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Enhancing Human-Robot Interaction in SMEs: Bridging Manual Workflows and Agile Automation

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ABSTRACT:

With rapid advancements in technologies, the demand for small and medium-sized enterprises to incorporate agile automation into their workflows has exponentially grown. The following study explores the research question that is “How can human–robot interaction (HRI) be designed and implemented in SMEs to ensure a smooth human-centred transition from manual workflows to agile automation?”

The literature focuses on four main components, which are Human–Robot Interaction (HRI), Agile Automation (AA), Human-Centred Design (HCD), and Organisational Change. These components are critical for the successful deployment of automation in SMEs. Research also highlights that human-centered design (HCD), trust, safety, and worker involvement are all essential for successful HRI adoption. Conversely current studies stay fragmented and rarely examine the human and organisational traits that influence how workers respond to collaborative robots (cobots) in real settings.

The study applies qualitative and exploratory approach based on the three experiments done under the ARISE project, which are RAPSEB, SUNRISE, and RISES. Thematic and comparative analysis driven by the Input–Process–Output (IPO) framework. The findings of these experiments reveal that an effective Human-Robot Interaction in small and medium enterprises is dependent on cultivating workers’ trust, effective communication through multimodal interfaces, ensuring human safety in shared workspaces, and supporting cognitive and organisational change. This study covers critical insights, limiting factors and recommendations to encourage trust, enhance usability, and workers’ acceptance during the transition from manual to human-centered agile automation.

KEYWORDS: Human-robot interaction (HRI), human-centered design (HCD), agile automation (AA), organizational change, small and medium enterprises (SME’s)

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Abbreviations

SMEs	Small and Medium-sized Enterprises
HRI	Human-Robot Interaction
HCD	Human-Centered Design
AA	Agile Automation

1 Introduction

1.1 Background of the Study

Small and medium-sized businesses (SMEs) are considered the backbone of economies not only in Europe but also around the world. The European Commission report, on the other hand, states that SMEs make up 99.8% of businesses and create 53.6% of the overall value of the economy (European Commission, 2025). Industry 4 is evolving, and some digital aspects of Industry 4.0 are cyber-physical systems, the Internet of Things, and advanced analytics, which make the basis of Industry 5. It also stresses production that is strong, long-lasting, and people-orientated (Zincume & Maier, 2025). It encourages implement automation and train workers to do their jobs effectively and efficiently.

Human-Robot Interaction (HRI) is the process of designing, developing, testing, and implementing techniques that simplify human and robot collaboration. People can work with collaborative robots, or "cobots", and carry out different tasks, such as putting things together in the appropriate manner and moving materials (Puttero et al., 2025). Effective use of automation can enhance worker performance, lower stress levels, and foster greater creativity (Kopp, Baumgartner, & Kinkel, 2021). So, companies need to be more flexible and cost-effective (Ayinaddis, 2025; Eiffe, 2025). SMEs continually find new ways to save power and reducing waste (De Mattos, 2024).

Agile automation is ideal since it offers adaptable technology and allows small and medium-sized enterprises (SMEs) to be flexible with respect to changes according to their needs and demands by allowing them to create high volumes of diversified products in small quantities (Bortolini, Galizia, Mora, & Pilati, 2021). However, it is still challenging to shift from manual intervention to automation. SMEs must transform their business operations, train employees, and closely monitor how they use technology

(Nguyen Ngoc, 2022). Guinjoan et al. (2024) clarify that technology works best when it is according to the needs, requirements, and abilities of the users. Participatory methods make it easier to implement, help people to trust each other, and make workers less stressed about losing their jobs (Riso & Adascalitei, 2024). Now a days many businesses employ robots according to the industrial robotics standards, such as ISO 10218 and ISO/TS 15066. But this new approach is assessing risks, imposing limits on speed, energy, and force, and, at times, resetting such boundaries (Anonymous, 2025; Manzardo & Vidoni, 2025). The automation system should be designed in a way that users feel comfortable and safe while working with it. If the workers trust the system, they will employ it fully and effectively.

Collaborative robots are developing rapidly; however, there are still many things we do not know. Mostly research is focused on engineering problems, although less attention has been paid to the social and organisational ones, which are critical in terms of acceptability (Howard et al., 2025). Research designed for large firms may not fit SMEs, which are capital-constrained and with streamlined managerial designs (Aarstad & Saidl, 2019; Schnell, 2021). There is limited research on psychological comfort, trust development, and perceived usability among collaborative robot workers (Guinjoan, Ros, & Garrell, 2024). This research is a collaboration with the ARISE project (GA 101135784). The ARISE project provides a special chance to investigate HRI (Human-Robot Interaction) in industrial environments under controlled experiments. The overall aim of this research is to investigate the robot experiments conducted by ARISE within SMEs and discuss how automation influences human employees.

1.2 Research Gap, Questions and Objectives

Small and medium-sized enterprises (SMEs) can grow when it comes to connecting humans and robots working together safely, effectively, and meaningfully. But it is difficult to implement automation due to capital, technology, and culture barriers. Most SMEs have sufficient funds to run their businesses. Initially, it is costly to buy cobots,

adjust production lines, and train staff (Costa, 2023). The government or EU may invest to some extent, but SMEs usually don't want to automate because it’s not only time-consuming but also difficult to connect cobots to old technology or company planning systems that weren't made to work together in real time (Halim et al., 2022).
Workers may be worried about job security or their job positions; meanwhile, employers may also be resistant to altering workplace procedures due to the lack of knowledge (Riso & Adascalitei, 2024). If workers had lack of knowledge on how to work with robots, they may perceive them as threats rather than viewing them as helpful tools, which could reduce productivity. Small and medium-sized businesses typically do not have safety engineers on staff and therefore have a chance to break the safety rules and risk people. Such traits make it challenging for SMEs to effectively benefit from agile automation.

Training programs and human-centered design are important in building employee’s comfort, confidence, and performance while collaborating with robots. Human-Robot Interaction plays the most monumental role in understanding how the use of technology is adopted and integrated in small and medium-sized enterprises. ARISE trials present real perspectives on SME adoption of collaborative robots and the responses of workers at flexible automation transitions. Despite these advancements, the existing literature remains incomplete and fragmented. Most current studies tend to focus on the technical and financial aspects of automation while neglecting the human and organisational dimensions, particularly within SMEs. There is limited evidence-based research on how human-centered design (HCD) and human-robot interaction (HRI) principles affect worker trust, safety, job satisfaction, and productivity during automation transitions. Despite of these, there is a significant gap that highlights the need to combine social sciences, and human factors while designing and implementation of automation system in SMEs.

This study aims to explore How can human-robot interaction be designed and implemented in SMEs to ensure a smooth human-centered transition from manual workflows to agile automation? With the following objectives.

- To examine how ARISE experiments facilitate the transition from manual processes to Agile automation in SMEs.
- To evaluate how human-centered design principles improve worker performance, confidence, and comfort during the adoption of automation.
- For finding challenges and best practices, in Human robotic interaction for SMEs, during “manual to agile automation move.”
- To present recommendations that should help to improve usability, trust, and adoptability of robot systems in SMEs.

This study is important as it gives useful information about how cobots can be acceptable, easy to use, and effective in resource-constrained environments by a stronger focus on HRI and human-centered design and empower workers with the confidence and the skills needed to work with technology instead of fearing it.

1.3 Definitions and Scope of the Study

This research is studying the five interrelated concepts that are important for determining how small and medium-sized businesses (SMEs) can implement human-robot interaction (HRI) and agile automation through a human-centered design (HCD) method. Following is a definition of each idea, coupled with a table that goes into further depth about what it implies for the study.

1.3.1 Small and Medium-Sized Enterprises (SMEs)

According to the European Commission (2025), “SMEs are businesses having less than 250 employees and an annual turnover not exceeding €50 million or an annual balance-sheet total not exceeding €43 million” (European Commission, 2025; European Court of Auditors, 2022). Table 1 highlights key attributes of SMEs and show how they impact on human-robot collaboration.

Table 1. Key features of SMEs and their implications (Source: European Commission (2025).

Attribute	**EU Standards**	**Implication For Research**
Employees	≤ 250	High individual impact
Annual Turnover	≤ €50 million	Low-cost automation
Balance Sheet	≤ €43 million	Limited investment
Management Structure	Lean	Low training

1.3.2 Human-Robot Interaction (HRI)

Human-robotic interaction refers to design, and deployment of systems in which humans and robots are working together to achieve mutual goals (Villani et al., 2018). It not only involves technical interfaces but also organisational and social aspects that play an important role in safety and effective collaboration. Other research shows that HRI is not only dependent on technical user interface but also give importance to physical, cognitive, and social aspects (Shah, Arockia Doss, & Lakshmaiya, 2025; Keshvarparast, 2024). Keshvarparast’s literature review explain that acceptance, trust, and socio-technical alignment are key successful factors in HRI adoption SMEs. The following table differentiates HRI into physical, cognitive, and social and how each supports worker safety, confidence, and acceptance objectives of the research.

Table 2. Key dimensions of HRI and relevance to the study (Source: Adapted from Villani et al. (2018).

Dimensions	**Description**	**Relevance to study**
Physical	Ergonomic, Human Robotic Interaction	Self-Integration
Cognitive	Two-way communication, Feedback	Effective response
Social	Trust, Culture, Acceptance factors	Higher Adoption

1.3.3 Agile Automation

Agile automation is a flexible, reconfigurable approach to production automation that allows quick adaptation to market or product changes (Bortolini et al., 2021). Traditional automation is expensive and time-consuming to adjust, whereas agile automation focusses on modularity, scalability, and flexibility. This approach allows SMEs to implement automation that can be incrementally flexible with minimal disruption (Buer, Strandhagen, & Chan, 2018). The following table shows the core features of agile automation and explains how each meets SME needs for low-cost, responsive production.

Table 3. Key Features of Agile Automation and Their Relevance to SMEs and HRI (Source: Bortolini et al. (2021), adapted for SME context).

Features	**Benefit to SME**	**Link to the Research**
Adaptability	Minimal disruptions	Supports variability
Incremental Flexibility	Gradually Expansion	Low investment
HRI	Safe Collaboration	Smooth automation.

1.3.4 Human-Centred Design (HCD)

HCD is an iterative strategy that ensures technologies are design according to the needs, abilities, and limitations of the users (ISO 9241-210; Nguyen Ngoc, 2022). Nguyen Ngoc (2022) discussing how continuous involvement, iterative prototyping, and contextual analysis are key for implementing automation into SMEs. The table clarifies key HCD principles and how it is applied to the design of collaborative robotics in SMEs**.**

Table 4. Key Principles of HCD and Their Application in SME HRI (Source: ISO 9241-210; Nguyen Ngoc (2022), adapted for SME collaborative robotics).

Principal	**Application in SME HRI**
Continuous involvement	Build Trust
Iterative prototyping	Users Feedback
Contextual analysis	Process Alignment

1.3.5 Organizational Change

Organisational change is the change in structure, culture, and procedure adjustments required to integrate new technologies effectively (Roth & Farahmand, 2023). Roth & Farahmand explain that changes are technical organizational and human. Lewin's change theory (Lewin, 1947) explain the basics to manage the organizational change. The table classifies key change areas, the challenges SMEs face specifically, and the importance of human-robot collaboration.

Table 5. Organizational Change and Their Importance for HRI (Source: Adapted from Roth & Farahmand (2023) and related SME change-management literature).

Change Area	**SME-Specific Challenge**	**Importance for HRI**
Leadership & strategy	Minimal management	Strong commitment
Workforce development	Limited training	Employee Upskilling
Process redesign	Ongoing production	Efficient mapping.
Culture & communication	Job security	Builds trust.

1.4 Structure of the Thesis

This thesis is organized to give understanding about how human-robot interaction (HRI) can be enhanced by bridging manual workflow to agile automation in small and medium-sized enterprises (SMEs).

Table 6. Structure of the thesis.

Chapter 1	Introduction	It presents the background, research gap, objectives, and definitions of key concepts i.e. small and medium-sized enterprises (SMEs), human-robotic interaction (HRI), agile automation, human-centered design (HCD), and organizational change.
Chapter 2	Literature review	It is a review of the literature. It explains about how HRI, agile automation, and HCD fit into small and medium-sized businesses (SMEs) and leads to organizational change.
Chapter 3	Methodology	Explains about methodology of research, including research design, data collection (ARISE experiments and documentation) and data analysis.
Chapter 4	Results	Examines the results of the ARISE experiments and find out challenges, and opportunities in human-robot collaboration.
Chapter 5	Summary	Chapter 5 conclude the findings, lists the limitations, and gives suggestions for future work.

2 Literature Review

This chapter discusses literature related to the adoption and application of automation technologies among small and medium-sized enterprises (SMEs). Literature is analysed through a human-centered design approach to emphasize how technology, human factors, and organizational readiness converge to influence the adoption process. The purpose of this review is to identify gaps in existing literature and explore how SMEs best manage to achieve balance between technological innovation and human and organizational factors.

2.1 The Scope of Human-Robot Interaction, Flexible Automation, Human- Centred Design and Organisational Change

Human–robot interaction (HRI) is multidisciplinary research and design of systems in which humans and robots work together to achieve mutual goals. Villani et al. (2018) discuses that Human-Robot Interaction is based on three corelated factors. The first factor is physical interaction, which takes into account safety of workers, ergonomics in shared workspaces. The second factor is cognitive interaction, which covers human understanding, communication, and feedback. The last factor is social interaction. This involves culture, trust and acceptance (Villani, Pini, Leali, & Secchi, 2018).

HRI defines agile automation as production systems that are modular, flexible, and capable of responding quickly to changing market or product needs. Bortolini et al. (2021) define agile automation as the combination of flexible software and hardware configuration from small to gradually big while minimizing financial risk by providing diverse and short production runs. Flexible automation, another idea that Reuther et al.

(2024) tested and confirmed, shows that giving workers a choice or the ability to switch levels of automation provides them with a feeling of autonomy and job satisfaction without adding to their workload. Small and medium-sized enterprises (SMEs) need to be extremely flexible, as they usually do not have funds, and their demand varies extensively. However, it is still challenging to connect agile automation to legacy systems and older equipment. Employees' training and safety certification are also challenging (Costa, Crupi, De Marco, & & Di Minin, 2023). HCD is a participatory, iterative methodology that makes technologies consider users' capabilities, needs, and limitations. Key tenets are early and continuous participation of workers, roundabout prototyping, and situational analysis for matching automation with current processes (Hien Nguyen, Ganix, & Ion, 2022).

Roth and Farahmand (2023) argue that successful change relies upon open communication, engaged stakeholders' participation, and step-by-step implementation to maintain production continuity during reengineering processes. SMEs also have their own distinct challenges: they generally do not possess specialized safety engineers or formal change-management personnel, but their lean structure and reduced decision chains can facilitate quicker experimenting so long as top management is committed (Aarstad & Saidl, 2019). Training programs, risk assessments with participation, and clear explanation of benefits are therefore required to overcome resistance based on fear of job loss or limited technical expertise.

Together, these four constructs form an interdependent system to reengineer SMEs as flexible human-robot coexistence. HRI facilitates the technical and social interface to work together; agile automation offers the adaptive production architecture; HCD renders the technology usable, acceptable, and safe; and organisational change offers the managerial and cultural foundations for long-term take-up. While all fields have been examined on their own, integrated studies that explore their cumulative contribution in SME environments remain limited.

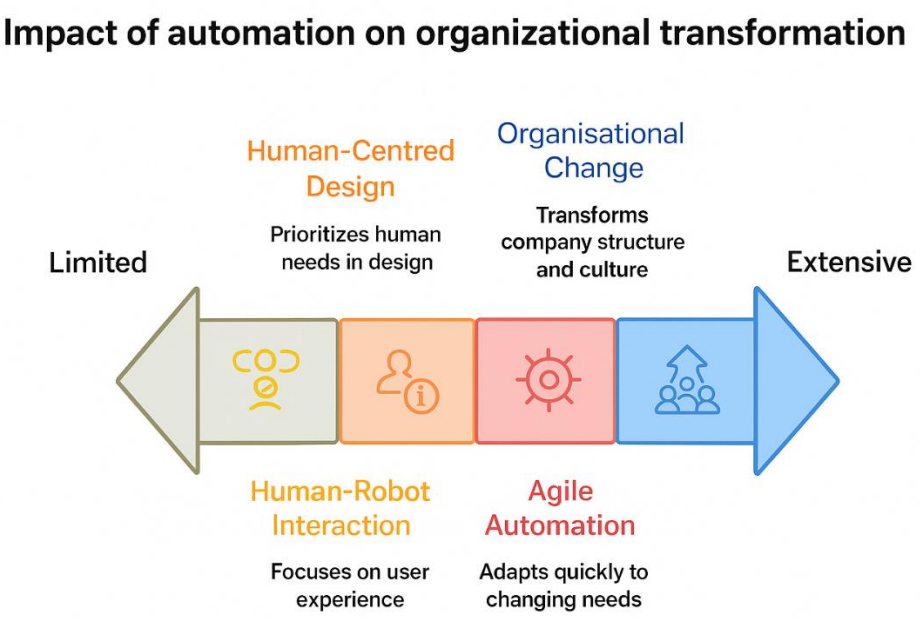


Figure 1. Interdependence of HRI, HCD, Agile automation, and Organizational change (Adopted from Aarstad & Saidl, 2019, Costa et al., 2023).

2.1.1 Human Robot Interaction in SMEs

Human-Robot Interaction (HRI) in Small and Medium-Sized Enterprises (SMEs) is a new method of performing industrial operations, where human employees and collaborative robots, or cobots, jointly work to achieve mutual goals. In contrast to large industries, CSMEs have unique constraints and opportunities in deploying robotic technologies, and their HRI strategy must balance technological capability, organizational design, and human factors to achieve successful integration (Kragic, Henten, & Neumann, 2023). Technologically, SMEs typically operate with limited financial and infrastructural capabilities, which limit their ability to invest in high-capability robotic systems. Compatibility with existing machinery, software, and process flows is a consideration required. Research by the National Institute of Standards and Technology (NIST) notes that it is a great challenge to ensure safety and productivity in such changing environments, considering that the robots need to learn about uncertain human

behaviour without compromising productivity (Walker, 2019). Organizational challenges are also extremely crucial in determining the success of HRI in SMEs. Implementation is greatly dependent on change and innovation culture. However, SMEs usually possess horizontal organizational management and limited access to off-the-job training facilities, which may impede effective application of robotic systems. Leadership plays an important role during this transformation, as managers must convey the reasons and benefit of robotic systems to subordinates effectively. Research articles in point out that effective leadership and effective communication strategies play a key role to avoid resistances to change and establish a common vision for the future of work (Kopp, Baumgartner, & Kinkel, 2021).

Low organizational readiness can even render technologically advanced robotic systems useless for delivering the anticipated productivity and efficiency gains. Human factors are the most significant problem in HRI, as human operators' comfort, trust, and acceptance largely rely on the performance of collaborating robots. Robots may be perceived by workers as a threat to jobs, leading to resistance or avoidance of interacting with automated systems. Research carried out by Asamaka.com indicated that whenever workers are made part of the planning and operation of robotic systems, their acceptance is upgraded, leading to improved and more productive human-robot collaboration (Asamaka, n.d.).

Safety and ergonomics are the general considerations in human-robot interaction, particularly in SMEs where space is shared by humans and robots operating close to each other. SMEs will also have to cope with psychosocial implications of stress, fatigue, and mental load that may arise from acquiring new technologies. Poorly planned interactions can lead to discomfort for employees or inefficiency. SMEs can ensure that human operators are able to comfortably interact with robots, maintain productivity, and be job-satisfied (Lu, Xie, Wang, Li, & Xu, 2022).

Table 7. Summarizing barriers vs. enablers of HRI adoption in SMEs.

Barriers	**Enablers**
Financial Constraints	Scalable cobot solutions
Legacy system incompatibility	Modular, flexible robotics
Informal structure	Strong, clear leadership
Lack of training	Inclusive worker participation
Job security concerns	Transparent change management
Ergonomic challenges	Safety-focused design

Human-Robot Interaction in SMEs requires an in-depth understanding of technological, organizational, and human factors. By developing a deeper understanding of these factors, SMEs can achieve enhanced productivity, improved process quality, greater worker satisfaction and as a whole allows SMEs to align themselves better with the changes in the technological landscape and as a result gain competitive edge. Moreover, the gradual integration of HRI enables SMEs to remain responsive, continuously innovate, and agile in the face of ever-changing market requirements (Kopp, Baumgartner, & Kinkel, 2021).

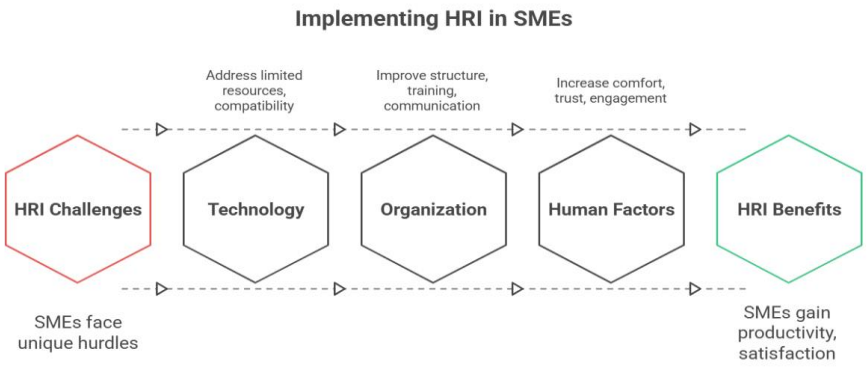


Figure 2. Implementing HRI in SMEs (Adopted from Kopp et al., 2021).

2.1.2 Agile Automation in SMEs

Traditional automation demands not only capital investment but also it is inflexible. On the other hand, agile automation offers flexibility to change, versatile functionality and the ability to do different tasks. Agile automation is designed to corresponded into changing production settings where operations are changing continuously (Buer, Strandhagen, & Chan, 2018). Agile automation aids small and medium-sized businesses (SMEs) stay competitive in a market that is always changing. The idea is to bring lean production and agile manufacturing into the digital age by employing robots, modular designs, and natural digital user interfaces (Bortolini, Galizia, & Mora, 2018). The combination of Human-centered Design (HCD) and agile automation offers technology improvement instead of replacing human roles. In SMEs, where workers are responsible for multiple functions and are experienced in what they do, greatly benefit from Human-Centered Design (HCD). Moreover, HCD prioritizes accessibility and usability of automation. In most scenarios, SMEs don't have any robotics experts on hand, therefore they need simple user interfaces and easy-to-understand programming (Villani, Pini, Leali, & Secchi, 2018).

Robots have been designed to work with humans in a shared place and help them by employing their accuracy. Agile automation encourage transformation in SMEs. It is modular and responsive, which makes it perfect for companies that don't have a lot of resources and need to make changes slowly and in line with their current workflows (Bortolini et al., 2021). Even though agile automation is flexible, but still, it's difficult to work with existing settings. Aarstad and Saidl (2019) say that small and medium-sized businesses often don't realize how hard and expensive it can be to combine new robotic systems with old machines. Costa (2023) highlights that the hidden costs, e.g., maintenance costs, customizing interfaces, and software updates, can be more costly than the original investment estimates, which decrease the return on investment.

The second crucial factor is cultural adaptation. Previous literature repeatedly puts across that resistance to change on account of fear of joblessness, low technology trust, or communication barrier still ranks as one of the greatest obstacles to automation deployment among SMEs (Schnell, 2021). SMEs generally lack the financial and technical strength to undertake automation projects independently (European Parliament, 2023).Combining human-centered design with Agile automation maximizes productivity and efficiency. People often fight against change because they are deeply worried about their roles, and the possibility of losing their jobs because of new technology (Schnell, 2021). Lack of internal communication and training tools makes this fear even worse in small and medium-sized businesses (Zincume & Maier, 2025) where workers often have more than one job and tacit knowledge is deeply ingrained (Riso & Adascalitei, 2024; Eiffe, 2025).

SMEs initiated focused automation projects such as automating a single workstation and then expanding from there as skills and confidence build up (Buer, Strandhagen, & Chan, 2018). Agile automation also generates role transformation and upskilling. Employees move out of hands-on, repetitive work into more valuable work such as robot monitoring, data analysis, and workflow optimization. Successful organizational transformation entails reskilling activities, including training programs and developing "automation champions" that span technical and shop-floor expertise (Riso & Adascalitei, 2024). The literature explains that in SMEs, agile automation drives from technological transformation to organizational change in a cycle. Figure 3 shows agile automation cycle.

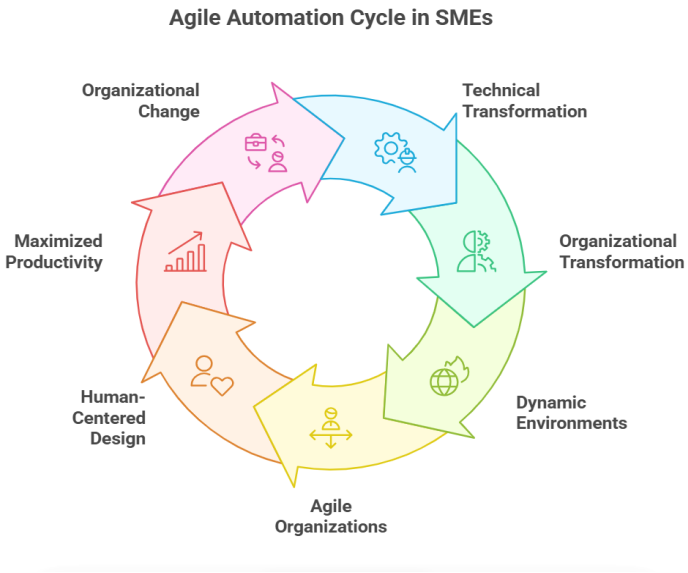


Figure 3. Agile Automation in SMEs (Adopted from Riso et al., 2024, Schnell, 2021, Zincume 2025)

2.1.3 Human-centered Design in SMEs

The HCD process depend upon repeatedly prototyping their testing and make changes according to the needs and demands of end-users. Through the inclusion of operators and shop-floor workers right from the concept phase, SMEs can formalize implicit knowledge about jobs, constraints, and pain areas (Hien Nguyen, Ganix, & Ion, 2022). Iterative prototyping means through feedback designs are continually developed and permits incremental execution of automation, lowering the chance that new systems and operations won't work together. One of the keys HCD principles is the analysis of the situation, breaking down the social, physical, and mental space in which technology will be applied. For SMEs, it is important because work procedures are usually not standardized and differ from company to company or even production batch to production batch (Aarstad & Saidl, 2019).

Such effects are vital in SMEs, where employees perform multiple functions and have key process knowledge hard to codify (Costa, Crupi, De Marco, & & Di Minin, 2023). It is

hard to do thorough user research and usability testing in SMEs because there aren't enough experts or ergonomists (Bortolini, Galizia, & Mora, 2018). While connecting HRI and HCD ensures that robots are working with humans to improve the productivity instead to replace the humans (Villani et al., 2018). This is the reason that HCD advances the automation and supports cultural adoption and helps an organizational change (Roth & Farahmand, 2023).

In short, SMEs need to use human-centered design to make sure that digitalization considers the skills and needs of their workers. Moreover, involve their workers while prototyping to design the system that is easy to use and understand. Small businesses don't have a lot, but good HCD methods and systems for working with robots can help them get the benefits of it. This could lead to the creation of Industry 5.0, which focuses on people.

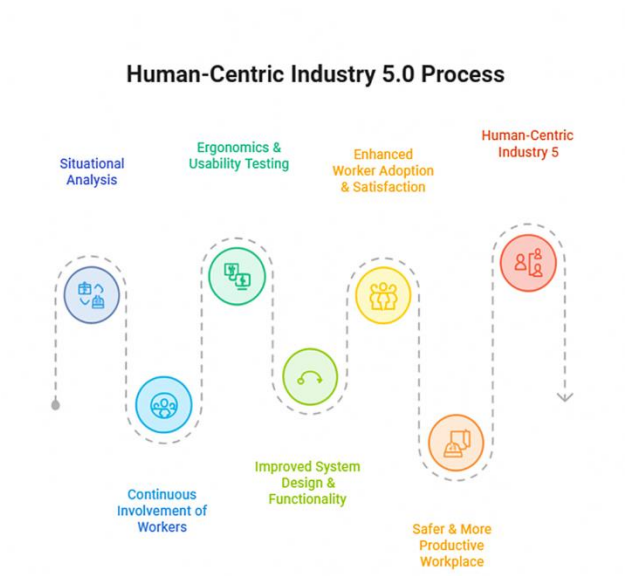


Figure 4. Process of Human-centric Industry 5 (Adopted from Villani et al., 2018, Roth & Farahmand, 2023, Aarstad & Saidl, 2019).

2.1.4 Organizational change in SMEs

In small and medium-sized enterprises, organizational change is driven out not only by social, cultural, and structural change but also the technological advancement. Human–Robot Interaction (HRI) technologies are mainly developed with a focus on human needs through Human-Centered Design (HCD). At the same time, the rise of agile automation pushes small and medium-sized enterprises (SMEs) to rethink their workflows, adjust the way employees work, and adopt a more open attitude toward new technologies (Hien Nguyen, Ganix, & Ion, 2022). Compared to large firms with dedicated resources for transformation management, SMEs operate in most instances with scant technical and financial capability, suggesting organizational transformation is as vital, if not more so, then the technical deployment of robots (De Mattos, 2024). The process of organisational change in small and medium-sized businesses (SMEs) can be understood when technical transformation leads to culture and structural changes in organization and improved productivity. Figure 5 illustrates transformation process, where SMEs change into human-centric organizations by focusing three key dimensions: role transformation and upskilling, cultural change and acceptance, and absorptive capacity and learning.

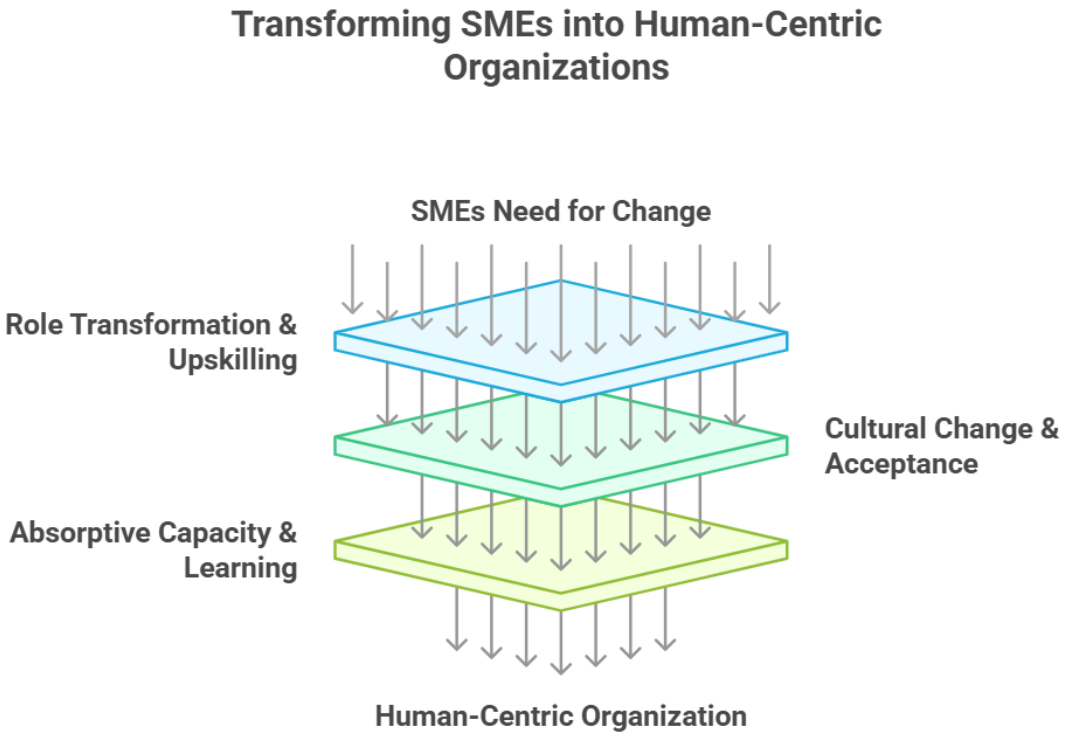


Figure 5. Transforming SMEs into a human-centric organization (Adopted from Keshvarparast, 2024), Eiffe, 2025).

Organizational transformation, in one way, refers to role transformation and upskilling. Agile automation makes incremental, modular deployment possible so SMEs can automate repetitive or hazardous activities without halting the entire process. Here, HRI systems do not replace people but augment workers who are reassigned to monitoring, supervisory, or decision-making activities that tap human imagination and judgment (Keshvarparast, 2024). Another element is cultural change. Resistance to technology adoption is still a key barrier for SMEs, whose employees are usually fearful of becoming jobless, suspicious of technology, or have doubts regarding the management's intentions (Eiffe, 2025). Agile automation enables this to happen through incremental, stepwise changes that result in minimal disruption and provide room for workers to adapt, and hence, cultural acceptance can build cumulatively.

Moreover, it is linked to absorptive capacity and organizational learning. SMEs that can successfully deploy HRI and agile automation possess higher absorptive capacity, i.e., they can sense, absorb, and utilize new knowledge in technology. This concept is different from change management, which emphasis on the management of employee's transitions and resistance, but organizational learning highlights to apply external knowledge over experience. A practical example is a Norwegian SME a furniture industry, which automated a single sanding station as a pilot. Agile automation enables flexibility, incremental optimization, and risk mitigation. All these dimensions enable SMEs to become resilient, agile, and human-centric organizations during the era of robotic and digital transformation.

Table 8. Stepwise model of organizational transformation under HRI adoption.

Phase	**Focus**	**Key Actions**
Planning	Awareness	Audit, Alignment
Piloting	Testing	Trail, Feedback
Alignment	Upskilling	Training, Role shift
Integration	Acceptance	Communication, Trust
Learning	Knowledge	Reflection, Sharing
Scaling	Optimization	Expansion, Improvement

2.2 Human-robotic interaction in the context of Agile Automation

Agile automation shifts industrial robotics from fixed-asset, high-volume devices to human-centric, reconfigurable systems that can be rapidly implemented, iterated, and re-tasked according to the need of the SMEs. In this model, HRI is not an add-on to safety; it is the organizing principle for dividing tasks, for designing the interfaces, for how people learn and trust the system, and for capturing value (Zafar, Langås, & Sanfilippo, 2024). Traditional automation presupposes constant products and long payback times—

conditions that are typically not the reality for SMEs. Scalable HRI solutions counteract this with the combination of power-and-force-limited (PFL) and speed-and-separation monitoring (SSM) modes, which not only enhance performance but also allow for quick task changeovers, benefiting the human (Manzardo & Vidoni, 2025). The 2025 revision of ISO 10218 specifies safety requirements for industrial robots and system integration (Anonymous, 2025). For SMEs, transparent standards lower amalgamation difficulty and risk estimation uncertainty (Howard, et al., 2025).

By combining strategy and intelligent perception increases probability without compromising the cooperative safety limits and increase workers trust (Shah, Arockia Doss, & Lakshmaiya, 2025). In agile HRI, the solution is to increase guidance, standard work, and change management into the technical scope. It means that develop standard toolboxes, produce reusable code, and making operator feedback loops as a part of the company's culture (Liu & Son, 2024). These outcomes are most obvious where companies merge HRI with detection, data capture, and iterative advancement processes.

Table 9. Empirical Studies on Agile HRI in SMEs.

Study	**Context**	**Outcomes**	**Themes**
Manual assembly and Human–Robot Collaboration in repetitive assembly processes (2023)	Repetitive assembly	Exertion ↓, Stress ↓, Defects ↓	Safety, Trust
Analysing psychophysical state and cognitive performance in human-robot collaboration for repetitive assembly processes (2024)	Assembly with cobot vs manual	Stress ↓, Failures ↓	Safety, Flexibility
Automation of SME production with a Cobot system powered by learning-based vision (2023)	SME with vision + digital twin	Adaptability ↑, Deployment faster	Flexibility, Safety

2.3 Human-robotic interaction in the context of Human-Centered design

Following the discussion on intelligent sensing, policy learning, and iterative improvement in robotics, it is significant to study how such industrial development support with human-centered design (HCD) values, mainly in SMEs. While the responsiveness and predictability of such systems improve with the addition of automation and robotics, such systems achieve their full potential only when they are aligned with the skills, needs, and experience of human operators (Shah, Arockia Doss, & Lakshmaiya, 2025). There are unique challenges facing SMEs that differentiate them from larger manufacturing firms, including limited financial resources, a less homogeneous workforce, and the need to integrate automation with existing manual processes (Liu & Son, 2024).

ISO recommendations and new research propose the Human–Technology–Organisation (HTO) model, integrating human factors, technological possibilities, and organizational design to align system design and adoption in SMEs (Zincume & Maier, 2025).

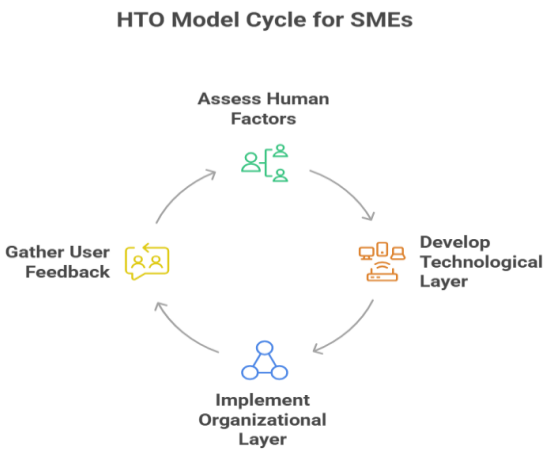


Figure 6. HTO model for SMEs (Adopted from Zincume & Maier, 2025).

Co-design, or participatory design, is a best practice that has been widely used as a best practice to make human-robot systems are driven by end-user needs. Involving workers in design tasks enhances system usability and trust.

Table 10. Summary of Key Studies on HRI in SMEs (HCD Perspective).

Theme of HRI	Robot Technology	Objective of the Study	Sample size	Key Findings	References
Explainability & Trust	Collaborative robot (cobot)	Improve usability and operator trust	15 operators	Early user involvement improved usability, trust, and adoption	(Guinjoan, Ros, & Garrell, 2024)
Social Robot Adoption	Social robots	Assess adoption barriers & employee engagement	50 SMEs	Organizational readiness and employee engagement are critical	(Islam, Rakshit, & Paul, 2025)
Interface & Multimodal HRI	Smart manufacturing robots	Enhance usability, trust, and collaboration	(survey-based study)	Multimodal interfaces improve usability, trust, and collaboration	(Wang, Zheng, Li, & Wang, 2023)
Adoption Barriers & Workforce Impacts	Cobots & robots	Identify adoption barriers and workforce impacts	Broad EU dataset	Psychosocial and safety concerns require employee involvement	(Riso & Adascalitei, 2024)

2.4 Human-robotic interaction in the context of organizational change

This provides an overview of the way human–robot interaction (HRI) is embedded in organisational change processes within small and medium-sized enterprises (SMEs). Moreover, it explains how the work is reshaped by the robots. The Technology Organization Environment (TOE) and Diffusion of Innovations (DOI) frameworks discuss the challenges faced by SMEs in automation, including cost, versatility, expertise, management, market competition, and labour shortages, all of which collectively impact

the adoption of automation (Sánchez, Calderón, & Herrera, 2025). HRI is not a technical imposition or a re-engineering of tasks, responsibilities, and norms that one should create at micro (person) and macro (industry/policy) levels. This approach puts in the centre that only by collective optimisation of social practice and technical affordances can one achieve effective change (Zincume & Maier, 2025).

Several empirical studies list common SME-specific barriers to implementation:

- SMEs do not generally own in-house robotics, AI, or systems integration abilities and must depend on external consultants, which slows down implementation and reduces in-house learning (Ayinaddis, 2025)
- Even "collaborative" robots require investment in safety, workspace modification, and worker training; SMEs may struggle to amortize such investments (Kopp, Baumgartner, & Kinkel, 2021).
- Employees and managers are techno-disbelievers, fear of job loss, or have a low perception of value; all of them are opposed to the re-design of workflows (Riso & Adascalitei, 2024).
- Most SMEs have very manual, implicit workflows that need to be documented, standardized, and redesigned several times to be able to be used in HRI-supported procedures that take a lot of time and money (Roth & Farahmand, 2023).

Research also records effective HRI integration, delineating a series of intricate facilitating conditions:

- Clear support from management, clearly articulated problems (what the robot will fix), and inclusion in strategic priorities make change legitimate (Ang, Sankaran, & Liu, 2024).

- Internal automation, on-the-job training, and partnerships with regional research centres allow SMEs to develop absorptive capacity rather than being eternally dependent on contractors (Aarstad & Saidl, 2019).

Table 11. Barrier vs. enabler comparative table for SMEs.

Category	**Barriers**	**Enablers**	**Reference**
Technology	Lack of expertise	Research partnerships	Ayinaddis (2025); Aarstad & Saidl (2019)
Cost	High Investment	Subsidies, leasing	Kopp, Baumgartner, & Kinkel (2021); Sánchez, Calderón, & Herrera (2025)
Workforce	Fear	Training, participation	Riso & Adascalitei (2024); Ang, Sankaran, & Liu (2024)
Management	Limited Vision	Leadership support	Ang, Sankaran, & Liu (2024)
Process design	Informal Workflow	Standardization	Roth & Farahmand (2023); Ayinaddis (2025)
External Environment	Weak Ecosystem	Strong networks	Zincume & Maier (2025); Aarstad & Saidl (2019)

HRI causes work to shift away from manual handling and towards supervision, exception handling, and quality control. Research further suggests regionally varied adoption patterns: where there is an existing support ecosystem, SMEs adopt more rapidly and with more human-centred outcomes (Zincume & Maier, 2025). The literature review

analysis five interrelated pillars that are important for SMEs to successfully integrate Human-Robot Interaction: agile automation, human-centered design, organisational change management, SME challenges, and technology alignment.

2.5 Summary of Theoretical Framework

Human–Robot Interaction (HRI) and flexible automation in small and medium-sized enterprises (SMEs) can be described through several interconnected theories. HRI theory defines how humans and robots can interact effectively and safely, and affect staff trust, workflow design, and productivity. Coating robots, or cobots, undertake repetitive tasks so that the staff members inspect, monitor, and diagnose, and in so doing improve productivity and job satisfaction. In SMEs organizational Agility Theory explains flexibility and adaptability. Incremental automation allows firms to develop processes without disturbing everyday business. Incrementalism lowers risk and allows new tools and methods. Human–Automation Trust Theory expand more and recommends that workers need to build trust in robot systems. Engaging workers in design decisions, using easy-to-use programming interfaces, and conformity to open safety standards, preventing underuse as well as overreliance on automation, builds trust.

Equally important is skill learning and acquisition. Social Cognitive Theory illustrate how new skills can be learned through observation and feedback. UX principles and Human-centered Design ensure that automated systems are user-friendly and designed according to the needs of the operator, which is more helpful to build trust. People who work on the development will find it easier to accept robots as helpers instead of replacements. Finally, the theory of organizational learning states that SMEs share information, improve processes, and keep getting better at what they do. These theories make connections among individuals, organizations, and technology. Using HRI, agile

automation, and human-cantered design, SMEs can build trust, train their workers to work effectively and efficiently.

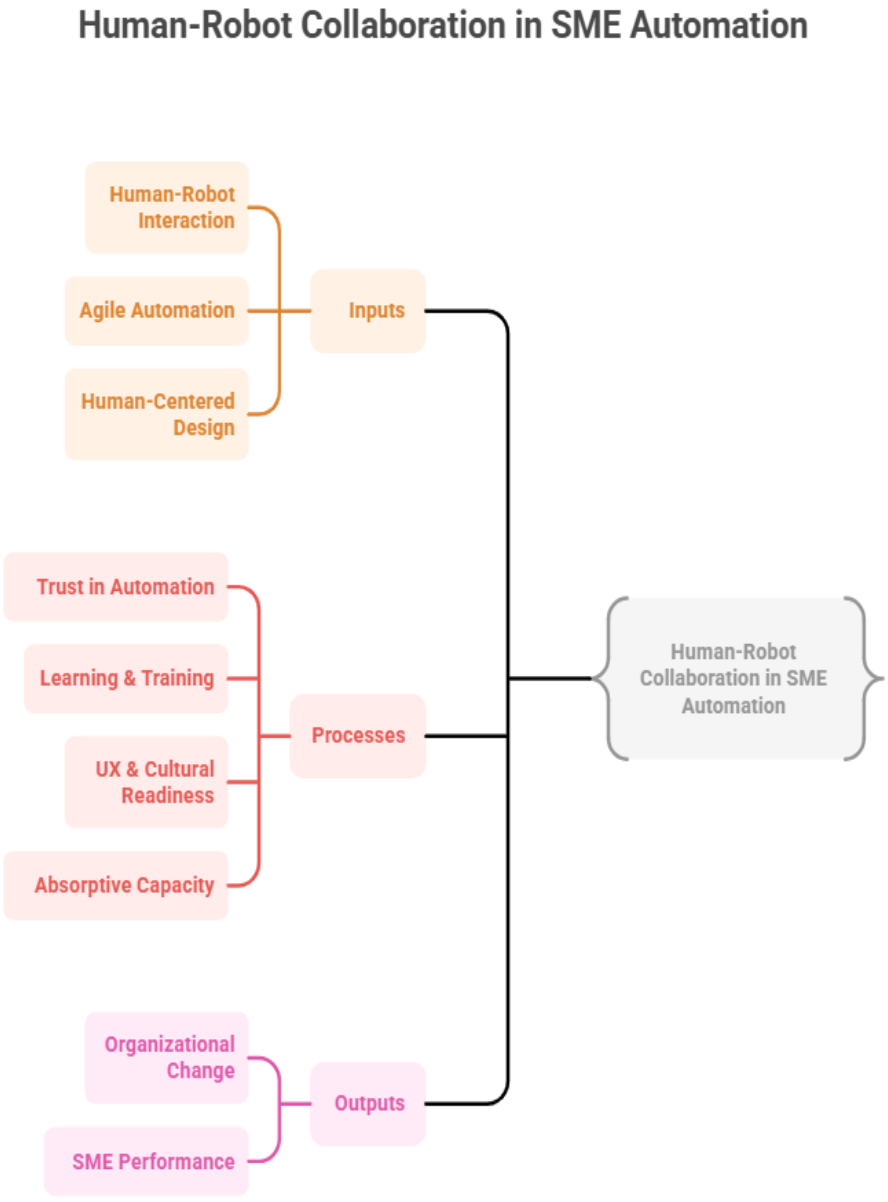


Figure 7. Theoretical Framework.

Table 12. Summary of key theories based on the Literature.

Components	**Role in SMEs**	**Key Elements**	**Theories with References**
Input	Factors initiating acceptance in SMEs	HRI (safe interaction, interaction with robots), Agile Automation (flexible, incremental operation), HCD (accessibility, usability, emotional satisfaction)	HRI Theory (Sultanov et al., 2022; Farooq et al., 2024), Organizational Agility Theory (Buer et al., 2018), UX Frameworks (Nguyen Ngoc, 2022; Villani et al., 2018)
Process	Factors affecting adoption effectiveness	Trust (balanced reliance, participatory design, safety standards), Learning (training, observation, automation champions), UX (intuitive, enjoyable interfaces), Cultural Readiness (employee acceptance), Absorptive Capacity (knowledge integration)	Human Automation Trust Theory (Shah et al., 2025) Social Cognitive Theory (Islam et al., 2025) UX Frameworks (Riso & Adascalitei, 2024), Organizational Agility Theory (Buer et al., 2018), Organizational Learning Theory (Sánchez et al., 2025)
Output	Results of successful adoption	Organizational Change (roles, culture, processes), Improved SME Performance (productivity, resilience, competitiveness)	Change Management Theories (Howard et al., 2025; European Commission, 2025)

Literature shows that SMEs are moving away from the traditional, autonomous method of automation towards adaptable, human-centered strategies in which humans and robots work together. New cobots are designed to collaborate safely with human workers so that work can be redefined easily and accommodate the rapidly changing needs of small firms. Studies emphasize that SMEs achieve their best results in robotics adoption by embedding Human–Robot Interaction (HRI), flexible automation, and Human-Centered Design (HCD). Agile automation provides low-complexity interfaces and modularity to enable SMEs to start small, e.g., automate a single workstation and

expand over time, retraining staff, and redefining jobs from manual to supervision, problem-solving, and quality assurance. Organizational transformation is just as essential as effective managerial sponsorship, staff training, and the ability to learn new skills dictate how easily technology integrates into existing workflows and culture.

3 Methodology

This chapter outlines how small and medium-sized enterprises (SMEs) can enhance human–robot interaction (HRI) as they transition from manual to agile workflow. A qualitative and exploratory case study design was adopted to best reflect real-world dynamics between humans, robots, and organizational systems. The research makes use of secondary qualitative data from the ARISE Project (Grant Agreement No. 101135784). Official and publicly accessible sources of data were the ARISE Middleware website and the European Commission's CORDIS database. The study utilized thematic and comparative analysis within the Inputs–Processes–Outputs (IPO) framework. This chapter altogether establishes the methodology foundation for understanding the role of human-centred and adaptive automation in SME transformation.

3.1 Research Design

The main objective of this study is to understand how SMEs shift from manual workflow to agile automation by developing HRI. The "research onion" approach of Saunders et al. (2019) is exercised in this study to present a structured description of the methodological preferences. Starting from the outer layers (philosophy) to the inner layers (data collection methodologies), the research onion exhibits the steps followed in building research design. This research study is based on the interpretivist theory, which believes that human actors provide the best explanation for reality by their experiences. Due of its focus on the socio-technical collaborations between humans and robots in SMEs, this model is suitable for the study's qualitative exploratory focus. Saunders et al. (2019) onion model research approach is shown below in Figure 8.

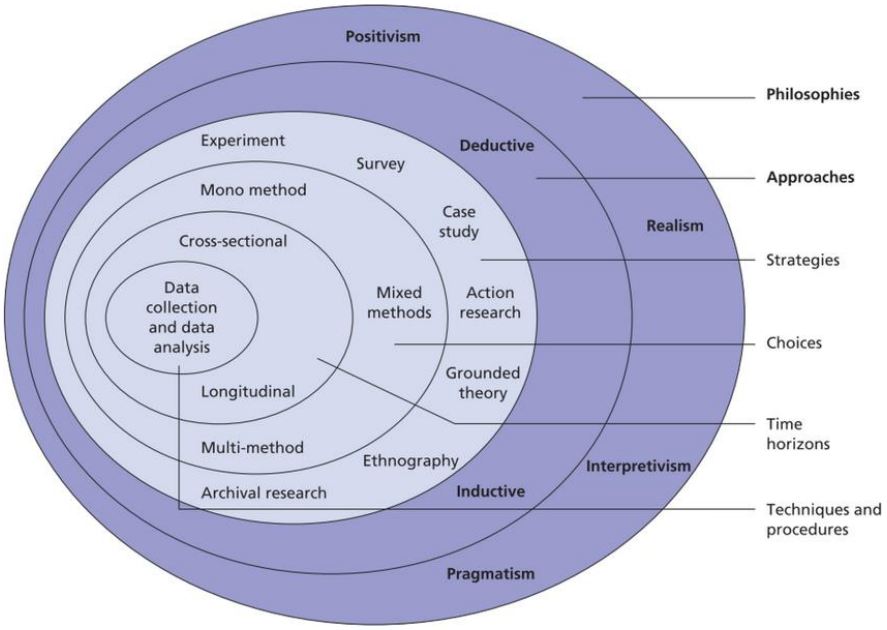


Figure 8. The Research Onion (Source: Saunders et al., 2019).

The study thus employs qualitative and exploratory case study research design that most appropriately fits the investigation of natural phenomena that are not readily quantifiable (Saunders, Lewis, & Adrian, 2019). The qualitative method is the most appropriate as it emphasizes authentic environment, perceptions, and experiences rather than solely quantitative metrics. The qualitative and exploratory design was chosen for of three reasons.

1. HRI in SMEs is a dynamic socio-technical phenomenon in which people, machines, and organizational systems interact dynamically. It cannot be interpreted in a vacuum, and case studies hence are the most suitable means of capturing such contextual nuances.
2. Second, the study is exploratory and aims to produce insights and theoretical comprehension rather than to test defined hypotheses.
3. Third, primary field data were not feasible in the view of the present work.

Primary data was not collected due to confidentiality limitations. Much of the operational data, interviews, and robotic system details are limited under project

confidentiality agreements and not accessible for independent research use. Therefore, the research is based on secondary data documented ARISE experiments (ARISE, 2025), project reports, and CORDIS dispatches (European Commission, 2025). These data sources are rich and reliable accounts of the ways collaborative robots. To summarize the methodological logic and ensure transparency between the research objectives and design decisions, the following figure illustrates how the study's philosophical stance, approach, strategy, and data sources align with its objectives. This visual representation matches the "research onion" framework by displaying how each methodological layer turns into practical research choices applied in this study.

Figure 9. Research design aligned with research objectives.

Three ARISE experiments (RAPSEEB, SUNRISE, and RISES) are empirical bases of this study. Each experiment signifies a definite quality of human-robot collaboration and

agile automation, presenting various perceptions balancing each other to foster a broad picture of the HRI process in SMEs.

1. **RAPSEB Experiment** (ARISE, 2025)

The RAPSEB experiment is related to PHEE (Greek SME) indicating in carbon-neutral mixtures from biomaterials (coffee waste and sea plants). The experiment aimed the automation of a previously physical procedure involving of epoxy binder use and pressing composite sheets. These jobs were tiresome and involved exposure of toxic materials for workers. Because of ARISE's middleware, the RAPSEB experiment proposed a collaborative robotic arm (UR10e) that possibly will execute the spraying procedure independently in combination with guaranteeing safe collaboration with human workers. The system used ROS2-based middleware, with FIWARE for exchanging information in simultaneously, and AI-based graphics as well as simulated knowledge to advance spray trails.

It prevents manual workers exposure to the epoxy spray completely. Meanwhile workers do quality control and monitoring activities. This will improve worker’s safety as well as increase trust on automation. RAPSEB accounted for 20% productivity improvement and raw-material savings of 12%, with extraordinary worker acceptance. This experiment shows how exceptionally trained, flexible automation can enhance human well-being while preserving flexibility priorities for SMEs adopting HRI.

2. **SUNRISE Experiment** (ARISE, 2025)

SUNRISE experiment is targeting human-centered flexibility in production and packaging facilities. It was designed for industries like cosmetics, food, or pharma in which the products are continuously being modified and short series are the norm. Robots should adjust quickly to new configurations without being programmed by professionals in such

types of environments. SUNRISE offers gesture-based and natural interaction styles that allow workers to teach robots new tasks through natural movement or low-code platforms. The purpose of the experiment is to enable non-expert users to program robots so that cognitive load is reduced, and automation systems are made agile for reconfiguration. The robot can learn from demonstration or tracking operator movements, and there is flexibility that works especially for SMEs when there is high task diversity.

ARISE middleware acts as a main communication connection combining ROS2 with FIWARE components tasked with real-time data exchange, safety monitoring, and system analytics. It is created through observance to Human-Centered Design (HCD) principles because workers are involved at the interface designing stage. Testers were the operators who operated different gesture sets and control modes to offer comfort, usability, and trust. The ARISE (Deliverable D3.1) humanities and social sciences framework, reports and continuous feedback, build trust in the operation of collaborative robots. SUNRISE demonstrate that intuitive communication reduces setup time, reduces error rates, and increase worker's engagement (European Commission, 2025).

3. **RISES Experiment** (ARISE, 2025)

The RISES experiment is for warehouse automation, specifically in brownfield environments in which the infrastructure is not flexible. The experiment seeks to combine autonomous or semi-autonomous forklifts and mobile robots into the system while humans involved in storage, retrieval, and transport operations. RISES is designed to achieve a secure, effective, and human-friendly automation platform where robots and humans share the same environment without physical separation. RISES combines 360-degree detection, speed control, and protection systems using ARISE middleware to

manage robot motion among humans. Instead of replacing workers, RISES redesigns tasks by involving both human and robots. Robotic do repetitive tasks e.g. transporting materials, while workers do supervision, task selection, and exception handling. This reduces the risk of harms and makes the job more efficient without risk.

3.2 Experiment Selection

Experiment selection is a critical method in qualitative research because it renders the data analysis relevant, in-depth, and useful. Experiments were chosen in this research from the ARISE Project, which is aimed at creating human-robot collaboration and adaptive automation based on a human-centered middleware architecture. The project consists of several experimental testbeds across various industrial domains with all of them seeking to demonstrate the role played by agile robots and AI in improving productivity, safety, and responsiveness in small to medium-sized companies (SMEs). Three experiments identified in ARISE that this research focuses its attention on are RAPSEB, SUNRISE, and RISES. These were picked because of the direct pertinence of respectively to the study aim, SME characteristics, and accessibility of valuable qualitative data from open sources such as ARISE's official website and the European Commission's CORDIS website. Focused selection is the best practice for qualitative exploratory research study because it permits the researcher to choose cases with optimal data in accordance with the research questions (Patton, 2015).

The experiments were picked thoroughly to allow a separate but consistent set of cases under the topic of developing human-robot interaction (HRI) in SMEs. The choice was established on various conditions.

- Firstly, the experiments were applicable to SME perspectives, controlling or modelling environments indicated by lack of sources, minimum experience with robotics, and there is a necessity for flexibility in the organizations. Each

experiment explains familiar SME difficulties such as inadequate space, varied production requirements, or skilling the labour.

- Second, each experiment stresses human robot collaboration, trust, safety, and human-centered design theories.
- Third, these experiments provide a collection of diverse industrial relevance. For diversity to HRI, different fields experiments were chosen. RAPSEB objectives manufacturing and ergonomics, SUNRISE goal is flexible manufacturing and packing and RISES objectives logistics and intralogistics automation. Diversity in areas allows to find sector-specific findings as well as general themes between industries.
- Fourth, the experiments provide qualitative data, for example, wide documentation, workflow designs, experiments results, and human-centered design, and software and hardware system architecture. Such documented richness permits detailed qualitative understanding and thematic investigation.
- Finally, the chosen experiments are well connected into the research goals, each directing whole but corresponding side of manual workflows and agile automation.

Together, these experiments were chosen to represent a different SME experience. These cover diverse industrial areas such as RASEB deals with manufacturing, SUNRISE deal with cosmetics and packaging, and RISES deal with logistics. These collectively correspond to the functioning variety in European SMEs. Even though sectoral changes, each experiment has SME type such as inadequate automation knowledge, automation need, and stress on human-centered transformation. This explains transferability, as understandings described from these experiments can be help the other SMEs facing similar problems e.g. resource limitations, employees' arrangements, and transformation challenges. The RAPSEB experiment explains the human-centered re-design of dangerous physical processes to safe, semi-automatic procedures in the environment of an SME. The RAPSEB proposal, implemented at PHEE, a modest Greek manufacturer of eco-environmentally friendly bio composite resources, required to

improve efficiency and workers welfare across robotic support. A joint robotic arm (UR10e) was initiated to accomplish spraying and pressing tasks with correctness.

The proposal employed ARISE's middleware-based design on ROS2 and FIWARE technologies for sensor, and digital control systems incorporation. A vision-guided AI drove the robot for accurate spray patterns, while operators could switch to supervisory and quality control functions. This redeployment increased safety, reduced fatigue, and optimized resource utilization, reaping a 20% increase in productivity and 12% reduction in material consumption.

- RAPSEB illustrate about the combination of ergonomics and automation with a human-centered workflow with physical and safety aspects of HRI. SUNRISE was selected because it addresses cognitive collaboration, ease of use, and quick modification, which is the key elements of effective HRI, especially in SME. SUNRISE studies explain about integration of robots into adaptive production lines where task changed frequently. SME face challenges because of the technical expertise that is required to reprogram robots.
- SUNRISE resolves this with the suggestion of gesture and low-code interfaces that enable non-experts to naturally teach robots. It is Human-Centered Design (HCD) based and enhanced with the ARISE Social Sciences and Humanities (SSH) framework that highlights participatory design and incremental usability testing. The experiment spans robotic control via ROS2 with FIWARE building blocks to enable real-time synchronisation among human gestures, robot motion, and feedback mechanisms. Outcomes from user testing and simulation testing showed decreased cognitive load, increased trust, and improved learning-by-doing. SUNRISE explain the adoption of agile automation, emphasizing significant human-robot collaboration in variable industrial settings.
- RISES experiment targets intralogistics and logistics automation in brownfield conditions, and hence it is most relevant to SMEs that work in existing plants with minimal space for building developments. Its main purpose is to integrate

autonomous mobile robots and forklifts into joint human-machine working spaces within warehouses. RISES relies on ARISE's middleware for control, sensing, and coordination to enable real-time coordination of many mobile platforms and human operators. The robots employ 360-degree perception systems, adaptive speed controllers, and dynamic path planning to ensure safe coexistence. Rather than replacing labour, RISES facilitates collaborative task allocation robots do repetitive pallet movement, and individuals focus on oversight and decision-making. This is an acceptable social form of automation suitable for incremental SME transformation. RISES also puts into context the required organizational adaptations to make such integration feasible, including workflow redesign, worker training, and digital coordination.

Table 13. Comparative Overview of Selected ARISE Experiments.

Experiments	**Objective**	**Core Technology**	**HRI Dimensions**
RAPSEB	Safety Improvement	UR10e, FIWARE	Physical collaboration
SUNRISE	Flexible Learning	Gesture interface	Cognitive collaboration
RISES	Workflow Integration	Mobile robots	Organizational coexistence

RAPSEB, SUNRISE, and RISES collectively give a general overview of human-robot collaboration in three dimensions of SME operations: physical collaboration and safety (RAPSEB), cognitive collaboration and learning (SUNRISE), and organizational integration and coexistence (RISES). The multi-case configuration facilitates comparative analysis of diverse forms of human-robot collaboration in diverse industrial environments with a common uniform human orientation. Each case provides information, whereas taken together, they constitute a consistent picture of opportunities and challenges in the application of agile automation in SMEs.

3.3 Data Collection

The data for this research were collected entirely from secondary qualitative sources associated with the ARISE Project (Grant Agreement No. 101135784). Two official sources were employed, the ARISE Middleware website (ARISE, 2025)the European Commission's CORDIS database (European Commission, 2025). These websites are official European Union websites that deliver actual, evident, and peer-checked facts of experiments and provide consistency and reliability of collected data. The data included an extensive mix of data containing formal project reports, experiment documentation, CORDIS project results, and multimedia sources. General, these sources carried complete data observing the extension, experimenting, and use of human-robot interaction (HRI), human-centred design (HCD), and agile automation principles in small and medium-sized enterprises (SMEs) in the ARISE programme.

These were supplemented by CORDIS deliverables that placed technological conclusions into situation to emphasize socio-economic effects for SMEs, suggesting policy-level support and triangulation of results. To clearly demonstrate the connection between the selected, ARISE experiments, their documented outputs, and the research themes of this study.

Table 14. Relevance of ARISE data to the research theme (Source: ARISE's official website and the European Commission's CORDIS).

Experiment/ Source	**Key Data Point**	**Relevance to Research Themes**
RAPSEB	Robotic arm automation	HRI theory – ergonomic shift
SUNRISE	Gesture/voice HRI modules	HCD & Trust theory – usability
RISES	Safe warehouse automation	Organisational learning theory – agility
Project Deliverables	SSH & TEF frameworks	HCD & Trust theory – grounding
Press Release	SME experiments	Organisational adaptation theory

Data gathering was guided by documentary analysis and qualitative content structuring. It started with searches and collection of all existing ARISE reports and outputs that are significant to the aims of the research. Each report was screened for the presence of keywords including human–robot interaction, human-centred design, agile automation, safety, trust, and SME adaptation. The screening was conducted manually through iterative keyword searches within document. Documents (experiments, reports, conference proceeding, summary of the projects) and related multimedia and deliverables were included as they provided direct empirical, methodological, or design evidence connected to HRI or SME implementation. Documents linked with ethics guides were ignored to maintain the data relevance. Carefully chosen documents were recorded in a structured folder supported with the three experiments (RAPSEB, SUNRISE, and RISES). Each file was described by file type.

The final dataset comprised, technical deliverables, reports of each experiment, and conference paper. To guarantee data reliability, all data were cross validated relating the ARISE source and subsequent CORDIS records to prove publication accuracy and reliability. Prospective resource bias across several document such as technical deliverables, experiment reports, and dissemination materials, to confirm neutral understanding. This research is based on open-access and publicly available data no ethical approval was needed. Approach to ARISE and CORDIS data authorized to get real, peer-validated proof of real-world HRI in SMEs, preventing fieldwork limits while maintaining investigation depth.

According to the volume of the NVivo export files, only the mainly important facts has been separated, combined, and reported as a separate document, which is comprised in the Appendices. This then provides a summarised, yet comprehensive overview of the key themes and insights identified through data analysis, as required to allow readers to appreciate the empirical basis of the study without working through all of the NVivo datasets in full. In this way, placing this material in the appendices keeps the main text

focused and readable but still allows transparent access to the underlying analytical evidence for those who wish to review it in more detail.

3.4 Data Analysis

The analysis phase interprets and organizes the qualitative data from only two confirmed publicly accessed sources: ARISE Middleware website (ARISE, 2025) and the European Commission's CORDIS project outcomes webpage (European Commission, 2025). The two sources consist of official deliverables, news releases, and dissemination reports document that show how the ARISE consortium designs and tests human-centric agile automation solutions for various industrial environments. Data collected from the two sources was compared to identify patterns of human-robot interaction (HRI) within small and medium-sized enterprises (SMEs) and how experimental work conducted by ARISE facilitates the transition from manual to semi-autonomous control. Two concurrent phases of analysis were conducted: thematic analysis to establish recurring themes and comparative analysis to compare differences between ARISE experiments by using NVivo.

3.4.1 Thematic and Comparative Analysis

Thematic analysis was done to methodically code and clarify qualitative data obtained from textual documents, workflows, and images from the ARISE Middleware and CORDIS project websites. Each document (technical descriptions, deliverable summaries, and press releases) was assessed several times for comprehensiveness and precision of data.

Consistent with Lorelli S. Nowell et al., 2017, the exploration contained interpretation the data, making primary codes, observing and examining themes, identifying and naming themes, and conclude with the final interpretation. Qualitative data were coded and investigated by using NVivo 15 software.

Coding employed both inductive and deductive coding approaches. Preliminary open coding let theories to emerge quickly from the project documentation, while the deductive part portrayed these codes on the theoretical IPO framework. Data triangulation among text, flowcharts, and images improved the consistency of the findings. The quotes from the coding process were methodically recorded and analysed using NVivo 15 to allow methodological clarity. Whereas most coding groups were deductively derived from the IPO framework, Inputs, Processes, and Outputs, a few new concepts "System Limitation," "Efficiency and Productivity," and "Innovation" emerged from the texts of ARISE deliverables inductively. During iterative coding, these developing codes were theoretically refined and combined into groups of the existing framework to increase the logical consistency. "System Limitation" emerged with "Learning and Training," "Efficiency and Productivity" emerged under "SME Performance," and "Innovation" emerged under "Organizational Change." These modifications founded a clear classified structure within NVivo's 15 coding system.

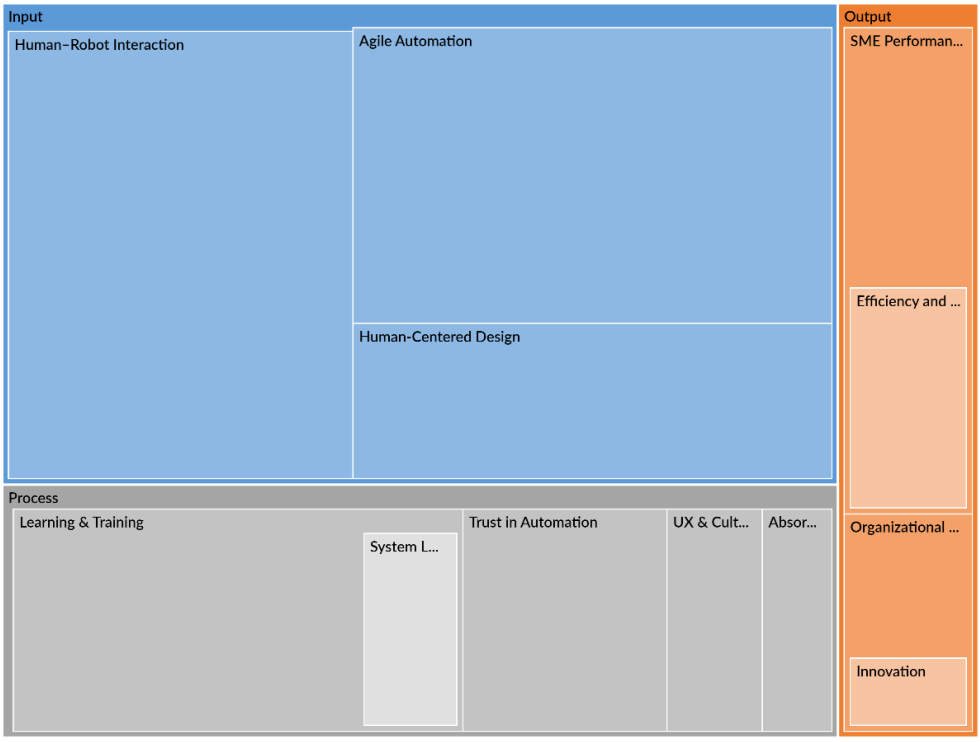


Figure 10. NVivo Hierarchical chart Based on the Input–Process–Output (IPO) Framework

Thematic validation was achieved across repeated verifying coded sections within NVivo 15 to verify the reliability of understandings. The section below asserts the conclusions of the thematic analysis conducted on ARISE's three experimental: RAPSEB, SUNRISE, and RISES. Each experiment was examined using the Inputs–Processes–Outputs (IPO) framework to systematically represent key themes developing from the ARISE Middleware and CORDIS project. The analysis highlights how human–robot interaction (HRI), agile automation, and human-centered design principles effect organisational developments and efficiency within small and medium-sized enterprises (SMEs). Table 15, 16 and 17 presents the key ideas identified from the experiment.

Table 15. Experiment 1 RAPSEB thematic Analysis (Source: ARISE's official website and the European Commission's CORDIS).

Framework Dimension	**Key Themes / Elements**	**Description (Based on ARISE & Framework)**
Input	Human–Robot Interaction	High-precision human and robots' collaboration to make bio composites.
	Agile Automation	Robots that can adapt to different types of materials and meet the needs of each product.
	Human-Centered Design	Robots help to make environmentally friendly materials more accurately and skilfully.
Process	Trust in Automation	Human trust robots in accuracy
	Learning & Training	Operators training to set up, keep an eye, and use precision robotics.
	UX & Cultural Readiness	Changing organizational culture to accept automation.
	Absorptive Capacity	The willingness of small and medium-sized businesses to use robotics, AI, and eco-friendly materials.
Output	Organizational Change	Changing the jobs of factory workers and adding sustainability and robotics to the way things are done.
	SME Performance	Higher overall manufacturing efficiency, better accuracy, less waste of materials, and more sustainability.

Table 16. Experiment 2 SUNRISE thematic analysis (Source: ARISE's official website and the European Commission's CORDIS).

Framework Dimension	**Key Themes / Elements**	**Description (Based on ARISE & Framework)**
Input	Human–Robot Interaction	Gesture and voice control make it easy for people and robots to work together in a natural way.
	Agile Automation	A flexible robotics system that can handle the small batch manufacturing and frequent product changes that are common in cosmetics production.
	Human-Centered Design	Robot systems that are made to make the work of operators easier, safer, and more adaptable to the needs of people on production lines.
Process	Trust in Automation	Reliability, openness, and quick response of gesture and voice systems to build user trust in robots.
	Learning & Training	Operators need to learn how to use gesture and voice systems, and the robot's AI learns from what the operator says and does.
	UX & Cultural Readiness	Changing the culture of the workplace from manual work to production with the help of robots.
	Absorptive Capacity	SME's ability to use AI and HRI technology in their current manufacturing processes.
Output	Organizational Change	Reorganizing workflows means that people will have to do more monitoring and decision-making duties.
	SME Performance	More flexible production, better ergonomics, fewer mistakes, and happier employees.

Table 17. Experiment 3 RISES thematic analysis (Source: ARISE's official website and the European Commission's CORDIS).

Framework Dimension	**Key Themes / Elements**	**Description (Based on ARISE & Framework)**
Input	Human–Robot Interaction	Humans and autonomous forklifts or mobile robots working together in the same warehouse location.
	Agile Automation	Robots that may change with the inventory, the layout of the warehouse, and the way orders come in.
	Human-Centered Design	Put safety and comfort first when using robots; they should help workers, not replace them.
Process	Trust in Automation	Building trust in robots by making sure they act in a consistent, predictable, and safe way in common spaces.
	Learning & Training	Building a culture of safety and being receptive to working with robots.
	UX & Cultural Readiness	Cultivating a culture of safety and receptiveness to joint endeavours with robots.
	Absorptive Capacity	Minimal disruption to the integration of robots' middleware and warehouse management systems (WMS).
Output	Organizational Change	People take care of exceptions, whereas machines take care of moving things that happen repeatedly.
	SME Performance	Run operations effectively and efficiently

After the thematic analyses, a comparative analysis was conducted to assess interrelatedness and frequent patterns among the three ARISE experiments.

Cross-case comparisons were conducted by using NVivo's Framework Matrix, which investigate the coded themes across RAPSEB, RISES, and SUNRISE. The matrix framework allowed acknowledgement of convergent and divergent associations in inputs, processes, and outputs, verifying a methodical amalgamation of how different forms of human–robot collaboration impact on organisational change, effectiveness, and sustainability.

Table 18. Comparative analysis of three experiments (RAPSEEB, SUNRISE, RISE) (Source: ARISE's official website and the European Commission's CORDIS).

Framework Dimension	**RAPSEB**	**SUNRISE**	**RISES**	**Common Themes / Insights**
Input	Precision HRI for sustainable bio composites; adaptive robotics for varied materials.	Gesture / voice control for small-batch cosmetics; ergonomic design.	Human–robot teamwork in warehouses; adaptable mobile robots.	Human-centred and agile design across contexts; robots augment human capability.
Process	Trust through precision; operator upskilling; cultural adaptation for sustainability.	Trust via intuitive interfaces; training and AI learning; absorptive integration.	Trust through safe behaviour; safety culture; seamless system integration.	Trust, learning, and cultural readiness as collective enablers; absorptive capacity varies by complexity.
Output	Sustainable production, reduced waste, redefined roles.	Workflow redesign, ergonomic gains, flexibility.	Task redistribution, safety, and efficiency	Organizational transformation and SME performance gains in flexibility, safety, and sustainability.

Comparative and thematic analysis reveal that all three experiments ARISE, RAPSEEB, SUNRISE, and RISES, have a consistent focus on human-centric and adaptable automation as enablers of SME change. Regardless of differences in industrial context, each experiment shows that fruitful collaboration between humans and robots depends on the building of trust, learning facilitation, and generating cultural readiness within organisations.

3.4.2 Trending, Changes, and Challenges in HRI

Advancements in Human–Robot Interaction (HRI) show a definite move toward automation that is human-centered. Collaborative robots are cost-effective, flexible, and simple to integrate. Adaptive interfaces allow robots to learn from operator actions and adjust their behaviour in real time. The ARISE experiments represent these trends in the employment of sensory system interaction e.g. gesture, voice, and shared space. It constructs trust and operating consistency between humans and robots.

Table 19. Trends, changes, and challenges in HRI (Source: D4.3 Periodic Report on the ARISE Testing and Experimentation Facilities).

Aspect	**Trends / Change**	**ARISE-Derived Evidence**	**Challenges**
AI & LLM	Natural communication	LLM-based intent and voice control	Unpredictable output
ROS4HRI	Tracking standardization	3D body tracking & RULA index	Inaccurate pose
Ergonomics	Real-time Monitoring	FIWARE ergonomic dashboard	Complex Interface
Interfaces	Gesture and voice	Hololens & VOSK modules	Limited Landmark design
Software Stack	ROS2 integration	Vulcanexus middleware upgrade	Compatibility issues

Aspect	Trends / Change	ARISE-Derived Evidence	Challenges
Social HRI	Intuitive app	TIAGo robot tablet interface	Time-intensive UI
Ethics and Trust	Privacy focus	Data-safe monitoring & SSH ethics	Trust Calibration

These conclusions demonstrate ARISE's association with HRI changes while exposing the constant difficulties in ergonomics, consistency, and trust. Main problem is lack of training. Workers should have knowledge to operate the robotic system meanwhile they must be aware about the surroundings. Another problem is limited resources which hinders SMEs to adopt automation. Moreover, technical limitations e.g. interaction difficulties, data privacy, and real-time decision-making delays, limit SMEs transformed. The ARISE data solve these problems and introduced technological innovation, continuous human learning, sharing system design, and ethical domination to qualify automation advancement, instead of human replacement.

3.5 Validity and Reliability

Confirming validity and reliability to the research findings, this study was established on qualitative document evaluation of publicly available documents from the ARISE Middleware and CORDIS websites. Organizational accuracy was confirmed through methodical data gathering practices, triangulation throughout numerous resources, and open coding practices. The studies followed Nowell et al. (2017) values of qualitative accuracy, confirming that explanations were both data-driven and theoretically knowledgeable. Reliability was also strengthened by coding, notes writing, and documenting during the study that make the results further reliable.

Table 20. Validity and Credibility Strategies (*Source: Adapted from Nowell et al., 2017*).

Strategy	**Application**	**Validity Criterion**
Triangulation	Cross-source check	Credibility
Open Coding	Iterative analysis	Dependability
Reflexivity	Self-reflection notes	Confirmability
Ethical Practice	Public data use	Integrity
Audit Trail	Transparent documentation	Dependability
Thick Description	Contextual Detail	Transferability

3.5.1 Triangulation of Sources

Data is collected from the ARISE Middleware website and the European Commission's CORDIS source. The two sources gave divergent depths on the group's purposes, experimental results, and materials. Using written documents, reports, flowcharts, images triangulate conclusion supported cross-verification and reduced the probability of false impression or bias from their resources. The use of both practical and technical materials, such as project summaries, progress reports, and case study descriptions, confirmed that explanations of Human–Robot Interaction (HRI) reproduced the group's main objective instead of singular account. This approach made the results more reliable by combining different types of data. Collecting data from (ARISE, 2025; European Commission, 2025) corresponded and approved the accurateness of the explanations.

3.5.2 Researcher Bias and Mitigation Strategies

As the researcher know about the nature of qualitative research reflexivity and methodological openness helped to reduce researcher bias. Reflexive diary was employed while coding the documents, investigative findings, and developing understandings. The theoretical IPO framework was used while coding in NVivo 15. Then documents were imported to code, organize, and connect raw data to the IPO

framework codes. Throughout this iterative process, three new codes “System Limitation”, “Innovation”, and “Efficiency and Productivity” appeared inductively from the documented data. Initially these inductive codes were not the part of IPO framework. Besides, by exactly understanding well-defined theme investigation processes (Nowell et al., 2017) and confirming that all analyses were attached in brief documented or visual evidence from primary sources, the study sustained informative validity and core reliability. These mitigation measures successfully deal with researcher bias thus increase the credibility, reliability of the study.

4 Results and Analysis

This chapter explain qualitative cross-case analysis of ARISE Project experiments (RAPSEB, RISES, and SUNRISE) indicating different SME situations. NVivo coding outputs originated from thematic and comparative analysis as drawn in Chapter 3. These results solve the research questions how HRI, HCD, and agile automation can assist SMEs transformation in different operational settings. By using NVivo 15 and an Input–Process–Output IPO coding framework, this study conveys deductive and inductive understandings to explore human–robot interaction, human-centered design, and agile automation affect in emerging workflows. The deductive analysis confirmed theoretical association with the input process and output model, however the inductive analysis discovered new themes that develop broader insight. This chapter first go over coding plans and word trends that display the unique significances of each experiment. It then identifies, across the cases, four developing HRI patterns, from safety-driven interaction to more advanced cognitive collaboration. The analysis also describes how Agile Automation is changing human roles, enabling workers to move from manual tasks to supervisory, coordination, and teaching tasks. Finally, the chapter highlights changes, trends, challenges, and opportunities at an organizational level when adaptive robotic systems start to be adopted by SMEs.

4.1 Summary of Case Study Observations

Analytical results of the qualitative analysis organized using NVivo 15, which was the main tool for the organizing, coding, and interpretation of data from the three experiments of the ARISE Project: RAPSEB, SUNRISE, and RISES. Although still in the experimental stage, these three experiments represent distinct real-time industrial contexts (manufacturing, smart factory operation, and logistics) and collectively illustrate how human–robot interaction, human-centred design, and agile automation are shaping workflow development within SMEs. The analysis followed the Input–

Process–Output (IPO) framework, and the coding categories were derived both deductively from theory and inductively from ARISE project material, resulting in a structured NVivo codebook comprising nine main codes as shown in NVivo image 1.

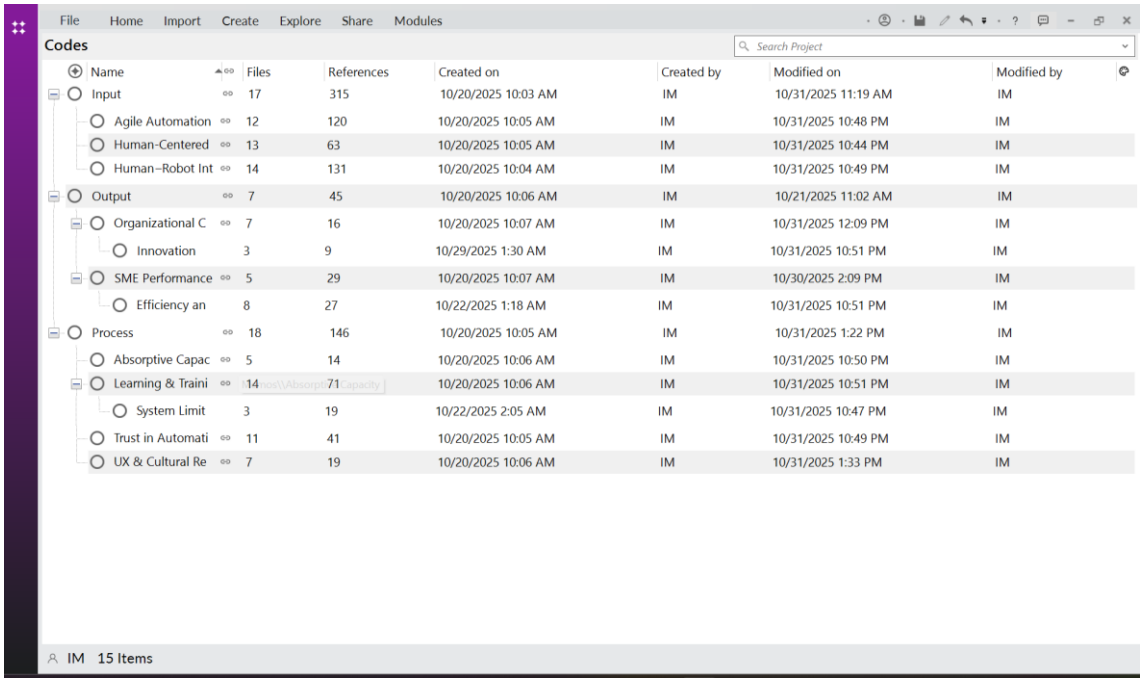


Image 1. NVivo image of codes.

Image 2 of NVivo depict all the files coded for the qualitative study. The three experiments RAPSEB, RISES, and SUNRISE are the main cases of the study. Additional documents (TEF workflows, architecture schematics, RULA assessments, and use case requirements) were coded only as supporting sources to provide contextual and procedural insight. Figure 11 distinguishes the primary case study sources from supplementary technical documentation used to enrich thematic interpretation. All primary case documents (RAPSEB, RISES, SUNRISE, and Summary-of-project) show 100% coding coverage; several larger supporting PDFs show partial coverage according to the relevance of the selected experiments.

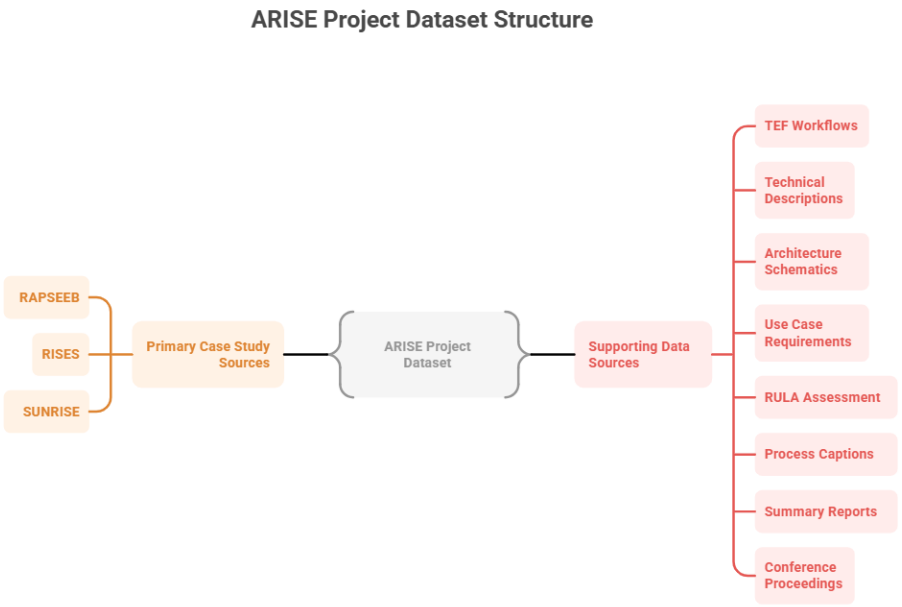
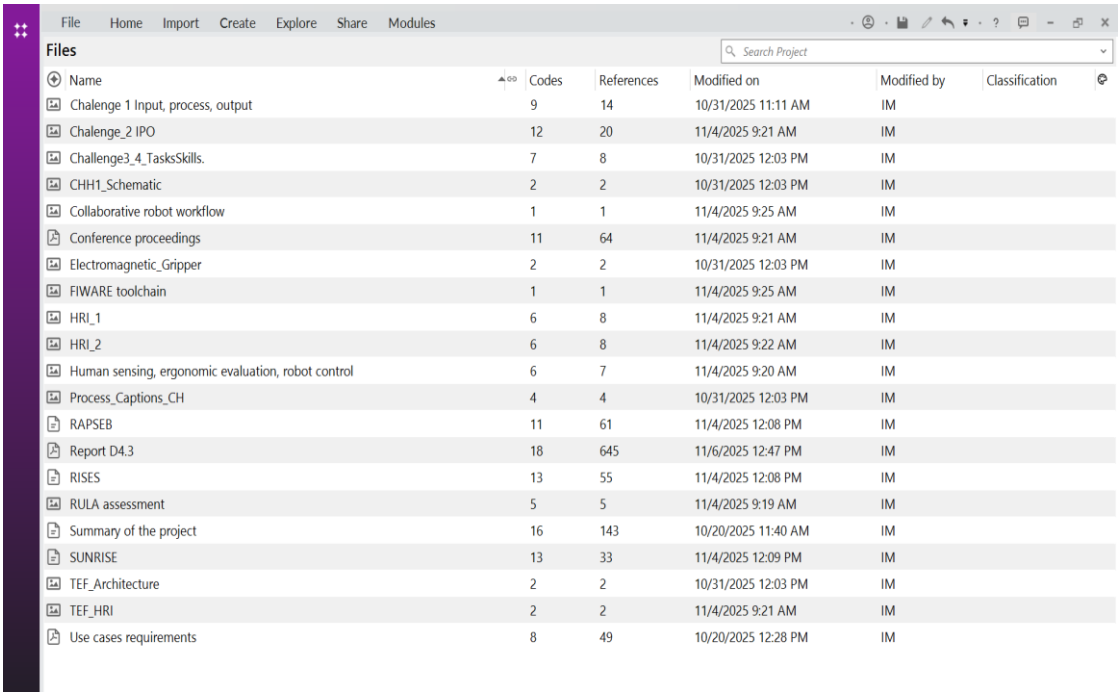


Figure 11. Arise Project Dataset.



File Home Import Create Explore Share Modules

Files

Search Project

Name	Codes	References	Modified on	Modified by	Classification
Chalenge 1 Input, process, output	9	14	10/31/2025 11:11 AM	IM	
Chalenge_2 IPO	12	20	11/4/2025 9:21 AM	IM	
Challenge3_4_TasksSkills.	7	8	10/31/2025 12:03 PM	IM	
CHH1_Schematic	2	2	10/31/2025 12:03 PM	IM	
Collaborative robot workflow	1	1	11/4/2025 9:25 AM	IM	
Conference proceedings	11	64	11/4/2025 9:21 AM	IM	
Electromagnetic_Gripper	2	2	10/31/2025 12:03 PM	IM	
FIWARE toolchain	1	1	11/4/2025 9:25 AM	IM	
HRI_1	6	8	11/4/2025 9:21 AM	IM	
HRI_2	6	8	11/4/2025 9:22 AM	IM	
Human sensing, ergonomic evaluation, robot control	6	7	11/4/2025 9:20 AM	IM	
Process_Captions_CH	4	4	10/31/2025 12:03 PM	IM	
RAPSEB	11	61	11/4/2025 12:08 PM	IM	
Report D4.3	18	645	11/6/2025 12:47 PM	IM	
RISES	13	55	11/4/2025 12:08 PM	IM	
RULA assessment	5	5	11/4/2025 9:19 AM	IM	
Summary of the project	16	143	10/20/2025 11:40 AM	IM	
SUNRISE	13	33	11/4/2025 12:09 PM	IM	
TEF_Architecture	2	2	10/31/2025 12:03 PM	IM	
TEF_HRI	2	2	11/4/2025 9:21 AM	IM	
Use cases requirements	8	49	10/20/2025 12:28 PM	IM	

Image 2. Image of files in NVivo.

4.1.1 Comparative Insights

Before detailed explanation it is valuable to draw brief comparative insights about the three ARISE experiments. RAPSEB is an example of a mature automation environment in manufacturing, concerned with safety, precision, and human-robot coordination. RISES, in a logistics scenario, focuses on dynamic mobility and navigation in warehouses, with safe coworking between humans and autonomous systems. SUNRISE, in the smart factory context, deals with cognitive interfaces, that is, multimodal human-machine interaction, where intuitive control and worker empowerment are in focus. While all three contribute to the understanding of HRI, HCD, and agile automation in SMEs, their industrial contexts differ quite considerably, as do their technological maturity levels.

Table 21. Comparative summary of experiments (NVivo Export).

Experiments	**Type of HRI**	**Level of Trust**	**Ergonomics Benefits**	**Summary Insights**
RAPSEB	Physical Collaboration	High	High	Safety Integration
RISES	Co-presence	Moderate	Medium	Adaptive Logistics
SUNRISE	Gesture-based	High	High	Cognitive Interaction

4.1.2 Cross-Case Coding Patterns

The cross-case thematic matrix (Figure 12) displays various patterns in three experiments RAPSEB, RISES, and SUNRISE simultaneously with human factors, agile automation, and organizational readiness. These experiments were compares and identified by NVivo's 15 cross-case coding matrix, which compares frequency of coded references under each

thematic set. The most advanced and novel experiment is RAPSEB, which prominence on Agile Automation, Human-centered Design, Human-Robot Interaction, and SME Performance. As shown in Figure 12, RAPSEB exhibits the elevated intensity of coding among Agile Automation and Performance themes, which reveals influential combination of automation and human-centred design systems as compared to the other experiments. It also shows that RAPSEB drives within an advanced innovative setting, where automation was embedded and assisted by effective human-centered design and performance goals.

On the other hand, RISES shows a more stabilized HRI, agile automation, Human-centered design with absorptive capacity, trust in automation, and cultural readiness. RISES constantly improves its fundamental skills, learning methods, and the cultural environment that is necessary for successful automation. Also, SUNRISE has the lowest numbers for most themes, which means that it is still in the early stages of the digital revolution, when automation, design integration, and organizational change are all still new.

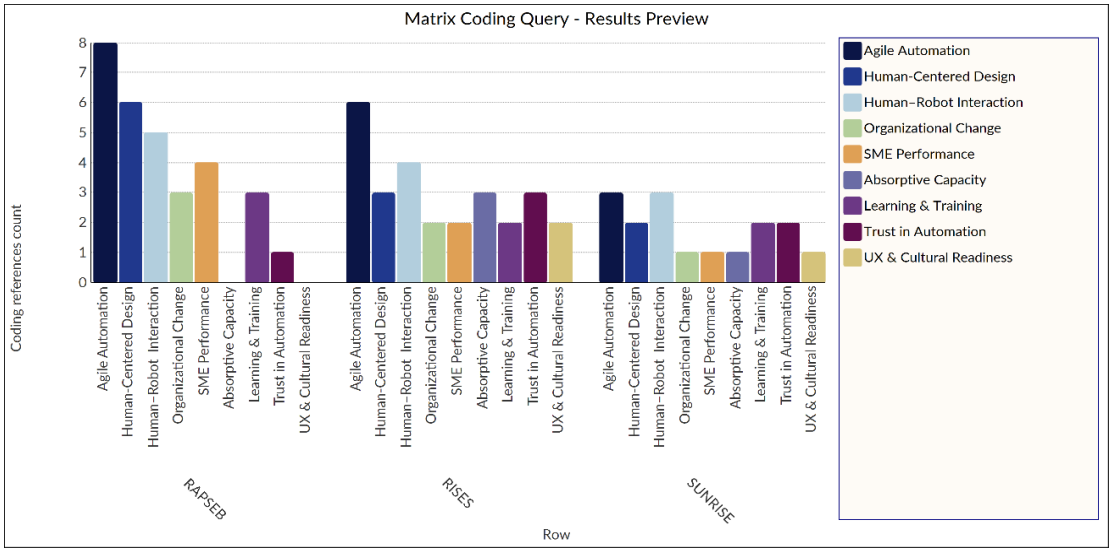


Figure 12. Matrix Coding Query of ARISE Experiments (NVivo Export, 2025).

4.1.3 Lexical Frequency and Thematic Orientation

NVivo's word-frequency analysis thus generated quite distinctive word clouds for RAPSEB, RISES, and SUNRISE, each capturing a different lexical signature linked to the operational environment and technological priorities of the different cases. Lexical analysis was applied to complement thematic coding by visually identifying dominant concepts and linguistic patterns that reflect the cognitive focus and communicative culture of each experiment. These visual patterns give meaning to the most frequent usage of the terms and underlying thematic orientations within discourse adopted by an organization.

1. **RAPSEB Word Cloud**:

RAPSEB word cloud (Figure 13) highlight the main frequency terms such as workers, exposure, spraying, control, module, and manufacturing, indicating concern with hazardous material handling and work safety. Chemical related words are epoxy, chemicals, composite, and irritative, indicating processes with the involvement of materials that is dangerous to human health; hence, it is critical to follow strict safety policies and limit exposure. Words such as robotic, precision, automation, line, and via indicate the presence of advanced robotic systems designed to automate these high-risk tasks with accuracy and consistency. The prominence of human, together with HRI (human–robot interaction), reflects an environment where workers and robots operate in close interaction, hence a need for safe integration. This lexical emphasis reinforces the theoretical dimension of human-centered safety design, where agile automation operates in high-risk environments to enhance worker protection and precision—a key tenet of adaptive HRI frameworks.

Figure 13. RAPSEB Word cloud (NVivo Word Frequency Output, 2025).

2. **RISES Word Cloud**

RISES word cloud (Figure 14) highlight the main frequency terms such as logistics, storage, forklifts, safe, dynamic, operations, workers, sensors, and warehouse. This term refers to warehouse environment, where arrangements, management, and decision-making must be managed in real time. Autonomous forklifts, navigation, cameras, predictive, and tracking are revealing advanced mobile robotic systems which navigate shared human–robot spaces safely. For example, words in relation to safe zones, obstacles, and barriers point to issues associated with spatial awareness and collision avoidance. Terms involve module, open, and automation, referring to scalability and flexibility at each system that can adapt to different warehouse arrangements. RISES thus shows a thematic training concerning automation driven by mobility. The importance of flexibility associates with the agile automation theory, explaining how adaptive robots and human relationship supports dynamic approach reconfiguration a fundamental side of understanding in HRI perspectives.

Figure 14. RISES Word cloud (NVivo Word Frequency Output, 2025).

3. **SUNRISE Word Cloud**:

SUNRISE word cloud (Figure 15) highlights the main frequency terms such as operators, design, voice, gesture, real-time, control, intuitive, feedback, and exposing focus on human-robot interaction and user interface design. Words such as monitoring, tasks, seamless, cognitive, and innovation exhibit a system planned to establish worker decision-making and decrease cognitive load through real interaction processes. The low-code, adaptive, error reduction, and quality shows flexibility and user-friendly automation. Terms such as machine, robotics, custom production, and manufacturing present that SUNRISE functions within a production perspective but stresses worker enabling rather than full automation. These lexical terms show cognitive HRI theory, highlighting a change from manual to multimodal interaction where human's role as cognitive partners rather than operators, supporting with the human-centered innovation within agile automation.

Figure 15. SUNRISE Word cloud (NVivo Word Frequency Output, 2025).

The “Insight Across Cases” word clouds reveal distinct thematic priorities for each project. The collective word cloud Figure 16 highlights conclusions by pointing the repeated terms across three cases, such as operators, humans, systems, and collaborative tasks. This shared term reflects the extensive emphasis on human roles, collaboration value, and system-level combination. Generally, the variations and similarities exhibit work environment, and automation policies significantly impact SMEs. The lexical patterns crosswise experiments validate the theoretic connection as automation develops more agile and human-centered, organizational shifts from safety and control to flexibility and intellectual relationship.

Figure 16. ARISE experiments Word cloud (NVivo Word Frequency Output, 2025).

4.2 Emerging Patterns in Human–Robot Interaction within SMEs

The cross-case NVivo analysis represents four emerging HRI patterns. These patterns are established in the codes conclusions obtained from NVivo outputs, containing coding charts, each experiment bar charts, word clouds, and matrix coding queries. These files encourage the discovery of four dominant emerging HRI patterns:

1. Safety-driven interaction
2. Co-adaptive coordination
3. Intuitive multimodal communication
4. Progressive cognitive collaboration.

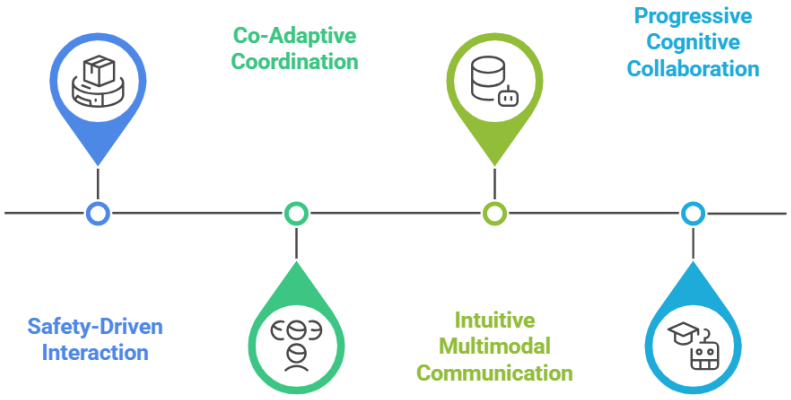


Figure 17. Emerging HRI patterns (Author's own source).

4.2.1 Pattern 1: Safety-Driven Interaction (RAPSEEB)

RAPSEB coding (Figure 18) shows an individual safety-focused HRI pattern. NVivo's coding division displays repetition for:

- Agile Automation ≈ 26.7%
- Human-Centred Design ≈ 21.4%
- SME Performance ≈ 17.8%

- HRI ≈ 15%

The prominence of codes such as *Agile Automation* (≈26.7%), *Human-Centred Design* (≈21.4%) and *SME Performance* (≈17.8%) suggests a safety-first trajectory in the sampled HRI activity. Theoretically, this pattern is consistent with human–robot interaction frameworks that emphasize human-in-the-loop control and graded automation: SMEs appear to adopt automation primarily where it reduces human exposure to hazards while preserving human supervisory authority. From a situation-awareness perspective, workers are retained as monitors who must maintain environmental awareness and detect robot anomalies; hence HRI designs that prioritize readability of robot states and clear feedback loops are likely to surface frequently in practitioner discourse. Similarly, models of levels of automation. Finally, the recurrent *Human-Centred Design* coding indicates that designers and operators are actively shaping robot affordances and interfaces to support safe monitoring, error recovery, and trust calibration rather than pursuing full autonomy immediately.

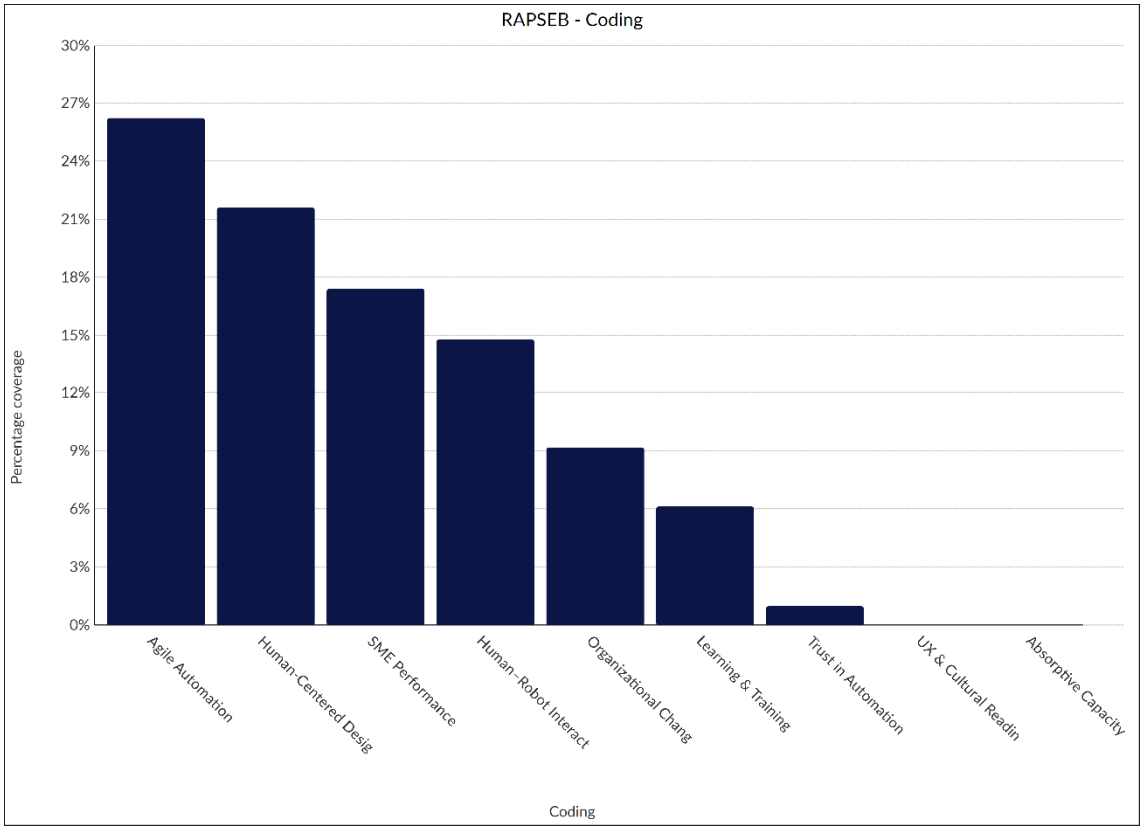


Figure 18. RAPSEB coding (NVivo Export, 2025).

The RAPSEB word cloud see Figure 13 show up central words such as “workers,” “exposure,” “spraying,” “hazard,” “control,” “environment,” representing an HRI pattern of assistive automation, where robots carry out hazardous or ergonomically taxing tasks, while humans retain supervisory control. Workers act as safety monitors, ensuring correct robotic behaviour while benefiting from reduced physical and chemical exposure. This pattern aligns with literature showing that SMEs often begin their HRI journey with risk mitigation and ergonomic benefits must be combined with guidance in observing and emergency response. Compliance frameworks must incorporate robot-specific risk assessments, updated SOPs, and regular safety audits to confirm both physical and cognitive safety of workers.

4.2.2 Pattern 2: Co-Adaptive Coordination (RISES)

The RISES coding (Figure 19) shows co-adaptive human and robot coordination in common settings. NVivo's coding distribution bar chart displays frequencies for:

- Agile Automation ≈ 24.9%
- SME Performance ≈ 14%
- HRI ≈ 12%
- Trust in Automation ≈ 9%

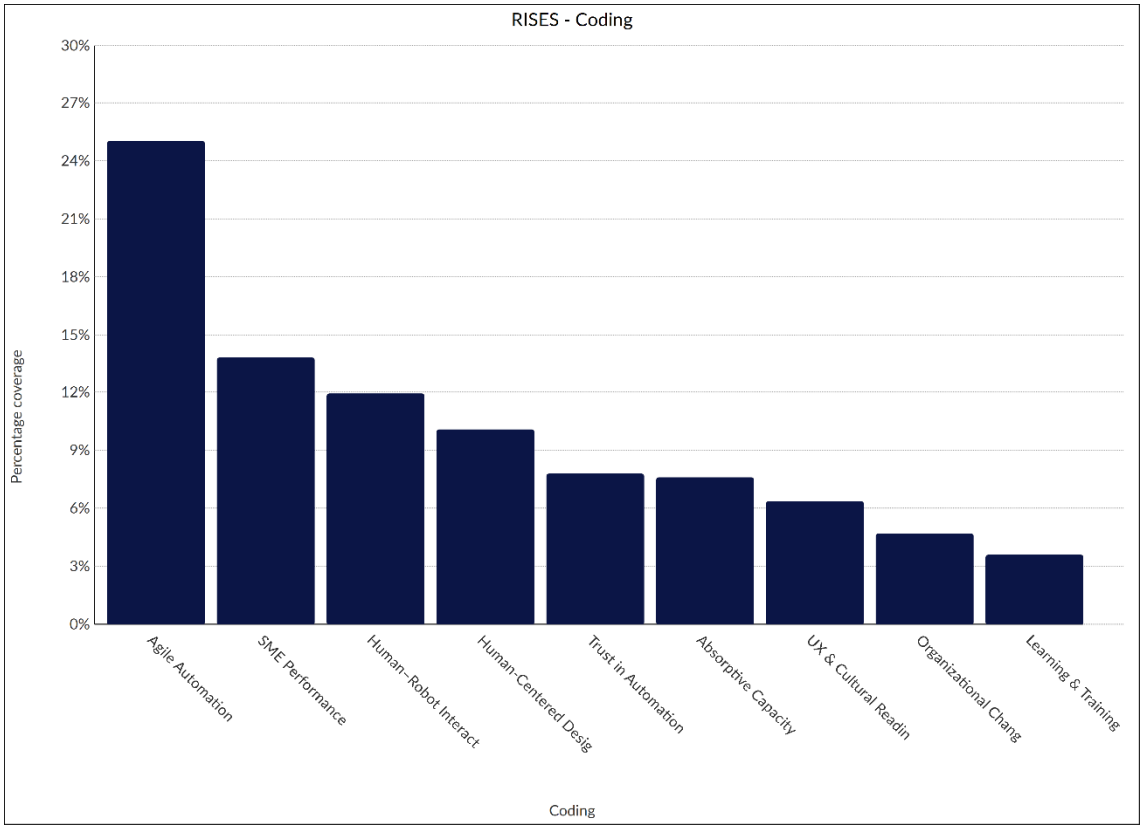


Figure 19. RISES coding (NVivo Export, 2025).

This division shows an effective setting where humans shared space, task with autonomous systems frequently. NVivo facts demonstrates this more concretely. For example, *"robots adjust their speed when workers enter the shared lane,"* and *"virtual barriers help organise staging areas and prevent interference."* Likewise, the dataset

contains notes to *"real-time monitoring enabling predictive alerts,"* exhibiting the system's constant responsiveness to human existence.

The RISES word cloud (see Figure 14) points out the terms such as: "logistics," "staging," "safe," "dynamic," "workers," "forklifts," indicating that collaboration is developed over:

- Collaborative material handling.
- Mutual predictability between human and robot movements.
- Human situational awareness guiding automation.
- Trust building through consistent robot behaviour.

In contrast to RAPSEB's protective approach, RISES embodies bidirectional adaptation. Workers change to automated trajectories and robots always recognize human existence paths. At the same time, shared autonomy emerges through coordinated workspace access, where human intent (e.g., entering staging areas) and robotic perception jointly determine navigation, task sequencing, and safety behaviour.

4.2.3 Pattern 3: Intuitive Multimodal Communication (SUNRISE)

SUNRISE coding (Figure 20) presents the most human-centric interaction design, characterized by gesture-based learning, voice commands, and intuitive robot control. NVivo-coded data emphasize:

- Human-Centred Design ≈ 14.1%
- Agile Automation ≈9.5%
- HRI ≈ 7.6%

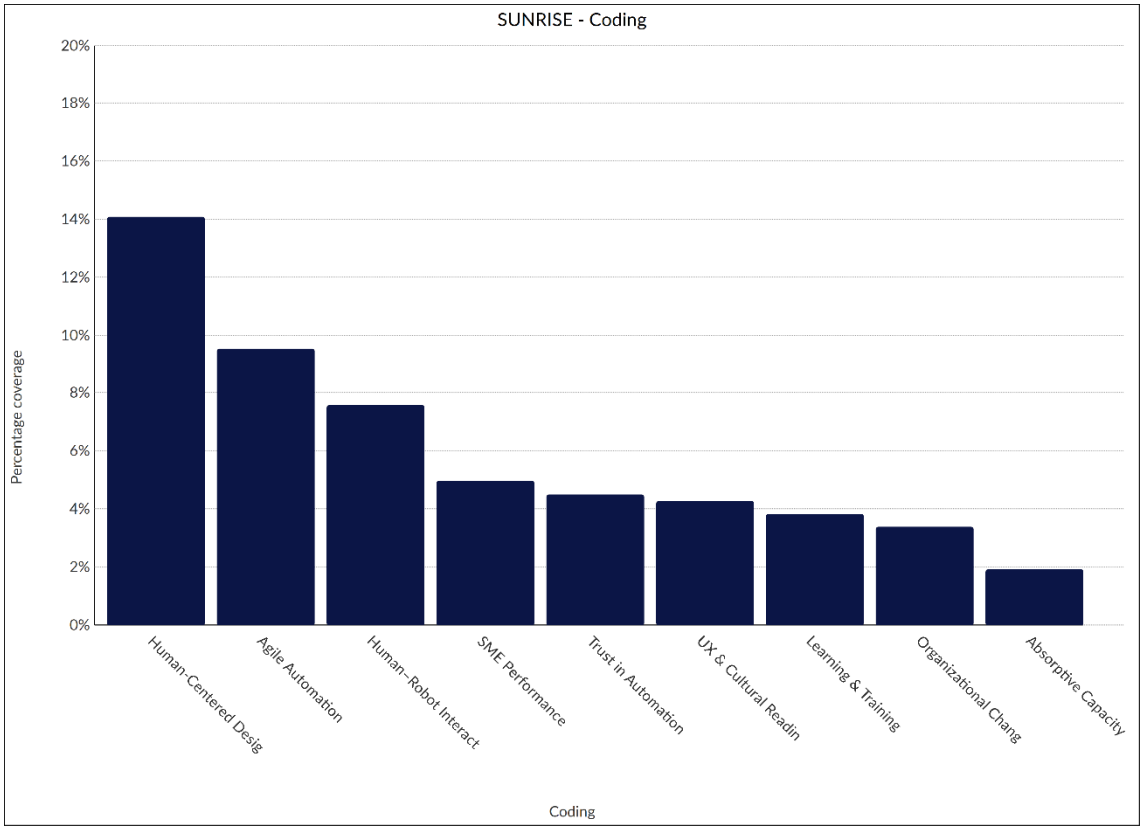


Figure 20. SUNRISE coding (NVivo Export, 2025).

The SUNRISE word cloud, see Figure 15 highlights keywords such as: “gesture,” “voice,” “control,” “feedback,” “quality,” “learn,” “intuitive,” “operator,” clearly showing that SUNRISE’s HRI pattern revolves around:

- Natural user interfaces
- Operator-led robot teaching
- Real-time feedback loops
- Reduction of cognitive strain through intuitive commands

NVivo-coded material associated with Human-Centred Design and HRI indicates that gesture and voice interfaces reduce the need for manual programming or complex menu navigation. By allowing operators to give commands through natural actions, such as pointing, guiding movements, or giving short verbal instructions, the system minimizes working memory demands and lowers attentional load. This finding is in line with insights coded under HCD: indeed, operators characterize the interaction as "intuitive,"

"less tiring," and "easier to correct in real time," all factors that directly reduce cognitive strain when performing a task. According to the HCD, SUNRISE correspond to attitudes of user control, clear user response, and association with human skills, as depicted in ISO 9241-210. The gesture and voice sensory system show the ISO constraint that co-operating systems should have. By situating robot control in forms of communication which humans already master fluently-such as pointing, demonstrating trajectories, or giving verbal cues-SUNRISE decreases the learning burden and supports the ISO guideline of minimizing unnecessary cognitive effort. Unlike RISES where interaction is spatial and operational, SUNRISE shifts HRI into the cognitive domain, where humans lead automation through subtle, natural communication channels. This reflects an emerging pattern of:

- High-level human–robot co-creation
- User-driven robotic learning
- Interface-based human empowerment

4.2.4 Pattern 4: Progressive Cognitive Collaboration (Cross-Case Pattern)

Derived from synthesis of NVivo coding outputs reveal a clear progression in how SMEs adopt HRI in three stages (Table 22, Figure 21).

Table 22. Stages of HRI (Summary Table)

Stage	Name	Robot Job	Human Job	Focus
1	Assistive (RAPSEB)	Handle hazards	Supervise	Safety, Ergonomics
2	Collaborative (RISES)	Share Autonomy	Co-work	Trust, Coordination
3	Cognitive (SUNRISE)	Adapt or learn	Lead	Learning, Multimodal

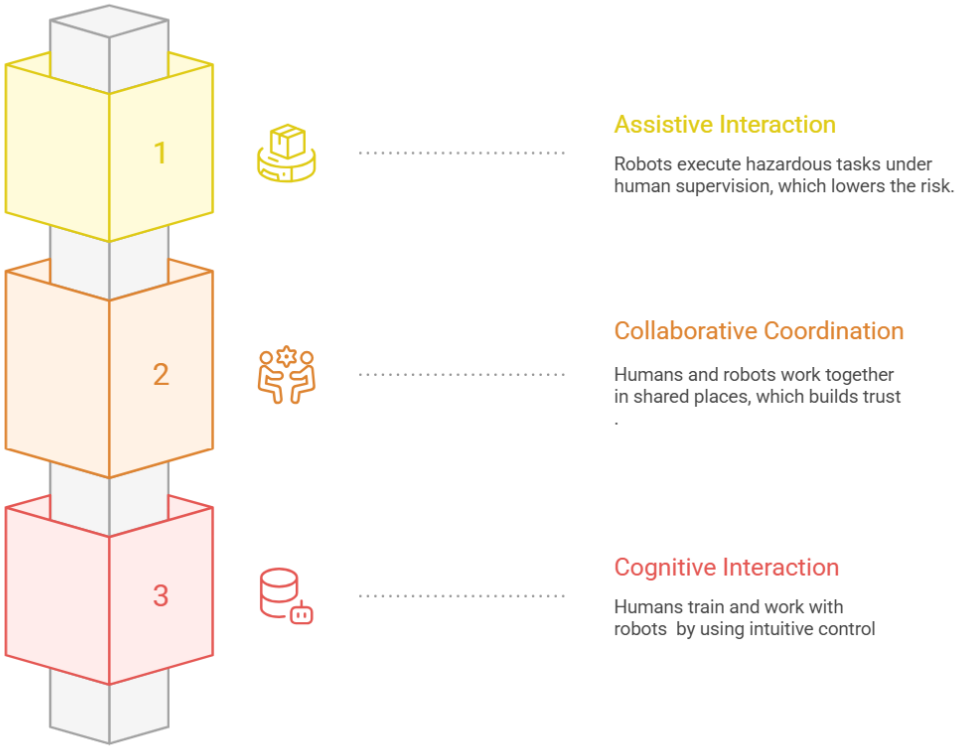


Figure 21. Stages of HRI (Author's own source).

4.2.5. Cross-Case Summary of Emerging HRI Patterns

The cross-case synthesis of RAPSEB, RISES, and SUNRISE shows four diverse yet interconnected patterns of Human–Robot Interaction. These patterns were derived directly from NVivo analytical outputs, including code frequency distributions, coding bar charts, word clouds, and the matrix coding figure, which visually demonstrates how the nine primary codes were distributed across the three experiments.

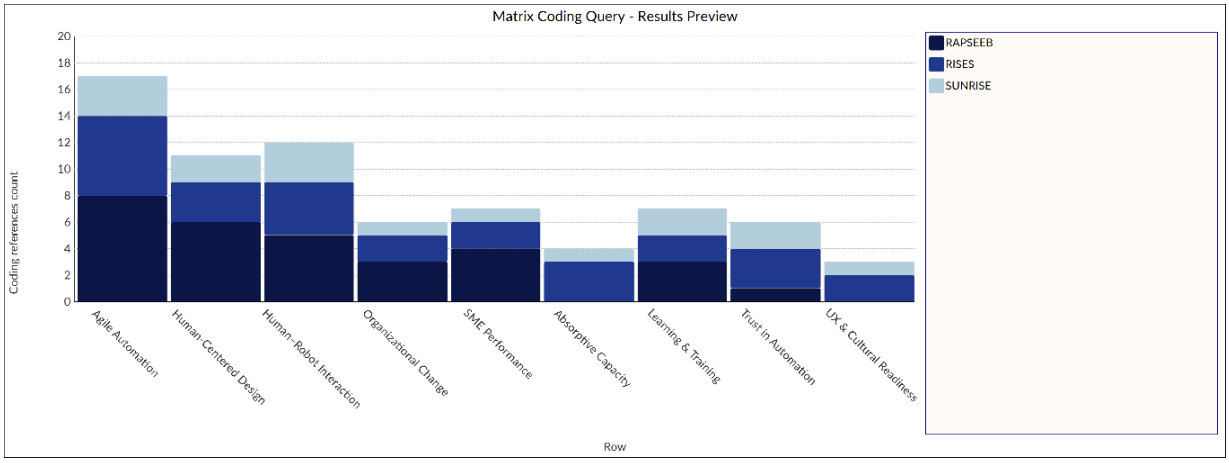


Figure 22. Cross case matrix coding query.

The matrix coding enabled a comparison of repeated themes such as Human–Robot Interaction, Human-Centred Design, Agile Automation, Learning & Training, Trust in Automation, and UX & Cultural Readiness, show a clear visual basis for finding cross-case similarities and disagreements.

Table 23. Progressive HRI Patterns

HRI Pattern	Experiments	Description
Assistive Safety-Driven Interaction	RAPSEB	Robots support by maintaining distances, ergonomic support, and supervised workflow.
Co-Adaptive Coordination	RISES	Humans and robots collaborate in mutual spaces with mutual feedback and adaptation.
Intuitive Multimodal Communication	SUNRISE	Collaboration driven by gestures, voice, and real instructions that lower cognitive load.
Progressive Cognitive Collaboration	Cross Case	Shared learning, worker-led system improvement, and cognitively strong teamwork across cases.

These four patterns were developed by systematic qualitative methodology carried out by NVivo's logical abilities. Deductive and inductive coding approach confirmed that theoretic concepts from HRI, Agile Automation, and Human-Centred Design were combined with developing understandings from the ARISE experiments. Notably, this development highlights a gap often noted in SME digital willingness literature. SMEs tend to implement assistive robots but face difficulties in evolving toward adaptive, in-built, or cognitively co-operative systems. NVivo-coded data reflects that SMEs face difficulties due to limited skills and training capability, and irregular UX maturity developments.

4.3 Impact of Agile Automation on Human Roles

Agile Automation became the most important input construct in the ARISE cases, driving both technological adaptation and changes in human roles in small and medium-sized businesses. However, Agile Automation does not bear only positive implications for human agency. Although it is pushing employees into cognition, supervisorial, and problem-solving roles, it may shift agency altogether where the repetitive or routine tasks become fully automated. Many coded segments reflected workers who feared a loss of task ownership or autonomy as robots handled predictable workflows. To what extent agency is enhanced or reduced, therefore, depends on organizational practices-particularly, the availability of training, the cultural readiness for change, and whether firms intentionally position humans in decision-making and creative tasks rather than simply replacing them.

The NVivo coding hierarchy confirms Agile automation as the most frequently referenced input node, with 12 file references**,** 120 (see figure 11). The Matrix Coding Query further shows that Agile automation receives the highest cumulative cross-case references among the nine main codes, indicating its substantial impact on workflow restructuring, skill redistribution, and organizational readiness. These coding patterns illustrate the IPO underlying Agile Automation's impact. Agile Automation repeatedly co-occurred with Human–Robot Interaction, Learning & Training, and Organizational Change. SME

Performance and UX & Cultural Readiness showed in selections where these process transformations occurred into organizational upgrading or new distributions of human roles. This confirms that Agile Automation acts as a technological input that starts process adaptations, which then translate into measurable changes in performance and human-role transformation.

Agile Automation means that robotic systems can adapt to changing production situations. It also means that people who work with, supervise, and create with these flexible technologies will have to take on new roles. It consistently serves as the conceptual bridge linking machine-level flexibility with human-level cognitive and supervisory work across RAPSEB, RISES, and SUNRISE. This section combines thematic density, case-specific insights, and patterns across cases to explain how Agile automation changes the roles of people in modern small and medium-sized businesses.

4.3.1 Thematic and Code Distribution

The results from the NVivo coding show that Agile Automation is the most-used Input in the ARISE dataset (see Figure 12). This shows that agile automation is not only a technology, but also changing the roles of people in RAPSEB, RISES, and SUNRISE. When look at the code distribution and the human-related codes, such as Learning, Trust in Automation, UX & Cognition, and Absorptive Capacity, you can see that changes in human occupations arise because technology is so adaptable and so much labour requires workers to think. As the trends reveal, role transition is based on two primary things:

Workers need to be ready to understand, adapt to, and work with robotic systems at the input level. Involvement at the process level means that workers learn new abilities by studying, interpreting systems, keeping an eye on them, and making choices. These data

illustrate that Agile Automation doesn't impact the way people work by changing only a few tasks at a time. It establishes setting where workers are constantly learning as they shift from manual task to supervisory roles.

Table 24. Thematic and Code Distribution related to change in human roles.

Codes	**Sub codes**	**File**	**References**	**Contribution to Human Role Change**
Input	Agile Automation	12	120	Initiates the transition from manual to adaptive human work.
	HRI	14	131	Transfers workers from manual duties to the coordination, monitoring, teaching, and real-time supervision of robots.
	HCD	13	63	Changes the jobs of workers as systems are designed that is easier to use and help to adapt automation.
Process	Learning and training	14	71	Develops new competencies and cognitive abilities.
	Trust in Automation	11	41	Establishes confidence in mutual work.
	UX and Cognitive Theory	7	19	Clarity of Task and cognitive load.
	System Limitations	3	19	Monitoring and real-time adjustments.
Codes	**Sub codes**	**File**	**References**	**Contribution to Human Role Change**
	Absorptive Capacity	5	14	Improves ongoing learning
Output	SMEs Performance	5	29	Reflects outcomes
	Efficiency	8	27	Increase Performance

4.3.2 Redefinition of Human Roles

Cross-case analysis uncovers an organized, progressive change in work through implementing Agile Automation in SMEs. This conversion follows a transparent trajectory within the ARISE experiments:

Table 25. Transformation of Human Roles Under Agile Automation

Cases	**Previous Human Job**	**New Human Job**
Assistive	Manual Spraying	Supervisory
Collaborative	Repetitive Task	Real Time Coordination
Cognitive	Manual Setup	Robot teaching

Table 25 clearly explains that agile automation supports role development, not replacement. This observation is constant with extensive job-redesign and automation literature works which explain that robots redesign human work toward more composite, supervisory and decision-oriented duties instead of removing them. Studies in Industry 5.0 and human-factors more identify that workforce gradually participate performing with automation systems (Trstenjak, Benešova, Opetuk, & Cajner, 2023). Across all cases, humans are superior into roles that expect:

- deeper system knowledge,
- decision-making authority,
- supervisory capabilities,
- creative problem solving.

These shifts present main effects for SME guidance. As human responsibilities converted into more cognitive, supervisory and interface driven. SMEs invest on upskilling workers to develop digital fluency, HRI competence, and adaptive problem-solving. Studies on

SME transformation steadily exhibits that inadequate training is one of the core barriers to implement automation. Continuous reskilling is important for agile automation.

4.3.3. Synthesis: Agile Automation as a Human Empowerment Mechanism

The NVivo results of three experiments shows that agile automation confirms safety of workers. In RAPSEB, the chemical exposure of workers is reduced with the use of robot arm. It makes it easier for people to work together with robots in common spaces, same in RISES. It also changes the job responsibilities of workers. Agile automation enhances absorptive capacity of an organization, which facilitates small and medium-sized businesses slowly implement automation. It also offers people more independence in all settings, especially in SUNRIISE. In it labour force teach robots through gestures.

These conclusion support theoretically by challenging conventional automation literature, in which automation is typically associated with worker displacement, deskilling, and rigid task substitution. On the contrary, agile automation assists worker encouragement through learning, and combined decision-making. Across all experiments explicit that workers don’t lose control rather actively guide and reshape the automation system. RAPSEB’s improved safety roles, RISES’s offers flexible HRI, and SUNRIISE’s training robots through gestures. This confirms that agile automation is not only a technological turn but also a theoretical base. The thesis thus develops Industry

5.0 belief by determining that encourage flexible, human-centered automation environment that was not present in the conventional automation consideration.

Figure 23. Impact of Agile automation (Author's own source).

4.4 Impact of Human–Robot Interaction and Agile Automation on Organizational Change

The combination of Human–Robot Interaction (HRI) and Agile Automation (AA) within the ARISE experiments is a medium for organizational change within SMEs. The NVivo coding reports show that Organizational Change develops steadily. It is the main output code, with 7 document-references**,** sub-coding (e.g., Innovation), and major connections to input codes HRI, Human-Centred Design, and Agile Automation (see Image 1). The Cross-Case Thematic Matrix Figure 22 emphasizes RAPSEB, RISES, and SUNRISE each link HRI and Agile automation with diverse forms of operating adjustment, workplace and cultural readiness. HRI initiated organizational change by shifting workers' roles from manual performance to supervising, directing and decision-making. To clarify these

shifts, NVivo-coded data explain the restructuring of workflows and human roles. For example, *"workflow redesign and change in roles,"* demonstrating that the initiation of adaptive automation involved changing the existing duties. Technical aspects also impacted to organizational change. One coded reference noted, *"impact of calibration"* required repeated changes in workflow. Organizational change in SMEs develop response to the active communication between people and robots. Three organizational changes were connected:

1. Structural workflow change
2. Cultural readiness
3. Innovation-oriented transformation.

These ways show how SMEs understand new automation abilities, redesign their processes, roles to support sustainable digital revolution.

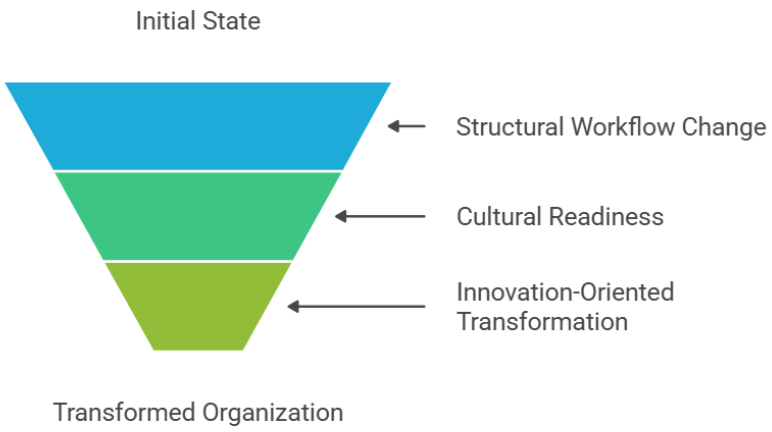


Figure 24. Organizational Change in SMEs (Author's own source).

4.4.1 Structural Workflow Transformation Through HRI and Agile Automation

All three experiments show notable workflow adjustments driven by the interplay of HRI and Agile Automation. This is most visible in the Input–Process–Output (IPO) matrix, where organizational change appears as a major output particularly in RAPSEB and RISES (see Figure 12).

Table 26. Cross Case Structural change.

Case	Changes	Workflow Shift
RAPSEB	Robotic spraying, automated handling, safety checks, and checking data.	Transitioning from human-operated jobs to robot-driven execution with human quality supervision.
RISES	Forklifts, digital tracking, new rules material flow.	Transitioning from manual to digital management through real-time routing.
SUNRISE	Gesture and voice commands, modifications made by the operator, and flexible assembly setup.	Transitioning from fixed automation to operator-driven

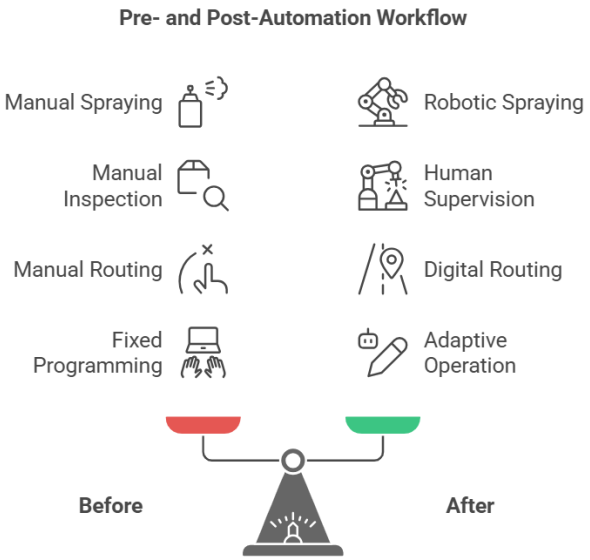


Figure 25. Pre- and Post-Automation Workflow (Author's own source).

4.4.2 Cultural Readiness, Trust, and Human Adaptation

The Process codes particularly Trust in Automation**,** UX & Cultural Readiness**,** and Learning & Training show strong thematic density across the experiments. The coding distribution (from the Matrix Coding Query chart) reveals that cultural readiness and trust are most prominent in RISES, moderately represented in SUNRISE, and least visible in RAPSEB.

1. **Building Trust in Human–Robot Collaboration**

Trust increases while automation is clear, and associated with human expectations:

- RISES workers trust mobile robots because FIWARE provides predictive alerts and clear visual feedback**.**
- SUNRISE workers trust gesture systems due to intuitive commands and real-time robot responses**.**
- RAPSEB build workers confidence robots due to precision control and visible reductions in hazard exposure**.**

Trust is not an automatic outcome; it forms through iterative positive interactions, safety assurance, and user-cantered system design.

2. **Cultural Readiness and Worker Acceptance**

The Case Classification Summary indicates that RAPSEB shows supportive but careful, RISES indicate adaptive and SUNRIISE indicate positive cultural readiness.

3. **Innovation-Oriented Organizational Transformation**

The Organizational Change code and innovation as its sub-node appear across all three cases, indicating flexible, and sustainable operations. This innovation is not only technological but also organizational, enabling frontline workers with design authority.

Table 27. Organizational change through innovation.

Cases	**Features**	**Impact**
RAPSEB	Safer production, material precision, ecological binder control	Stronger sustainability focus and worker well-being
RISES	Robotic mobility, predictive monitoring, IoT integration	Improved scalability and responsive warehouse operations
SUNRISE	Easy robot programming, flexible production, real-time feedback	Greater operator empowerment and reduced errors

4.4.3 Cross-Case Synthesis: HRI + Agile automation as Drivers of Organizational Evolution

Across RAPSEB, RISES, and SUNRISE, these collective effect on HRI and Agile automation leads to organizational change.

Table 28. Summary of Organizational changes.

Changes	**Key Elements**
Structural	Hybrid workflows, robot-assisted tasks, layout, and flow redesign.
Cultural	Worker trust, enhanced learning, absorptive capacity, cultural readiness.
Innovation	User-centric automation, data-driven job redesign, innovative operative autonomy.

These transformations show that HRI and Agile Automation employ a two-fold effect.

1. Reshape technical systems
2. Reshaping organizational culture, worker identity, and operational logic.

The learning and absorptive capacity explains the differences in trust, cultural readiness, and adoption. In this way,

1. RISES presents that workers not only use technology but also cause workflows and processes that use the Internet of Things (IoT).
2. SUNRISE shows an empirical learning approach with the use of gesture.
3. RAPSEB illustrates incremental learning through progressive enhancements in safety and precision.

These shows that diverse settings of SMEs can be performed well with adaptive robots. These results are further explained by differing absorptive capacities:

1. RISES promoted strong learning and integration.
2. SUNRIISE workers can adapt new routines quickly due to intuitive interaction.
3. RAPSEB relates external understanding mainly to develop sustainability and safety.

Altogether, these cases show that structural and cultural change in SMEs emanates not just from advanced HRI and agile automation technologies but from the organizations' capability to learn and absorb and apply new knowledge. Combining these enables higher levels of work autonomy, innovation, and human-centeredness in practice, closely matching Industry 5.0 principles.

4.5 Key Trends, Challenges, and Opportunities

The research reveals many major trends, challenges, and opportunities that mark the emerging growth of HRI and Agile Automation within SMEs. Thus, the results reveal both new possibilities and present problems, since the automation settings analysed in this study are still in experimental, prototype, or scale-up testing stages. NVivo coding patterns, lexical frequency outputs, system documentation, and operator insights collectively delineate three overarching domains influencing the future direction of SME-oriented human–robot collaboration.

1. Trends

The dominant trends across the experiments human-centered, AI-supported, flexible robotics systems. There is a clear move towards combining multi-modal communication (speech, vision, gestures, touchscreens) and using LLM-driven intent recognition to make robots more intuitive for non-experts. This trend strongly aligns with your Human robot interaction, UX, Learning, and Human-centered Design codes, as robotics shifts from pre-programmed automation to adaptive, collaborative behaviour. Another strong, visible trend is the emphasis on ergonomics and operator well-being, supported by ROS4HRI and RULA scoring, linking directly to Human Factors, Ergonomics, and Agile Automation. Industries are moving toward modular and flexible setups that can be rapidly reconfigured, which relates to the Process, Systems, and Efficiency codes. Overall, the trend is clear, modern robotics is becoming more intelligent, more accessible, and more adjusted to human needs.

2. Challenges

These experiments, apart from issues related to technical, social, and organizational aspects, have brought up many other problems. Lighting problems, shadows, wrong depth readings, limited fields of view are included in the problems that vision and

sensing systems must face. These are directly related to Input, Design, and Process Complexity codes. Speech recognition and LLM produced wrong results, especially with accents, influencing the codes Human, Trust, UX, and Communication. The move from ROS1 to ROS2, enhancing drivers and nodes, caused major combo problems. These involve issues related to Learning, Efficiency, and Systems Integration. AGVs, and PLCs work together added to the delays. The safety and ergonomic delay the ability to perform actual testing appeared in Human Factors and Trust in System.

Table 29. Internal vs. External Challenges

Internal (Organizational) Challenges	**External (Technological) Challenges**
Operator skill gaps	Sensing and perception limitations
Learning barriers	System-integration issues
Communication issue	LLM and speech-recognition inaccuracies
Human-factors concerns	Hardware and prototype constraints
Workflow/process complexity	

3. Opportunities

Nevertheless, despite the challenges, some very strong opportunities exist for future growth in human-robot collaboration. Advancing LLM-enabled interaction has huge potential for more natural language programming and intuitive control, directly supporting Learning, UX, Trust, and Human codes. Better perception pipelines, body tracking, and ergonomic monitoring will enhance safety and workflow optimization, strengthening Efficiency, Ergonomics, and Design. Increased simulations and digital twins provide the ability to conduct rapid prototyping, operator training, and low-risk testing related to SME Perspective, Process, and Agile A. Full migration to ROS2 and Vulcanexus will improve modularity, speed, and scalability that can support Systems Thinking,

Output, and Efficiency. Drawing on these opportunities together, the path forward for more intelligent, reliable, and human-centered robotic systems is bright.

5. Summary and Conclusion

This chapter explain the summary of key findings and key contributions of the research study meanwhile discuss the limitations and recommendations for the future studies.

5.1 Summary of Key Findings

This study investigated how HRI can be designed and implemented for SMEs to support a smooth human-centered transition from manual workflows to agile automation. It studied ARISE experiments, specifically RAPSEB, SUNRIISE, and RISES, applying the IPO framework to investigate HRI, agile automation, HCD, and organizational change effect on industries. The study highlights some significant conclusions.

Across three experiments, the robots constantly helped people in carrying out activities that were dangerous, repetitive, or that those required a lot of accuracy.

1. Robot arm spraying prevented the workers from chemicals exposures.
2. Mobile robots performed heavy transportation operations

This shows that combination of HRI and HCD, can reduce accidents, exhaustion, enhance the quality of products and accomplish the tasks effectively and efficiently. Critically, this reflects a change toward protective automation policies associated with worker safety.

Moreover, NVivo outputs shows that SMEs benefit from flexible automation systems without creating problems to accomplish the task. These structures can change tasks quickly according to the demand of manufacturing and no longer require programmers. This cuts down on the extra costs and work in industrial automation. Collectively, these

findings highlight on agile automation worth in accepting flexible production environments.

Workers can work better with the automation system when the system is easy to use and understandable. Continuous feedback, iterative prototyping, and ergonomic advances lower the fear to work with automation and increase workers' trust. In addition, training decreased cognitive load, and workers can work in an eased environment effectively and efficiently. This pattern across cases highlights the importance of HCD in supportive worker procedures and implementing sustainable technology. All three experiments established organizational change with the combination of HRI and HCD. Workers shifts from manual tasks to supervision, monitoring, and decision-making. At the organisational level, new routines were developed within SMEs with trainings, system monitoring, and cross-functional communication robotic systems. A continuing cultural transformation also showed as employees confidence on agile automation.

The cross-case assessment clarified that HRI, agile automation, and Human-Centred Design collaborating each other in a considerable way.

1. HRI begins the foundation for humans and robots collaborate.
2. Agile Automation prepares the flexibility necessary for smooth system deployment.
3. HCD confirms that the technology continues usable, safe, and appropriate for workers.

In general, the results show that HRI is a technological user interface as well as a socio-technical technique.

Table 30. Research question and objective correspondence to the results

Research Question / Objectives	**Conclusion of study corresponding to research questions / Objective**
How can human-robot interaction be designed and implemented in SMEs to ensure a smooth human-centered transition from manual workflows to agile automation?	For a successful deployment of Human-Robot Interaction in SMEs, they need to develop a strategy that is centered around Human-Centered Design, using easy-to-use automation for repetitive or hazardous tasks, provide workers with effective training, feedback, and introducing automation from basic level and gradually moving up step by step. This will lead to safety, effective utilization, worker trust and a seamless transition from manual tasks to agile automation.
Objective 1. To examine how ARISE experiments facilitate the transition from manual processes to Agile automation in SMEs	Robots have taken on repetitive tasks and have also provided enhanced safety for workers, output quality and customization. They have also reduced the need for extensive programming.
Objective 2. To evaluate how human-centered design principles improve worker performance, confidence, and comfort during the adoption of automation.	Practical user interfaces, workers involvement, their feedback, and training eased cognitive load, build trust and also increase efficiency.
Objective 3. For finding challenges and best practices, in Human robotic interaction for SMEs, during “manual to agile automation move.”	Challenges: Job loss fear, limited skills, limited training uncertain robot behaviour. Best practices: Worker engagement, clarity, iterative model design, formal training.
Objective 4. To present recommendations that should help to improve usability, trust, and adoptability of robot systems in SMEs.	Start with minimal advancements, provide training so workers can get familiarized, make use of user-friendly interfaces that are easy to understand, deploy adaptive safety, encourage change readiness, and offer incentives to SMEs.

5.2 Contributions to Research and Practice

This research offers several contributions for academic understanding, industry practice, and the wider transformation of SMEs adopting collaborative robotics. The following section focuses first on the academic contributions of this study, followed by practical implications. It combines Human–Robot Interaction, agile automation, Human-Centred Design, and organisational change, which are generally studied separately. Given the fragmented nature of research between technical, human, and organisational issues, as highlighted in Chapter 1, this study directly addresses the highlighted gap. The uniqueness of this research is in its combination of such areas into one model, which previous studies on SME automation have not done.

The IPO framework was chosen due to structured analysis of human, industrial, and organizational factors help to implement automation. Moreover, the ARISE experimental adds depth, practicality, and applicability to the conclusions. Utilizing IPO framework in SMEs signifies a methodological expansion, as prior studies have infrequently used this framework to examine HRI or agile automation. The results also show that workers involvement, training and learning positively affects the implementation of automation.

From a practical point of view, this research recommends actionable support for SMEs having limited resources. The findings show that SME's start with small initial projects and scaling up gradually. Overall, these insights help small and medium-sized businesses (SMEs) figure out how to introduce new technology in a way that fits with workforce development, organizational routines, and cultural readiness.

5.3 Limitations of the Study

As study contains meaningful contributions, there are also various limitations that explain the scope of the findings. These limitations relate to selections, data sources, and limitations of qualitative research. The first limitation is the dependency on secondary data (publicly available ARISE documentation and CORDIS reports). Privacy restrictions hindered direct interviews, observations, or field investigations, which can be enhanced the analysis with primary data. As a result, the study could not contain first-hand worker perceptions, knowledge, or experimental accounts that naturally improve the credibility of qualitative studies. Additionally, secondary documents specifically TEF reports may comprehend project-level bias, as they frequently emphasize accomplishments and underreport working challenges or failures.

A second limitation related with the limits of the data used for qualitative coding. The study used NVivo to structure thematic analysis, yet the presented materials were not constructed originally for research purposes. This broadly limits the complexity and hardness of the coding procedure, given that themes can only develop from what is accepted. Furthermore, it was not possible to triangulate NVivo coding with alternate data sources, such as interviews, observations, and questionnaires, which would develop practical strength.

A third limitation relates to the case contexts of the ARISE experiments. These projects were conducted in semi-controlled or pilot environments where risks, workflow disruptions, and organizational pressures are easier to manage than in fully operational SME workplaces. Real-world difficulties e.g. financial uncertainty, unpredictable workers abilities, conflict to change, or shifting organizational priorities might produce outcomes that are quite different from those obtained in controlled experiments. The sector-specific nature of the experiments, engaging in manufacturing, packaging, and

warehouse logistics, means that for SMEs operating in other sectors, different adoption barriers or opportunities might be faced. These limitations help to clarify the scope of study applicability.

5.4 Recommendations for Future Work

Following the findings and limitation, recommendations are made that would assist both researchers and industrial practitioners, as well as policymakers, in improving future work on human-robot collaboration within SMEs. These suggestions are organised around methodological, technological, and organisational needs to ensure direct alignment with the gaps identified in this study.

From methodological perspective future research should conduct long-term and longitudinal studies to obtain insights into evolving roles of workers, organizational culture, and performance before, during, and after the adoption of automation. There is a need for deeper research stress, building trust, and emotions. Moreover, mixed-methods research will enhance the qualitative insights with quantitative indicators. The results suggest measures for the SME to transformed towards automated processes.

In terms of technological suggestions, SMEs are suggested to start with small and progress steadily. Meanwhile enable learning and risk reduction. These pilots help organisations test usability, safety, and system adaptability before scaling. Future research and improvement should focus on suggesting more clear and insightful HRI boundaries, including voice commands, gesture control, and extended feedback devices, which can decrease cognitive load and improve worker approval. Researchers should also explore adaptive safety systems that dynamically respond to worker behaviours.

Organisational implications include training and upskilling the workers by clear guidelines to use robots, safety guidelines, and user interface. SMEs should invest in continuous skill development to fulfil the training needs. Policymakers and industries need to know how these initiatives might help small and medium-sized businesses. Subsidies, grants, and tax breaks are all examples of financial incentives that make it easier for small and medium-sized businesses (SMEs) to make the initial investments that typically keep them from automating. Training and digital literacy programs help workers and managers learn the skills they need to use new technology effectively. Safety rules for HRI that are clear and easy to understand would assist small and medium-sized businesses feel more confidence about meeting regulatory standards, making it easier for them to do so. Finally, regional innovation networks that connect small and medium-sized businesses (SMEs) with universities, research institutions, and technology suppliers will help people share information, make it easier for companies to learn new things, and speed up the appropriate use of automation in all areas.

References

Aarstad, A., & Saidl, M. (2019). *Barriers to Adopting AI Technology in SMEs: A Multiple-Case Study on Perceived Barriers...* Master's Thesis, Copenhagen Business School, MSc in Business Administration & E-Business. Retrieved from https://research-api.cbs.dk/ws/portalfiles/portal/60704162/790410_Aarstad_Saidl_Barriers_to_Adopting_AI_Technology_in_SMEs.pdf

Ang, K. C., Sankaran, S., & Liu, D. (2024). Sociotechnical considerations on developing human robot teaming solutions for construction: A case study. *Construction Robotics, 23*, 8. Retrieved from https://link.springer.com/article/10.1007/s41693-024-00140-y

Anonymous. (2025). Industrial robot safety standards get major updates for 2025. *Modern Materials Handling (Warehousing Management Edition), 80(3)*, 9. Framingham, United States. Retrieved from https://www.proquest.com/docview/3177945475/fulltextPDF/53FB74F74CA44509PQ/1?accountid=14797&sourcetype=Magazines

ARISE. (2025). *Open-Source, real-time middleware for Industrial Human-Robot Interaction*. Retrieved from ARISE: https://arise-middleware.eu

Asamaka. (n.d.). *Human-robot interaction in industrial environments: Key challenges and how to overcome them*. Retrieved September 2025, from Asamaka (Blog): https://asamaka.com/blogs/human-robot-interaction-in-industrial-environments-key-challenges-and-how-to-overcome-them

Ayinaddis, S. G. (2025). Artificial intelligence adoption dynamics and knowledge in SMEs and large firms: A systematic review and bibliometric analysis. *Journal of Innovation & Knowledge, 10*(3). Retrieved from https://www.sciencedirect.com/science/article/pii/S2444569X25000320

Bortolini, M., Galizia, F. G., & Mora, C. (2018, October). Reconfigurable manufacturing systems: Literature review and research trend. *Journal of Manufacturing Systems, 49*, 93-106. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0278612518303650?via%3Dihub

Buer, S.-V., Strandhagen, J. O., & Chan, F. T. (2018, March). The link between Industry 4.0 and lean manufacturing: Mapping current research and establishing a research agenda. *International Journal of Production Research, 56*(8), 2924–2940. Retrieved from https://www.tandfonline.com/doi/full/10.1080/00207543.2018.1442945

Casaletto, P. (2024). Digital Twin application for dynamic speed regulation in collaborative robots. *Politecnico di Torino*. Italy. Retrieved from https://webthesis.biblio.polito.it/33613/1/tesi.pdf

Costa, A., Crupi, A., De Marco, C. E., & & Di Minin, A. (2023). SMEs and open innovation: Challenges and costs of engagement. *Technological Forecasting & Social Change, 194*, 122731. Retrieved from https://pdf.sciencedirectassets.com/271733/1-s2.0-S0040162523X00079/1-s2.0-S004016252300416X/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEHMaCXVzLWVhc3QtMSJGMEQCIEY2EzmyAURqDX7TIxVK9Qqz6vc7bARh2eE8F84k%2FpfMAiAVs8HOsn%2BMT3tNk2eVP5hXDFnv7GBxOX%2BrCSDGco

De Mattos, C. S. (2024). Systematic literature review on technological transformation in SMEs: A transformation encompassing technology assimilation and business model innovation. *Management Review Quarterly, 74*, 1057–1095. Retrieved from https://link.springer.com/article/10.1007/s11301-023-00327-7

Eiffe, F. F. (2025). *SME digitalisation in the EU: Trends, policies and impacts.* Eurofound. Dublin: Eurofound. Retrieved from https://www.eurofound.europa.eu/en/publications/all/sme-digitalisation-eu-trends-policies-and-impacts

European Commission. (2025). *Agile, human-centric, and Real-time enabled open Source technologies advancing industrial HRI in Europe*. Retrieved from CORDIS – EU research results: https://cordis.europa.eu/project/id/101135784/results

European Commission. (2025). *Annual report on European SMEs 2024/2025*. Retrieved 09 02, 2025, from SME Performance Review – European Commission: https://single-market-economy.ec.europa.eu/smes/sme-strategy-and-sme-friendly-business-conditions/sme-performance-review_en

European Court of Auditors. (2022). *ERDF support for SME competitiveness: design weaknesses decrease effectiveness of funding.* Luxembourg: European Court of Auditors. Retrieved from Corporate Finance Institute: https://www.eca.europa.eu/en/publications?did=60921

European Parliament. (2023). *Analysis exploring risks and opportunities linked to the use of collaborative industrial robots in Europe.* Scientific Foresight Unit (STOA), European Parliamentary Research Service. Retrieved from

https://www.europarl.europa.eu/RegData/etudes/STUD/2023/740259/EPRS_STU%282023%29740259_EN.pdf

Farooq, M. U., Kang, G., Seo, J., Bae, J., Kang, S., & Jang, Y. J. (2024). DAIM-HRI: A new Human-Robot Integration Technology for Industries. *2024 IEEE International Conference.* Melbourne, Australia: IEEE. Retrieved from https://ieeexplore-ieee-org.proxy.uwasa.fi/stamp/stamp.jsp?tp=&arnumber=10557811

Gervasi, R., Capponi, M., Mastrogiacomo, L., & Franceschini, F. (2023). Manual assembly and Human–Robot Collaboration in repetitive assembly processes: a structured comparison based on human-centered performances. *The International Journal of Advanced Manufacturing Technology, 126*, 1213–1231. doi:https://doi.org/10.1007/s00170-023-11197-4

Gervasi, R., Capponi, M., Mastrogiacomo, L., & Franceschini, F. (2024). Analyzing psychophysical state and cognitive performance in human-robot collaboration for repetitive assembly processes. *Production Engineering, 18*, 18:19–33. doi:https://doi.org/10.1007/s11740-023-01230-6

Gualtieri, L., Rojas, R. A., Ruiz Garcia, M. A., Rauch, E., & Vidoni, R. (2020). Implementation of a Laboratory Case Study for Intuitive Collaboration Between Man and Machine in SME Assembly. In D. Matt, V. Modrák, & H. Zsifkovits (Eds.), *Industry 4.0 for SMEs.* Palgrave Macmillan. Retrieved from https://link.springer.com/chapter/10.1007/978-3-030-25425-4_12

Guinjoan, F. G., Ros, R., & Garrell, A. (2024). Participatory design for explainable robots. *X-HRI Workshop.* Boulder: X-HRI Workshop. Retrieved from https://www.inf.uni-hamburg.de/research/projects/trail/publications/pdfs/2024-03-gebelli-hri24.pdf

Halim, J., Eichler, P., Krusche, S., Bdiwi, M., & Ihlenfeldt, S. (2022, October). No-code robotic programming for agile production: A new markerless-approach for multimodal natural interaction in a human-robot collaboration context. *Frontiers in Robotics and AI, 9*, 1001955. doi:10.3389/frobt.2022.1001955

Hien Nguyen, N., Ganix, L., & Ion, I. (2022). Human-centred design in Industry 4.0: Case study review and opportunities for future research. *Journal of Intelligent Manufacturing, 33*(1), 35–76. doi: 10.1007/s10845-021-01796-x

Howard, J., Murashov, V., Roth, G., Wendt, C., Carr, J., Cheng, M., . . . Petery, G. (2025, May). Industrial robotics and the future of work. *American Journal of Industrial Medicine*. Retrieved from https://doi.org/10.1002/ajim.23729

Islam, N., Rakshit, S., & Paul, T. (2025). Antecedents and consequences of social robots adoption for SMEs: Reimaging emerging technologies in the context of the new normal. *Technological Forecasting & Social Change, 210*. Retrieved from https://pdf.sciencedirectassets.com/271733/1-s2.0-S0040162524X00104/1-s2.0-S0040162524006851/main.pdf?X-Amz-Security-Token=IQoJb3JpZ2luX2VjEDAaCXVzLWVhc3QtMSJHMEUCIGaoyvN3iilyDzhOzg9vr%2BhkTc%2F2hAcGMKUS0l3iU5x2AiEAyuOmQTH7dQyeWb3MsC5KpTisBGibWFBpDC4tnNxE

Keshvarparast, A. B. (2024). Collaborative robots in manufacturing and assembly systems: Literature review and future research agenda. *Journal of Intelligent Manufacturing, 35*, 2065–2118. Retrieved from https://link.springer.com/content/pdf/10.1007/s10845-023-02137-w.pdf

Kopp, T., Baumgartner, M., & Kinkel, S. (2021). Success factors for introducing industrial human–robot interaction in practice: An empirically driven framework. *International Journal of Advanced Manufacturing Technology, 12*, 685–704. Retrieved from https://link.springer.com/article/10.1007/s00170-020-06398-0

Kragic, D., Henten, E. J., & Neumann, G. (2023). Collaborative robots in small and medium-sized enterprises: Implementation processes, challenges, and success factors. *ResearchGate*. Retrieved from https://www.researchgate.net/publication/379622985_Cobots_in_SMEs_Implementation_Processes_Challenges_and_Success_Factors

Lewin, K. (1947, June). Frontiers in Group Dynamics: Concept, Method and Reality in Social Science; Social Equilibria and Social Change. *Human Relations, 1*(1). Retrieved from https://journals.sagepub.com/doi/10.1177/001872674700100103

Liu, D., & Son, S. (2024, December). Exploring the impact mechanism of collaborative robot on manufacturing firm performance: A dynamic capability perspective. *Sustainable Futures, 8*. Retrieved from https://www.sciencedirect.com/science/article/pii/S2666188824001114?utm

Lu, L., Xie, Z., Wang, H., Li, L., & Xu, X. (2022). Mental stress and safety awareness during human-robot collaboration – Review. *Applied Ergonomics, 105*. doi:https://doi.org/10.1016/j.apergo.2022.103832

Manzardo, M., & Vidoni, R. (2025, June 06). Safe and Fluent Industrial Human Robot Collaboration Via Combination of PFL, SSM and Escape Trajectories. *EEE Robotics and Automation Magazine, 10*, 6480 - 6487. doi:10.1109/LRA.2025.3568567

Nowell, L. S., Norris, J. M., White, D. E., & Moules, N. J. (2017). Thematic analysis: Striving to meet the trustworthiness criteria. *International Journal of Qualitative Methods, 16*. doi:https://doi.org/10.1177/1609406917733847

Patton, M. Q. (2015). *Qualitative Research & Evaluation Methods: Integrating Theory and Practice* (Vol. 4). Saint Paul, MN: SAGE Publications, Inc. Retrieved from https://uk.sagepub.com/en-gb/eur/qualitative-research-evaluation-methods/book232962

Puttero, S., Verna, E., Genta, G., & Galetto, M. (2025, March 21). Collaborative robots for quality control: an overview of recent studies and emerging trends. *Journal of Intelligent Manufacturing*. Retrieved from https://link.springer.com/content/pdf/10.1007/s10845-025-02600-w.pdf

Puttero, S., Verna, E., Genta, G., & Galetto, M. (2025). Collaborative robots for quality control: an overview of recent studies and emerging trends. *Journal of Intelligent Manufacturing*. Retrieved from https://link.springer.com/content/pdf/10.1007/s10845-025-02600-w.pdf

Riso, S., & Adascalitei, D. (2024). *Human–robot interaction: What changes in the workplace?* Retrieved from https://www.eurofound.europa.eu/en/publications/all/human-robot-interaction-what-changes-workplace

Roth, K., & Farahmand, K. (2023). A Socio-Technical Study of Industry 4.0 and SMEs: Recent Insights from the Upper Midwest. *Sustainability, 15*(16), 12559. Retrieved from https://www.mdpi.com/2071-1050/15/16/12559

Sánchez, E., Calderón, R., & Herrera, F. (2025, June). Artificial Intelligence Adoption in SMEs: Survey Based on TOE–DOI Framework, Primary Methodology and Challenges. Retrieved from https://www.mdpi.com/2076-3417/15/12/6465

Saunders, M., Lewis, P., & Adrian, T. A. (2019). *Research Methods for Business Students.* Harlow: Pearson Education. Retrieved from

https://ebookcentral-proquest-com.proxy.uwasa.fi/lib/tritonia-ebooks/detail.action?docID=5139642

Schnell, M. (2021). *Challenges when introducing collaborative robots in SME manufacturing industry.* Master's thesis, University of Skövde, Skövde. Retrieved from https://www.diva-portal.org/smash/get/diva2:1568656/FULLTEXT01.pdf

Shah, R., Arockia Doss, A. S., & Lakshmaiya, N. (2025, September). Advancements in AI-enhanced collaborative robotics: Towards safer, smarter, and human-centric industrial automation. *Results in Engineering*. Retrieved from https://www.sciencedirect.com/science/article/pii/S259012302501775X

Spurný, T., Ján, B., Zdenko, B., & Aleš, V. (2025). Dynamic Proxemic Model for Human–Robot Interactions Using the Golden Ratio. *Scholarly Journal, 15*(15), 8130. doi:DOI:10.3390/app15158130

Sultanov, R., Sulaiman, S., Li, H., Meshcheryakov, R., & Magid, E. (2022). A Review on Collaborative Robots in Industrial and Service Sectors. *2022 International Siberian Conference.* IEEE. Retrieved from https://ieeexplore-ieee-org.proxy.uwasa.fi/stamp/stamp.jsp?tp=&arnumber=10003014

Trstenjak, M., Benešova, A., Opetuk, T., & Cajner, H. (2023). Human Factors and Ergonomics in Industry 5.0—A Systematic Literature Review. *Applied Sciences, 13*(1). Retrieved from https://mdpi-res.com/applsci/applsci-15-02123/article_deploy/applsci-15-02123.pdf?version=1739802445

United Nations. (2023). *Micro-, Small and Medium-sized Enterprises Day*. Retrieved from United Nations: https://www.un.org/en/observances/micro-small-medium-businesses-day

Villani, V., Pini, F., Leali, F., & Secchi, C. (2018, November). Survey on human–robot collaboration in industrial settings: Safety, intuitive interfaces and applications. *Mechatronics, 55*, 248–266. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0957415818300321

Walker, M. (2019, Feburary 22). *Working and Growing with Collaborative Robots*. Retrieved from NIST: https://www.nist.gov/blogs/manufacturing-innovation-blog/working-and-growing-collaborative-robots

Wang, T., Zheng, P., Li, S., & Wang, L. (2023). Multimodal Human–Robot Interaction for Human-Centric Smart Manufacturing: A Survey. *Advanced*

Intelligent Systems. Retrieved from https://advanced.onlinelibrary.wiley.com/doi/10.1002/aisy.202300359

Weidemann, C., Mandischer, N., van Kerkom, F., Corves, B., Hüsing, M., Kraus, T., & Garus, C. (2023, March). Literature review on recent trends and perspectives of collaborative robotics in Work 4.0. *Machines, 11*(3). Retrieved from https://www.mdpi.com/2218-6581/12/3/84

Yang, X., Zhou, Z., Sørensen, J. H., Christensen, C. B., Ünalan, M., & Zhang, X. (2023). Automation of SME production with a Cobot system powered by learning-based vision. *Robotics and Computer–Integrated Manufacturing*, 102564. doi:https://doi.org/10.1016/j.rcim.2022.102564

Zafar, M. H., Langås, E. F., & Sanfilippo, F. (2024). Exploring the synergies between collaborative robotics, digital twins, augmentation, and industry 5.0 for smart manufacturing: A state-of-the-art review. *Robotics and Computer-Integrated Manufacturing, 89*, 102769. Retrieved from https://www.sciencedirect.com/science/article/pii/S0736584524000553

Zincume, P. N., & Maier, M. (2025). Human-centred SME factories: the future of work in SMEs under industry 5.0. *Future Business Journal, 11*. Retrieved from https://fbj.springeropen.com/articles/10.1186/s43093-025-00553-3?utm

Zincume, P. N., & Maier, M. (2025). Human-centred SME factories: the future of work in SMEs under industry 5.0. *Future Business Journal, 11*. Retrieved from https://fbj.springeropen.com/articles/10.1186/s43093-025-00553-3

Zirar, A., Ali, S. I., & Islam, N. (2023, June). Worker and workplace Artificial Intelligence (AI) coexistence: Emerging themes and research agenda. *Technovation, 124*, 102747. Retrieved from https://doi.org/10.1016/j.technovation.2023.102747

Appendix 1

This appendix records the full methodological workflow used during qualitative analysis. The dataset comprises of multiple NVivo-exported reports, experiment files, and supporting project documentation.

1 Data-collection criteria

The following criteria governed which documents/sections were collected and coded:

1. **Case selection — experiments as bounded cases**

Three field experiments were treated as primary case units: **RAPSEB, RISES, SUNRISE** (each represented by one main file/report). These were chosen because each documents a discrete experiment in the TEF (Test Environment Framework) and addresses human–robot interaction design choices. (NVivo lists RAPSEEB, RISES, SUNRISE as distinct experiment files).

2. **Inclusion criteria for textual sources**

Written reports, experiment descriptions, use-case requirements, and technical reports that document the TEF, HRI components, and evaluations. NVivo file summary lists e.g., “Report of the experiment,” “Use cases requirements,” and experiment files with word/paragraph counts.

3. **Exclusion**

Non-text artifacts were not excluded outright but were coded only where they contained textual captions or explicit descriptive metadata. (NVivo shows images/pictures present but with fewer text references.)

2 Dataset size & NVivo counts (key numbers)

These counts are taken directly from NVivo exports and are the basis for all synthesis and triangulation below.

Table 31. Experiment Case Summary report.

Experiment Name	Total Coded Words	Total Coded Paragraphs	Total Coding References
RAPSEB	**3,949** (530 from Document + 3,419 from PDF)	**104** (36 from Document + 68 from PDF)	**24** (1 Text + 21 Text + 2 Image)
RISES	1,711 (from PDF)	50 (from PDF)	17 (from PDF)
SUNRISE	3,723 (from PDF)	86 (from PDF)	23 (from PDF)

Table 32. Experiment Case Summary Codes report.

Theme	RAPSEB (References Count)	RISES (References Count)	SUNRISE (References Count)	Total References
Agile Automation	8	6	3	17
Human-Centered Design	6	3	2	11
Human–Robot Interaction	5	4	3	12
Organizational Change	3	2	1	6
SME Performance	4	2	1	7
Absorptive Capacity	3	0	1	4
Learning & Training	5	4	3	12
Trust in Automation	1	3	2	6
UX & Cultural Readiness	2	0	1	3

Table 33. Files summary report.

File Name	Total Words in File	Total Paragraphs in File	Coded Percentage of File	Number of Nodes Coding File	Total Text References	Total Image References
Document Files (Text)						
Files\Summary of the project	937	20	1.0000	13	140	0
Files\RAPSEB experiment	530	36	1.0000	11	61	0
Files\RISES experiment	516	54	1.0000	12	54	0
Files\SUNRISE experiment	471	35	1.0000	12	32	0
PDF Files (Text)						
Files\Report of the experiment	14,819	531	0.3190	18	645	0
Files\Use cases requirements	15,822	707	0.0210	8	49	0
Files\Conference proceedings	8,269	175	0.0420	11	64	0
Picture Files (Visual)						
Files\Chalenge_2 IPO	0	0	0.9920	12	0	12
Files\Challenge 1 Input, process, output	0	0	0.9204	9	0	8
Files\Challenge3_4_Tasks Skills.	0	0	0.6724	7	0	4
Files\HRI_1	0	0	0.9365	6	0	4
Files\HRI_2	0	0	0.9388	6	0	4
Files\Human sensing, ergonomic evaluation, robot control	0	0	0.9017	6	0	4
Files\RULA assessment	0	0	0.9864	5	0	3
Files\Process_Captions_CH	0	0	0.8484	4	0	2
Files\CHH1_Schematic	0	0	0.7087	2	0	1
Files\Collaborative robot workflow	0	0	0.8336	1	0	1
Files\Electromagnetic Gripper	0	0	0.7809	2	0	1
Files\FIWARE toolchain	0	0	0.9324	1	0	1
Files\TEF_Architecture	0	0	0.6913	2	0	1
Files\TEF_HRI	0	0	0.9306	2	0	1

Table 34. Coding Summary Report.

Code Nickname (Hierarchical Name)	Aggregated Code	Total Words Coded	Total Paragraphs Coded	Total Number of Files Coded	Total References
Codes\Input	**Yes**	**7,793**	**333**	**17**	**295**
Codes\Input\Agile Automation	No	2,986	132	12	120
Codes\Input\Human-Centered Design	No	1,228	58	13	63
Codes\Input\Human–Robot Interaction	No	3,579	143	14	131
Codes\Output	**Yes**	**1,004**	**47**	**7**	**43**
Codes\Output\Organizational Change	No	352	15	7	16
Codes\Output\Organizational Change\Innovation	No	177	10	3	9
Codes\Output\SME Performance	No	652	32	5	29
Codes\Output\SME Performance\Efficiency and Productivity	No	472	24	8	27
Codes\Process	**Yes**	**3,090**	**139**	**18**	**131**
Codes\Process\Absorptive Capacity	No	309	14	5	14
Codes\Process\Learning & Training	No	1,668	69	14	71
Codes\Process\Learning & Training\System Limitations	No	457	20	3	19
Codes\Process\Trust in Automation	No	765	38	11	41
Codes\Process\UX & Cultural Readiness	No	348	18	7	19

Table 35. Code Metrics Breakdown by File Type

Code Name (Nickname)	File Type	Number of Files Coded	Number of Coding References	Number of Words Coded	Number of Paragraphs Coded
Codes\Experiments\RAPSEB	Document	1	1	530	36
	PDF	1	21	3,419	68
	Picture	2	2	N/A	N/A
Codes\Experiments\RISES	PDF	1	17	1,711	50
Codes\Experiments\SUNRISE	PDF	1	23	3,723	86
Codes\Input (Aggregated)	Document	4	68	1,590	72
	PDF	3	226	6,203	261
	Picture	10	1	N/A	N/A
Codes\Input\Agile Automation	Document	4	27	624	30
	PDF	3	86	2,362	102
	Picture	5	7	N/A	N/A
Codes\Input\Human-Centered Design	Document	4	16	370	16
	PDF	3	41	858	42
	Picture	6	6	N/A	N/A
Codes\Input\Human–Robot Interaction	Document	4	25	596	26
	PDF	3	99	2,983	117
	Picture	7	7	N/A	N/A
Codes\Output (Aggregated)	Document	4	28	776	32
	PDF	1	15	228	15
	Picture	2	0	N/A	N/A
Codes\Output\Organizational Change	Document	4	13	340	14
	PDF	1	1	12	1
	Picture	2	2	N/A	N/A
Codes\Output\Organizational Change\Innovation	Document	1	2	20	2
	PDF	2	7	157	8
Codes\Output\SME Performance	Document	4	15	436	18
	PDF	1	14	216	14
Codes\Output\SME Performance\Efficiency and Productivity	PDF	3	22	472	24
	Picture	5	5	N/A	N/A
Codes\Process (Aggregated)	Document	4	46	971	47
	PDF	3	84	2,119	92
	Picture	11	1	N/A	N/A

3 Step-by-step processes while Coding:

Step 1 — Data Collection, Preparation, and Project Setup

All experiment-related materials from the ARISE platform and CORDIS portal were collected, converted into Word format where necessary, and imported into NVivo. Baseline NVivo exports, comprising File Summary, Code Summary, Coding Summary, were generated to capture initial document structure and coding metrics.

Step 2 - Open (Initial) Coding

Each experiment document was read thoroughly, and descriptive codes were employed established on the IPO framework. New inductive codes, such as System Limitations, Efficiency, and Innovation, emerged and were incorporated further down appropriate IPO categories. Most of the documents had high coding coverage, between 0.9 and 1.0.

Step 3 — Axial Coding (Organizing Codes into Higher-Order Families)

Descriptive codes were grouped and aligned with the IPO framework. Overlapping codes emerged using NVivo's node joining facility. These underlying improvements were documented in Code Summaries.

Step 4 — Selective Coding / Theme Development

Final themes were established using the intense and most referenced codes. Theme structure was focused on high-density codes, e.g. Human–robot interaction. The evidence to establish these themes was obtained from word counts, reference counts, and the coverage of coding in NVivo.

Step 5: Coding of Images, Workflows & Supporting Documents

Coding was expanded further than text to involve diagrams, images, workflow schemas, and technical artifacts. Visuals were coded into the same IPO framework as the other documents to allow triangulation across the content types. NVivo's coding system followed references throughout documents, PDFs, and images.

Step 6 — Cross-case Synthesis and Triangulation

The within-case analysis outcomes of each experiment (RAPSEB, RISES, SUNRISE) with file-to-code patterns. Triangulation across textual and visual documents, justified through NVivo reports, increased reliability and methodological accuracy.

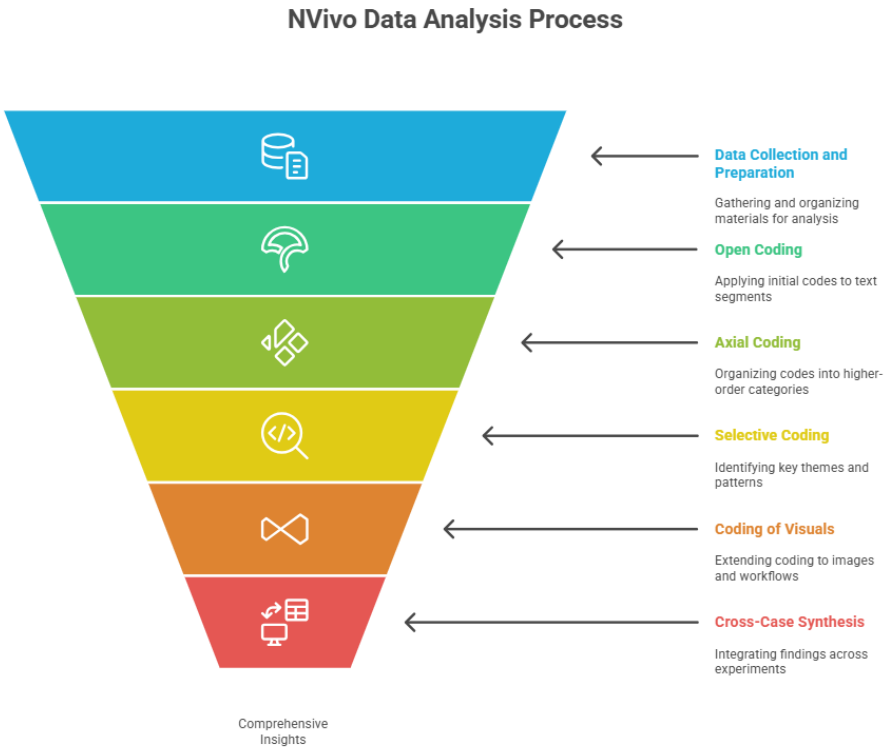


Figure 26. Data analysis process while coding n NVivo (Author's own source).

6. Synthesis & triangulation strategy (explicit)

To confirm findings were strong, the following triangulation checks were completed:

1. **Data-type triangulation**: cross-check among documents vs PDF vs Picture captions. NVivo exports show different types of data that were used and coded; this allowed cross-checking explanations vs. representation descriptions.
2. **Case triangulation**: cross-check themes between experiments: a theme present in ≥2 experiments was considered within the TEF document. The Coding Summary by File report was used to count occurrences between the experiment files.

Database Used for the research study:

Table 36. Database used for research.

Database Used	**Links**
Tritonia Finna (University of Vaasa e-sources)	https://tritonia.finna.fi/?lng=en-gb
Google Scholar	https://scholar.google.com/
CORDIS-EU	https://cordis.europa.eu/
ARISE	https://arise-middleware.eu