Organizational factors" are also among the other determining pillars in this area. This dimension includes components such as leadership and governance, organizational culture, resource allocation, and innovation culture. Organizational factors, including forward-looking leadership, support for innovation, a culture of knowledge sharing, optimal resource allocation, and encouragement of creativity, provide a conducive environment for successful technology transfer within organizations. The presence of such factors facilitates the acceptance and implementation of new technologies. Corroborating previous findings such as Carayannis et al. (2023), Ren et al. (2023), Wang et al. (2024), and Berretta et al. (2023), organizational factors are considered determining elements in technology transfer (Berretta et al., 2023; Carayannis et al., 2023; Ren et al., 2023; Wang et al., 2024). These findings indicate that for successful technology transfer in the Industry 5.0 era, special attention to organizational factors and their proper management is essential. Organizations should focus on establishing strong leadership, fostering a culture that supports innovation and knowledge sharing, strategic resource allocation, and encouraging creativity to create an environment conducive to the successful transfer and acceptance of new technologies in the Industry 5.0 era.

Ultimately, the "performance and impact" dimension is one of the final but most vital stages in the technology transfer process. This dimension includes components such as effectiveness and efficiency, innovation and value creation, customer satisfaction, and return on investment. Evaluating the performance and impact of technology transfer through indicators such as goal attainment, cost-effectiveness, time to market, creation of new products and processes, customer satisfaction, and return on investment is critical for assessing the success of this process. Previous research (Abrash, 2021; Carayannis et al., 2023; Ciccarelli et al., 2023) has highlighted the need to evaluate performance and impact in technology transfer. These findings indicate that for an accurate assessment of the success of technology transfer in the Industry 5.0 era, attention to all aspects of performance and impact, including effectiveness, innovation, customer satisfaction, and return on investment, is essential. Organizations should focus on continuously monitoring these indicators and continuously improving processes based on the feedback received to be able to benefit from the maximum advantages of technology transfer in this new era.

Based on the findings of this research in the field of technology transfer in the Industry 5.0 era, the following recommendations are provided for researchers and organizations. Organizations should focus on the continuous training of their human resources in specialized fields related to the organization's activities. Additionally, developing communication, problem-solving, and

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flexibility skills through workshops and training courses is essential for employees to interact effectively with AI and play an active role in the technology transfer process.

Given the pivotal role of AI in technology transfer in the Industry 5.0 era, organizations should invest in developing and implementing advanced AI capabilities such as automation, autonomy, big data processing, learning and adaptation, and integration with human processes. This can be achieved through collaborating with technology companies, allocating budgets for research and development projects, and attracting specialized talent in this field.

Forming teams composed of individuals with diverse expertise and backgrounds, alongside advanced AI systems, can lead to effective interaction and collaboration between these two pillars. In this regard, holding regular meetings for exchanging perspectives, establishing mutual understanding of roles, and building trust is essential. Additionally, a focus should be placed on establishing clear and effective communication among team members.

Having well-defined and predetermined processes for technology transfer is necessary. These processes should include strategic planning, implementation, acquisition and adaptation of required knowledge, dissemination and integration with existing systems, and continuous evaluation and monitoring. For this purpose, organizations can draw inspiration from successful technology transfer models in leading organizations and design appropriate processes tailored to their specific conditions.

For successful global technology transfer, it is essential for organizations to respect cultural diversity and consider cultural values and norms. They should also comply with intellectual property regulations, data privacy, and ethical considerations related to the use of AI. To this end, organizations can seek assistance from experts in international affairs and cultural mediators.

Organizational factors such as forward-looking leadership, a culture supporting innovation, strategic resource allocation, and encouragement of creativity play a decisive role in the success of technology transfer. Therefore, organizations should focus on creating such an environment through structural reforms, culture-building, and a shift in managerial mindset.

Accurately evaluating the performance and impact of technology transfer using indicators such as effectiveness and efficiency, innovation and value creation, customer satisfaction, and return on investment is vital. This will enable organizations to identify strengths and weaknesses in their processes and take steps towards continuous improvement. They can also implement necessary corrective actions based on the feedback received.

Ultimately, paying attention to all the identified dimensions and components in this research and implementing the above operational recommendations can significantly aid organizations in successful technology transfer in the Industry 5.0 era and gaining competitive advantages. Constructive human-AI collaboration, leveraging structured processes, considering socio-cultural contexts, creating a conducive organizational environment, and continuous performance monitoring are among the key factors in this endeavor.

While this research provides valuable insights into the factors influencing technology transfer in Industry 5.0, with a focus on AI and human factors, it is essential to consider its limitations as well. This research was conducted using a qualitative approach and the meta-synthesis method, limited to reviewing the literature and analyzing existing findings. Therefore, it is recommended that future research be conducted using quantitative and field methods to lend greater credibility to the results. Additionally, this research focused solely on the area of technology transfer and the Industry 5.0 era. It is suggested that future research examines broader aspects of emerging technologies, such as advanced AI, IoT, nanotechnology, and digital technologies. On the other hand, due to the global nature of the topic, conducting case studies in different countries and cultures could provide deeper insights into the role of cultural and legal factors in technology transfer. Furthermore, given the importance of human-AI interaction, conducting empirical experiments and psychological studies could play a crucial role in better understanding collaboration dynamics and designing appropriate user interfaces.

Authors' Contributions

All authors equally contributed to this study.

Declaration

In order to correct and improve the academic writing of our paper, we have used the language model ChatGPT.

Transparency Statement

Data are available for research purposes upon reasonable request to the corresponding author.

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Declaration of Interest

The authors report no conflict of interest.

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Ethics Considerations

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