Analyzing Previous Human-Robot Interaction Implementation in Agriculture: What Can We Learn from the Past?

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***Abstract*—With the recent shift from conventional industrial robots to more collaborative Human-Robot Interaction (HRI) robots[1] within industries such as the agriculture sector, it has become essential to understand the challenges associated with the adoption of these robots to ensure a smooth integration with minimal resistance. As with all new technologies, there is often push-back when changing approaches and initiating new pathways within company operations, which can cause hesitation and even halt the adoption process. This paper draws from interviews with agricultural companies that have previously attempted to implement robots requiring direct human interaction, focusing on individuals within those companies who had decision-making capabilities during the implementation process. From these interviews, a set of action principles has been developed based on transferable knowledge found within the participating companies. The main results of this user study highlight that previous implementation attempts, whether positive or negative, influence future adoption. The study also identifies the multitude of barriers surrounding the agricultural sector's adoption of these technologies and suggests potential actions for companies to take to minimize the issues associated with implementing HRI robots. By identifying common successes and failures and contextualizing them for other companies to follow, this study aims to utilize lessons learned from past implementation attempts to shorten the learning curve and reduce hesitation in adopting HRI robots within the agricultural sector.**

***Index Terms*—HRI; pHRI; Interaction; Agriculture; Adoption; Integration**

I. Introduction

The agricultural sector is facing issues such as labour shortages, the effects of climate change, and increased production costs [1]. Robotics technologies offer a promising solution to tackling these issues and advancing sustainable practices [1]–[4]. Because of the nature of the sector, which is heavily dependant on human involvement, Human-Robot Interaction (HRI) must be explored to help transition from this entirely human-dependent approach to semi-autonomous farming [5]. As current research suggests, the agricultural industry is starting to transition away from the idea of more traditional industrial robots and is starting to consider a new pathway which fosters a more beneficial collaborative approach between robot and humans [6].

In spite of robotics technologies' potential for revolutionizing the sector, the agriculture industry is slow to adopt these technologies due to various factors, including high initial costs [7], lack of technical expertise [8], and resistance to change [9], [10]. HRI offers numerous benefits that could significantly enhance agricultural practices, such as automation and increased efficiency in labor-intensive tasks, precision in planting and harvesting, and the ability to operate in hazardous environments, thereby reducing human risk [2]–[4]. However, the agricultural sector is struggling to adopt HRI robots largely due to the lack of supporting infrastructure [11]. Although physical implementation is considered a significant issue, the Technology Readiness Levels (TRLs) of these robots are in their final stages. However, even with these robots ready for deployment, the environments in which they are intended to operate are not yet fully prepared for the technology. This is reinforced by by Schnack *et al.* [12], who explored adoption readiness by considering multiple elements, including social issues, to better understand the hesitation to adopt these technologies within different consumer groups. Due to the novelty of robotics technologies, there are few studies addressing the adoption challenges and, although their study discussed the different acceptance rates between countries and companies, they did not identify common concerns among companies.

Studies combining human and technological elements in agriculture are uncommon, nor have there been studies that adopt a co-creation approach involving stakeholders and end users in this sector. However, these methods have been utilized successfully in other fields, such as educational robotics [13], [14], assistive robotics [15], and the automotive sector [16]. To extend the state-of-the-art, in this paper, we present a mixed-methods study that provides insights into how previous attempts to adopt HRI robots within the agricultural sector have any effect on the potential of future

[1]In this paper, the term 'HRI robot' is used to underscore the significance of the interaction between robots and humans, rather than focusing on the type of robot involved (e.g., cobot, social robot) or the nature of the interaction (e.g., instruction-based, social interaction-based), when we refer to HRI robots we refer to any type of robot a person/s may interact or engage directly with during a task.

adoption. Our user study involved conducting semi-structured interviews with eight companies from the agricultural sector who had previously attempted to adopt HRI robots. Through these interviews we aimed to get a better understanding of the companies' adoption journey, direct effects of adoption, and what lessons they had learnt from their experiences. We utilized a between-subjects design which included half of the participants having been successful in previous attempts of adoption and the other half unsuccessful. The complexity of defining success and failure in technology adoption is well-documented. The variability in organizational contexts and the subjective nature of success criteria make it challenging to establish universal benchmarks for success or failure [17]. Additionally, the multifaceted nature of technology adoption, which includes factors such as user acceptance, organizational readiness, and the specific characteristics of the technology, further complicates this definition. Due to the complexity of defining success/failure as well as being able to interpret lessons learnt from previous attempts of adoption, we decided to create our own criteria for success or failure based on two factors: (1) continued usage after implementation, and (2) quality of human-robot interaction; while also utilizing an approach known as 'Action Principles' [18].

By reflecting on past experiences with technology adoption, the agricultural sector and others like it can avoid repeating mistakes and instead focus on sustainable, inclusive, and responsible integration of robotics technologies. This proactive stance has the potential to not only enhance the sector's resilience to future challenges but also to play a pivotal role in achieving the broader Sustainable Development Goals (SDGs) which are at the heart of the 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015 [19], ensuring a sustainable and prosperous future for all.

With our study we addressed the following research questions: (RQ1) What are the persistent challenges in the agricultural sector regarding the adoption of HRI robots?, and (RQ2) How does success or failure during previous adoption attempts influence companies' attitudes towards future technology adoption?

From these research questions, we worked with the following hypotheses: (H1) The social factors will have a stronger influence on the adoption process than technological factors, and (H2) An individual's past experiences with adoption will influence their attitude towards potential future adoption (a positive experience will lead to a more positive attitude, whilst a negative experience will lead to a more negative one).

Throughout this paper we use the following terms: (1) adoption, referring to the initial process of setting up and configuring a new technology within an organization, including installing hardware, software, and ensuring that the necessary infrastructure is in place; (2) integration, which goes a step further by embedding the new technology into existing systems and workflows, ensuring that it works seamlessly with other tools and processes; (3) implementation, which is the broader process that encompasses both adoption and integration, covering the acceptance and effective use of the technology by the end-users. Implementation involves change management, training, and ongoing support to ensure that the technology is fully embraced and utilized to its full potential.

II. Related Work

A. The Use of Robotics Technologies in Agriculture

The early introduction of industrial robots in agriculture was motivated largely by the need for increased efficiency, safety, and labour savings [1]. Research on autonomous agricultural vehicles began in the 1960s, and current advances in sensors, GPS, and GIS have enabled the development of robots for a variety of crops and duties [20]. However, the agricultural sector is in the process of moving away from industrial robotics towards fostering a more human-robot collaborative approach to address the more complex challenges within the sector. This notion is further supported by Romanov *et al.* [21], as they highlight the potential benefits and limitations of human-robot collaborations within the meat processing industry.

B. Adoption of Robotics Technologies in Agriculture

Within the academic community there is a considerable amount of research advocating for the adoption of robotics technologies in agriculture, however, some are still hesitant towards these solutions. These technologies have primarily been studied from the perspectives of economic and operational efficiency [7], ignoring the importance of social acceptability hurdles that can prevent agri-field labourers from adopting them. This is supported by Rose *et al.* [22], who highlight that the development of autonomous agriculture has been focused on the technical aspects far more than on the *"substantive inclusion and deeper reflexivity on the subject"* that is adoption. A recent study suggests human-robot synergistic systems are a promising socially viable alternative for sustainable rural development, given the significance of the growing societal issues associated with the ongoing digitization of the manufacturing process [23]. However, potential negative sociocultural impacts of these technologies must be considered. The development and implementation of agricultural robots may be delayed by a failure to address public concerns and sociopolitical consequences, which could have a knock-on effect on the environment, society, and economy. Recent research states of these sociocultural concerns that *"public fears and stakeholder anxieties often stand as significant barriers to the development and adoption of new technologies"* [8]. Society's resistance to automation could be responsible for a recent drop in adoption, despite a previously rising trend possibly caused by the advantages of effectiveness and affordability for farmers [24]. Specifically regarding HRI robots, where safety concerns should be managed, Benos *et al.* [25] underline the importance of specific and detailed formal standards for promoting the adoption of agricultural digitization. In addition, another area of focus that has been highlighted is the need to remain vigilant when taking into account the ethical implications of agriculture's adoption of robotics, especially in the area of HRI if the adoption process is to be hastened [26].

Robot density in the agricultural industry is predicted to rise later than in other industries such as the automotive sector [27], staying at 1.0 robots per million hours worked by 2025, rising to 8.0 robots per million hours by 2030, and then reaching 21.6 robots per million hours worked by 2035. By 2035, associated productivity growth is projected to be in the range of 0.9% compared to the baseline. This leaves the agricultural sector at risk of falling even further behind other industries if something is not done to correct its course and improve the uptake of these robots, this can be achieved by having a better understanding of the hesitations within the sector in regards to robotic adoption.

C. Human-Robot Interaction in Agriculture

Human-Robot Interaction (HRI) is a common term for all form of intercommunication between robots and humans, using robots that can interact with people to perform agricultural tasks including planting, harvesting, weeding, and crop monitoring and are intended for direct human robot interaction within a common space, or where humans and robots are in close proximity, with them being known as cobots. The implementation of these robots in agriculture holds the promise of increased productivity, reduced labour costs, and enhanced crop yields. Marinoudi *et al.* [28] advocate for the adoption of HRI robots in agriculture, emphasizing benefits such as improved collaboration with humans, enhanced accuracy, and reduced labour costs. Similarly, Grobbelaar, Verma, and Shukla [29] support these claims, asserting that HRI robots can significantly advance the agricultural sector and suggesting that *"Robots can be the permanent solution to end this food crisis"*. Further evidence supporting the adoption of HRI robots within agriculture is presented in a recent study that suggests that *"the synergy of humans and robots demonstrated the best results in terms of system performance, physical workload of workers, and time needed to execute the performed tasks"* but that also makes reference to still having a long way to go [2].

III. Methods

In this study, we aimed to understand the parameters driving the adoption of HRI robots in the agricultural sector. To accomplish this, we conducted eight in-depth semi-structured interviews with representatives from eight different agricultural companies from [anonymous country]. Each company's attempts to integrate HRI robots were assessed and classified as successful or unsuccessful/failure utilizing custom-designed criteria as can be seen in Table I. These criteria took into account a variety of variables, including (1) continued usage after initial implementation and (2) quality of Human-Robot Interaction. Thematic analysis [30] was then used to assess the interview responses. Further to the thematic analysis, we generated a set of action principles [18] designed to guide agricultural companies' future efforts to successfully implement HRI robots.

Ethical approval for this study was obtained from the University of Lincoln Ethics Committee (Ref.: UoL2023_15840). Participants were informed about the study prior to deciding if they wished to participate and informed consent was taken before any data collection took place.

A. Design

Our study followed a mixed-methods, between-subjects design. The main data collected was qualitative data from the semi-structured interviews, but we collected quantitative data on the success and failure of past adoption attempts to help contextualize participants' responses. Our independent variable was whether their attempt at adoption was a success/successful or a failure/unsuccessful, with our dependent variable being the self-reported likelihood of them adopting robotics technologies in the future based on their prior experience, measured on a 10-point Likert scale (completely unlikely to completely likely). The topics explored during the semi-structured interviews were focused on: (1) Adoption Journey, (2) Value Delivered, and (3) Lessons Learned.

B. Participants

Eight employees from eight different companies from within the agricultural sector in the UK took part in the study. These companies had activities in areas ranging from tulip harvesting to crop monitoring. Companies had to meet a two-stage set criteria to be able to participate: (1) they must have attempted to implement the use of HRI robots within their company (successfully or unsuccessfully), and (2) a high-level employee with access to in-depth details regarding the attempt at implementing these technologies (e.g., manager/project lead, high-level technician) must have been available to participate in the study and willing to discuss this information with us.

Furthermore, we established eligibility criteria surrounding the nature of the robotics technologies used. The main differences of exploring HRI robots as opposed to robotic technologies more widely are their interactive properties. Because of these, the robotic technologies that the participant companies attempted to adopt had to be either of: (1) a cobot previously implemented within their company to work alongside existing workers; (2) an autonomous robot that required some level of human interaction to complete a given task; or (3) a robot that, even if fully autonomous, was only used for part of a process within the company where human interaction was also required.

C. Criteria to define success and failure

Two key determining factors were identified as the baseline of whether or not a company's previous attempt of adoption was a success or a failure/unsuccessful. These two factors were: (1) the continued used of the robot and (2) the quality of Human-Robot Interaction, and can be seen in more detail in Table I. Measures such as not finishing the implementation process, not continuing use of the HRI robots beyond 12 months, or strong qualitative data indicating failure were critical when defining whether the implementation was successful or not.

TABLE I
DETAILS ON THE ADOPTION SUCCESS AND FAILURE CRITERIA DEFINED FOR OUR STUDY

Factor	Metric	Criteria	Indicator questions	Measure
Continued Usage after Initial Implementation	Utilization Duration	Measure the duration of time the HRI robot is actively used by the industry after the initial implementation. Set a threshold or benchmark for what is considered a meaningful and sustained period of usage. This could be a specified time-frame post-implementation (e.g., months or years).	Did the industry finish implementation and continue to use the HRI robot/s beyond the initial implementation phase? What is the average duration of robot usage post-implementation? Are there patterns or trends in usage over time?	Yes/No Number of months/still using or not Qualitative data indicating success or failure
Quality of Human-Robot Interaction	Interaction Satisfaction Index	Assess the quality of human-robot interaction through user satisfaction surveys or qualitative assessments. Consider factors such as perceived ease of use, efficiency gains, and user feedback on the robot's responsiveness and adaptability.	How satisfied are users with their interactions with the HRI robot? Are there reported efficiency gains or improvements in task completion times? What qualitative feedback has been gathered regarding the robot's responsiveness and adaptability?	10-point Likert scale Yes/No Qualitative data indicating success or failure

D. Action Principles

Approaches based on design science and action research are typically suggested strategies for influencing Information Systems (IS) practice, largely through innovation (for design science) and intervention (for action research) [31]. The action principles approach also aims to have a direct impact on IS practice [32].

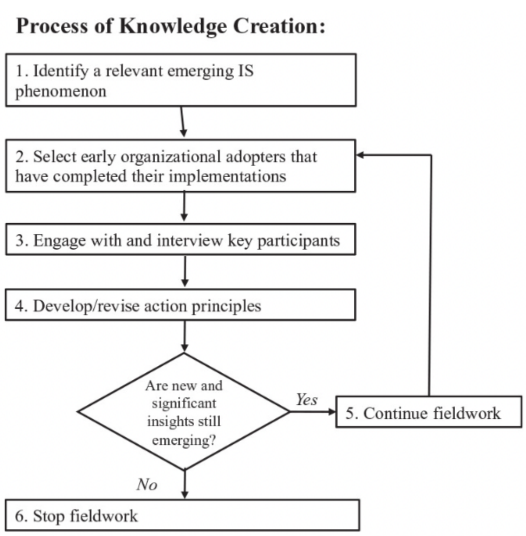

Fig. 1. An overview of the action principles approach [9]

Our action principles approach, based on the diagram that can be seen in Figure1, utilizes three different directions of questioning which are: (1) Adoption Journey, (2) Value Delivered, (3) Lessons Learned.

From these directions, a semi-structured interview was designed with 26 questions. The action principles approach is constructed of a set of predefined assumptions, a process for knowledge creation with an evaluation criteria set, and future steps to allow for optimal knowledge dissemination. It was chosen as the approach to follow as it allows to pick up where you left off after initial data collection, which will allow for further expansion of the study to incorporate more participants from other companies from the same or other sectors or country, hence helping us create in the future a wider understanding of how to guide companies towards a successful implementation of HRI robots more widely. We describe a continuation how we followed the action principles steps that can be seen in Figure 1.

1) Identify a relevant emerging IS phenomenon: Our emerging IS phenomenon is the barriers surrounding the adoption of HRI robots within agriculture. After analysing the literature, we decided that we would focus on companies that had previously attempted to automate a specific task within their company and not an entire process, with the aim of isolating specific issues that can be addressed in the immediate future.

2) Select early organizational adopters that have completed their implementations: This step involves investigating initial adopters who have successfully executed the technology or practice. It utilizes purposive sampling, which is employed to pinpoint and choose information-rich cases that enable the *"the most effective use of limited resources"* [33]. To execute purposive sampling effectively, and as proposed by scholars such as Teddlie and Yu [34], we created the criteria to define adoption success and failure that has already been described.

3) Engage with and interview key participants: Key participants are professionals within organizational roles that grant them access to the information required to address the research inquiries at hand [35]. For our user study, key participants included managers and high-level technicians involved in the implementation process.

4) Develop/revise action principles: After reviewing and analysing each individual interview transcript, a action principles were created or updated. Once all participants were interviewed, a final version was refined.

5) Continue fieldwork: The research continued by finding more companies using purposive sampling. However, due to the difficulties in finding suitable participants, we introduced the use of snowball sampling, where we asked participants to assist us in identifying other potential subjects.

6) Stop fieldwork: When no new and significant insights were emerging, the fieldwork was halted, which led us to eight participants. We decided to limit our study to the agriculture sector in [anonymous country], however, the nature of an action principles approach will enable us to expand our study to other sectors or geographical areas in the future.

E. Procedure

Upon receiving ethical approval, a public call for participation was distributed. Interested participants contacted the research team directly and received more information when this was requested, followed by a consent form for those that confirmed participation. Interviews were scheduled at a convenient date and time for participants and conducted online over Microsoft Teams. At the beginning of the interview, participants were reminded that the session would be recorded for transcription purposes, they were briefed on what to expect, and any extra questions regarding the study were addressed. Interviews lasted approximately one hour each. The data gathered from the interviews were derived from questions such as; *"Tell us your organization's previous implementation journey from your perspective"*, *"Why was automation considered?"*, *"Did the organization do a proof-of-concept?"*, *"How did automation affect employees?"*. Once the interviews were completed, each company's previous attempt was assigned as successful or unsuccessful, which was later used to derive the action principles.

IV. Results

To answer our research questions we performed a reflective thematic analysis on the qualitative data, following Braun and Clarke's [30] approach using Nvivo[2]. Ontologically we adopted a relativist position and epistemologically we took an interpretive approach. Whileaddressing our hypotheses by performing statistical analysis of the quantitative data to contextualise our findings.

A. Barriers of Adoption

Throughout the interviews, companies highlighted several barriers they felt were affecting their adoption of HRI robots. Figure2 and Table II show a summary of these barriers, which helped form our initial themes. From these, 2nd Order Themes were derived to form our final set of five themes.

TABLE II
NUMBER OF OCCURRENCES OF THE MAIN BARRIERS FOR ADOPTION

Main barriers and number of occurrences			
Investment	7	Recruitment	6
Operators-Skills	4	Cost	4
Machine-Flexibility	4	Implementation	4
Testing	3	Rigidity	3

[2]https://lumivero.com/products/nvivo/

Fig. 2. Wordcloud showing occurrences of the main barriers for adoption

*1) **Theme 1: Financial Barriers**:* a major obstacle to the adoption of HRI robots by agricultural companies is funding. One participant reported that *"The primary challenge within the business has been the availability of funding for implementing automation"* (P.102810[3]), with another stating that *"the most recent robot project required a significant investment, representing a large portion of the company's annual revenue"* (P.696969).

It was also noted that *"high costs associated with adoption, including high initial costs, can be prohibitive, especially for small and medium-sized farms"* (P.949133). Concerns were also raised about the payback time *"a payback period that was three years ago is not as quick now"* (P.120409), with companies hoping to see a return on investment in less than two years.

Another difficulty highlighted was lowering the cost per unit to harvest, with a participant indicating that they had to *"reduce the cost per unit to harvest by a small percentage to make it viable"* (P.949133). Another participant said that there was a *"need to invest in their business and not expect others to foot the bill"* (P.782961), indicating that enterprises must make internal investments rather than depend on outside finance. According to one respondent, a key for this is *"overcoming the cost barrier with government support and by helping technology providers align more closely with their needs"* (P.782961).

However, more than one participant drew our attention to difficulties when trying to get funding due to the robots not being *"autonomous enough"* (P.012810) to warrant the financial support of the government. This raises questions and concerns for companies trying to work towards the synergy of humans working with robots, and makes achieving this more difficult if funding is directed towards those seeking to use robots as a fully autonomous replacement for the human counterparts.

*2) **Theme 2: Machine-Related Barriers**:* agricultural companies deploying HRI robots face substantial operational and technological constraints. One participant said that *"the machines needed for automation are not readily available for certain crops"* (P.443055). Furthermore, *"no readily transferable machine"* (P.012810) currently exists for automating the process of growing various crops. This issue was

[3]Participant IDs in this section follow the format P.XXXXXX

present within all companies that were interviewed, with the general consensus that there were no readily available robots designed to do the tasks that they require. They reported feeling *"stuck with off the shelf solutions"* (P.650021) which required them to change the environment to better fit the robots' needs rather than the robots being able to adapt to their environment.

Another obstacle highlighted was *"robotics and complex vision equipment in the field"* (P.650021) and the *"need to achieve satisfactory performance first"* (P.120409). Other difficulties are weather-related, with participants claiming that they *"must accept that automation won't work perfectly in all weather conditions"* (P.220273), the *"complexity of new technologies"* (P.949133) and the *"lack of rural connectivity"* (P.782961).

Automation in agriculture often introduces rigidity, as one company noted, *"some of the barriers to automation are that it brings a lot of rigidity"* (P.012810). This is particularly evident in site-specific automation, where *"at our other sites, which are fully automated with 11 lines, if we decided to change from packing a plastic tray to a cardboard tray, they couldn't do it because the machinery is so automated"* (P.120409). The loss of flexibility was seen as a significant concern, with another company stating *"you lose the flexibility of the production line based on what the end of the line is doing"* (P.120409).

Process changes can be challenging, as illustrated by one participant: *"if we had a great idea to change from green trays to black trays and there's a 50-centimeter difference, we'd need to change our whole process now because we're so rigid on that size"* (P.120409). Therefore, companies *"must be cautious about how fully automated we want to become"* (P.782961). This only further supports the need to move towards a more collaborative approach when it comes to robotics adoption before humans are cut out of the loop entirely.

3) ***Theme 3: Human Resource and Skills Barriers****:* Human resource and skills barriers are critical challenges, with participants highlighting the *"need for required skill levels for operators and maintenance technicians"* (P.650021). Transitioning from traditional equipment to advanced systems was seen as another hurdle, as *"changing the workforce to be more technically oriented is another barrier"* (P.120409). Unlike a decade ago, *"we now need technically minded people who can adjust, tweak, and teach the machine new things"* (P.120409).

Recruitment has also evolved, with companies now seeking *"a technically minded operator"* (P.782961) rather than the same calibre of person as five to ten years ago. However, *"the industry probably doesn't attract those sorts of people"* (P.120409). It was highlighted that over the past couple of years this issue has started to become prevalent and was a previously unseen challenge with many of the companies admitting that they spent a lot of time focusing on the task at hand and didn't consider recruiting the required workforce to be a problem. However, a participant indicated that *"the sector just doesn't appeal to the younger generation"* (P.782961).

4) ***Theme 4: Risk and Reluctance Barriers****:* one company mentioned the *"risks involved in adopting new technology"* (P.696969), as a primary concern. A participant introduced the term *"horizon scanning"* (P.782961) were they stressed the point that when starting your adoption journey you cannot simply look at the problems in front of you, but you need to have a bird's eye view of the situation considering the past but also looking up and to the future, otherwise you run the risk of developing something that ends up outdated before it's even implemented: *"if you're not looking ahead, you could make a wrong turn"* (P.782961).

There is a strong *"need for thorough testing before deployment"* (P.696969), with a preference for *"seeing technology tested in other companies"* (P.696969) first. This reluctance to be the first adopter was evident, as companies prefer not to be the first to adopt new technology. Additionally, there is a *"need for suppliers to convince and assure through testing"* P(650021) to mitigate these risks.

5) ***Overcoming the Barriers****:* despite these barriers, companies found creative solutions. One firm repurposed grading machines originally designed for optical grading, demonstrating that *"by rewriting software and adapting the machines, the company has successfully used them to bunch certain types of flowers"* (P.012810). Learning from experience, another company highlighted that *"moving to a service provision model is the biggest step forward that they've learned from their experience"* (P.443055). To overcome barriers, companies are exploring *"leasing options or agritech-as-a-service models to spread out the financial burden"* (P.949133) and providing *"comprehensive training and support for staff to help them adapt more easily"* (P.949133).

B. The Effect of Previous Attempts of Adoption

Four companies were classified as having successful adoption attempts, while the other four were classified as having unsuccessful/failed attempts. We asked participants to self-report their willingness to adopt HRI robots in the future based on their previous attempts using a 10-point Likert scale. The effects of successful and unsuccessful attempts on participants' responses can be seen in Figure 3. The group where their previous attempt was classified as unsuccessful had an average score of 6/10 in comparison to the other group whose average score was 9/10.

A paired sample t-test was conducted to assess whether there was a statistically significant difference in the results between the successful and unsuccessful adoption groups.

Results suggest that participants working for companies with previous successful attempts to adopt HRI robots have higher willingness to try future attempts (9.00 ± 0.816) as opposed to those that worked for companies with previous unsuccessful attempts (6.25 ± 1.708), with a statistically significant difference of 2.75 (95% CI) $t(3) = 3.22$, $p < .05$, $d = 1.708$.

Although the results indicate overall that both groups expressed a willingness to adopt HRI robots in the future, companies with previous unsuccessful attempts showed more

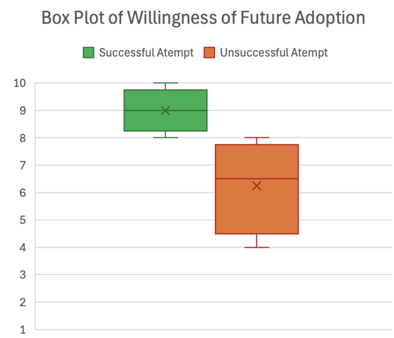

Fig. 3. Effects of successful & unsuccessful attempts on adoption

hesitation. They preferred to either complete their previous adoption processes successfully or to conduct more extensive research before trying to automate another task. This contrast highlights the impact of past experiences on future adoption decisions.

V. Discussion

Despite the benefits that the implementation of HRI robots offers to sectors such as agriculture [28], [29], and as highlighted in the literature, there are still significant barriers that keep companies from successfully adopting these [7]–[10]. With the study presented in this paper we explored: what are the persistent challenges in the agricultural sector regarding the adoption of HRI robots (RQ1), and how success or failure during previous adoption attempts influence companies' attitudes towards future technology adoption (RQ2). Further to this, we hypothesized that the social factors would have a stronger influence on the adoption process than technological factors (H1), and an individual's past experiences with adoption will influence their attitude towards potential future adoption (a positive experience will lead to a more positive attitude, whilst a negative experience will lead to a more negative one) (H2).

Regarding RQ1, our research highlights multiple persistent challenges that the agricultural sector faces when attempting to adopt HRI robots. Five themes were identified including: Financial Barriers, Technological and Operational Barriers, Human Resource and Skills Barriers, Risk and Reluctance Barriers, and Rigidity and Flexibility Barriers. Across all interviewed participants, several common concerns emerged. Notably, recurring issues were the challenges associated with government funding, and the already mentioned difficulty in recruiting skilled workers [8]. The lower level of autonomy of HRI robots vs. fully autonomous robots was frequently cited as a barrier to securing funding, as companies struggled to obtain financial support due to the perception that their robots were not *"autonomous enough"*. This penalization for striving towards workplace synergy poses a significant challenge to maintaining momentum in the adoption of these technologies and contrasts with the benefits of this synergy as highlighted in the literature [2]. Additionally, the recruitment of skilled workers was highlighted as a critical issue, playing a crucial role in the successful implementation and sustained use of these robots within the industry. Relating to H1, these findings underscore that, beyond technological barriers, social factors seem to have a stronger influence in impeding the adoption of HRI robots in the agricultural sector.

Regarding RQ2, our findings highlight an increased hesitation towards future adoption of HRI robots after experiencing an unsuccessful previous attempt. The group where their previous attempt was classified as unsuccessful had an average score (6/10) in comparison to the other group (9/10) when they were asked if they would be willing to automate again in the future. It is worth noting that, whilst the difference between groups was statistically significant, indicating that having been exposed to unsuccessful attempts does affect negatively their willingness to future attempts, both groups reported a high willingness to embark in the adoption process in the future. The reasoning of the unsuccessful group collectively was that they were more wary to *"jump straight into another project"* as they felt they would need to spend more time researching their problem beforehand. Relating to H2, this suggests that previous adoption attempts, whether successful or unsuccessful, do in fact affect companies attitudes towards future adoption.

A. *Set of Resulting Action Principles*

After analysing the results of our study, we followed the outlined criteria for assessing and producing a set of action principles from them [18]. The primary goal of these action principles is to influence practice through pre-intervention strategies. The set of action principles that we have developed are presented in Table III, and pose recommendations for agricultural companies considering adopting HRI robots within their processes, with the objective to alleviate some of the barriers that were identified during our study. For simplicity they have been categories into topics: "Financial Strategies" (FS), "Technological Adaptability" (TA), "Workforce Development" (WD) and "Risk Management" (RM)

B. *Limitations and Challenges Encountered*

Although our study extends the state-of-the-art providing interesting and valuable insights into the barriers for adoption of HRI robots within the agricultural sector, whilst using the novel approach of producing action principles to guide the adoption journey of other companies, we found significant challenges regarding the lack of engagement from the agricultural companies that we initially approached. Many were unresponsive or unwilling to share details about their experience, hence did not wish to participate. This led to a more time-consuming process with less companies involved than what we originally intended, which may affect how the broader industry is represented in our study.

Another challenge encountered was the varying degrees of openness among participants when discussing their experiences. While some participants were forthcoming from the beginning about their challenges and failures, others were more reserved, possibly due to concerns about reputation or competitive advantage. This variability in openness may have introduced bias and required careful consideration both

TABLE III
ACTION PRINCIPLES RESULTING FROM OUR THEMATIC ANALYSIS

Topic	Action	Outcome
FS	Aim to diversify funding sources	to mitigate the risk of relying on a single source
FS	Implement a cost-benefit analysis	to justify investments and demonstrate potential returns to stakeholders
FS	Adopt service provision models	to reduce upfront costs and ensure ongoing support and improvements
FS	Leverage government support	to offset initial costs and align technology development with industry needs
TA	Invest in R&D	to create adaptable and transferable automation solutions for various crops
TA	Enhance machine versatility	to maximize utility and reduce redundancy
TA	Improve connectivity	to support the implementation and operation of advanced technologies
TA	Focus on incremental improvements	to achieve continuous improvements in automation performance and reliability
TA	Simplify user interfaces	to reduce learning curve & make automation systems accessible to a broader range of users
TA	Multi-skill the robots	to extract more business value
TA	Design for flexibility	to develop automation systems with modular components that can be easily reconfigured
TA	Plan for adaptability	to ensure automation can accommodate different product specifications & packaging requirements
WD	Spend time to up-skill workforce	to ensure operators and technicians can manage and maintain advanced systems
RM	Make it essential to conduct pilot projects	to test new technologies in controlled environments before full-scale deployment
RM	Engage suppliers throughout implementation	to ensure thorough testing and validation of new technologies before adoption
RM	While in early implementation stage use robot outside of normal working hours	to ensure normal workflow remains uninterrupted until initial problems have been addressed
RM	Utilize “horizon scan”approach to adoption looking at the past and the future plans	to have a full view of what is trying to be achieved and not get lost in the task at hand
RM	Regularly review processes	to ensure they remain aligned with business needs and market demands
RM	Learn from experience	to apply lessons from past experiences to improve future automation projects

when conducting the interviews and when analysing the data. Initiating honest conversations proved to be a delicate task. Many interviewees tended to highlight their successes and downplay or omit their struggles, which could lead to an incomplete picture of their experiences. Efforts were made to encourage candid discussions, but the tendency to present a positive image remained a barrier. This limitation underscores the difficulty in obtaining a balanced view of the adoption process, as the narratives provided may lean towards self-promotion rather than an objective recounting of events.

We believe that it is also important to bear in mind that our study was conducted in [anonymous country], and that, whilst our findings might apply to other countries, the study would need to be extended or replicated to include companies based in other countries to be able to provide a broader picture that applies to them.

C. Future Work

Going forward, the next step is to conduct a comparative study to identify not only sector-specific issues but also transferable similarities between different sectors. By employing an action principles approach, this can be seamlessly achieved due to the method’s inherent flexibility, allowing us to add participants from different sectors to our study. This approach will enable a deeper understanding of the unique/ common challenges faced by various sectors in adopting HRI robots, providing a more comprehensive view of the landscape.

Additionally, future work could expand to include a comparison between different countries. This international perspective would offer valuable insights into how cultural, economic, and regulatory differences impact the integration of robotics technologies. Such a comparative analysis could uncover best practices and innovative solutions that are applicable across borders, further enriching the field of HRI research.

VI. CONCLUSION

The main takeaways from our study looking into previous HRI implementation in agriculture are that (1) the main obstacles to adopting (HRI) technologies in agriculture are not just technological but largely social. These include financial constraints, machine-related issues, human resource challenges, risk aversion. While technological barriers exist, such as feasibility, the more substantial challenges are related to how people, organizations, and society interact with and accept these technologies; (2) whilst there is general willingness to attempt to adopt HRI robots in the future, having being exposed to past unsuccessful attempts has a negative affect, generating more hesitation among companies within that group. Further to this, we provide a set of recommendations as action principles to help guide future adoption attempts by other agricultural companies.

We have presented an effective approach to conducting applied research in the field of HRI within agriculture. Our research is timely, thoroughly examines the phenomena under investigation, and offers valuable insights for various stakeholders. Notably, several participants commented on our process which prompted them to reflect and take the time to reconsider their current practices and future strategies. This underscores the need for more reflective research in HRI to advance the field, especially as we study rapidly evolving technologies with significant impacts on individuals, organizations, and society. The action principles approach used supports these goals and facilitates meaningful contributions to the implementation of these technologies.

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