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RESEARCH

Embracing Levin's Legacy: Advancing Socio-Technical Learning and Development in Human-Robot Team Design Through STS Approaches

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Abstract
This paper investigates the synergy between Levin's theories on technology transfer as a socio-technical learning and developmental process (TLD process), and what we learnt about socio-technical systems (STS) theories in a case study developing human robot solutions for the construction sector. Levin's extensive work highlights the significance of technology transfer as a means for organizational development. His TLD process emphasizes the intricate interplay between technology, organizational change, and learning and highlights the importance of incorporating cultural knowledge and skills into the technological transfer process. Contemporary STS views developed through our own work are introduced to complement and extend Levin's theories by providing a systemic lens to understand the broader socio-technical context in which technology transfer occurs. To illustrate the synergies and potential challenges from Levin's theories of technology transfer with contemporary STS concepts, we use a qualitative study of a unique case about the design and development of human-robot teams (HRTs) for construction tasks. Our findings reveal that while Levin's theories provide a valuable foundation for understanding technology transfer and organizational change, contemporary socio-technical systems face unique challenges in the context of AI-driven human-robot teams, where intelligent robots also contribute to the socio-technical learning process. Moreover, the rapidly evolving nature of technology and innovations could exponentially impact on multidisciplinary design teams, stakeholder participation and inter-organizational dynamics. The discussions suggest an extension of co-generative learning to incorporate 'collaborative intelligence' between human-robot teams enabled by artificial intelligence (AI). Consequently, we suggest that Levin's theories of technology transfer, developed before the rapid application of AI, may not have fully considered further social challenges caused by the introduction of autonomous systems such as AI-driven HRT systems. We extend Levin's important work by suggesting that addressing such challenges requires ongoing dialogue and collaboration among researchers, practitioners, and policymakers with different disciplinary backgrounds to develop robust and reliable socio-technical systems frameworks to navigate the complexities of robotics and AI in today's rapidly evolving technological landscape.

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Introduction

This paper investigates the synergy between Morten Levin's theories (Levin 1993a, b, 1997) on technology transfer as a socio-technical learning and developmental process (TLD process), and socio-technical systems (STS) theories. Levin's extensive work in organizational change, especially within technology-dominated environments highlights the significance of technology transfer as a means for organizational development. His TLD process emphasizes the intricate interplay between technology, organizational change, and learning.

Levin's insights into the socially constructed nature of technology highlight the importance of incorporating cultural knowledge and skills into the technological transfer process. Levin's application of STS emphasizes the importance of considering human factors in technology design and recognizes that successful technology transfer involves more than the physical movement of artifacts -- it encompasses the transfer of embedded cultural skills. He postulates that the organizational developmental process is intrinsic to successful technology transfer, outlining its participative nature and continuous learning aspects.

STS views by other researchers complement Levin's theories by providing a systemic lens to understand the broader socio-technical context in which technology transfer occurs. Contemporary STS frameworks such as those presented by Davis et al. (Davis et al. 2014) encompassing 'Goals, People, Infrastructure, Technology, Culture, and Processes', Pasmore et al.'s (Pasmore et al. 2019) socio-technical action research process incorporating various levels of design, balanced optimisation combining design of the ecosystem, technical system, organisation and social system and levels of outcomes, and Maguire's (Maguire 2014) 21st century view of STS postulating developing technologies extend Levin's theories by explicitly addressing the interconnectedness of several elements.

This paper contributes by integrating Levin's TLD process, and STS principles into the study of human-robot teams (HRT) development. It makes the significant shift in perspective by focusing on a different group of actors, namely the supplier, and the earliest stage of the process, researcher-driven technology development. The synergistic approach taken is significant in determining the complexities inherent in multidisciplinary teams engaged in HRT development, with implications for broader technology development and transfer initiatives. The challenges, contrasts and opportunities identified in the study provide practical insights for fostering co-generative learning, facilitating organizational innovation, and supporting technology transfer in contemporary contexts.

Upon applying Levin's TLD model and STS perspectives to the findings from the case study, a novel contribution of this paper is in the new STS concept of 'collaborative intelligence'. Rapidly developing technologies like artificial intelligence (AI) and human-robot teams opens up a fresh area for future research as new types of (quasi) autonomous agents join existing socio-technical systems.

This paper is structured as follows: Firstly, Levin's theories of technology transfer and various socio-technical systems thinking concepts are outlined, compared and contrasted to identify the research questions. Next, to address the research questions, the qualitative research methodology is described. This is followed by the findings and discussions.

Finally, we conclude by summing up the insights and implications, and offer suggestions for further research.

Identifying and Comparing Levin's Theories with Other Socio-Technical Systems Thinkers

Levin's Theories of Technology Transfer

Levin's extensive work in organizational change, especially within technology-dominated environments highlights the significance of technology transfer as a means for organizational development. The Technology Transfer as a Learning and Developmental process (TLD) model emphasizes the importance of incorporating cultural knowledge and skills into the technological transfer process (Levin 1993a, b). Levin argues that successful technology transfer involves more than the physical movement of artifacts; it encompasses the transfer of embedded cultural skills (Levin 1997). Therefore, the organizational developmental process is intrinsic to successful technology transfer, outlining the participative nature, co-generation of learning and continuous learning aspects (Levin 1993a, b, 1997). Levin's model for technology transfer as a socio-technical learning and developmental process (also known as the TLD process in Levin, 1993a, p. 513) suggests that technology transfer encompasses an innovation process that contributes to the successful use of new machines and equipment.

Socio-Technical Systems (STS) Theories and Thinking

Socio-technical systems theory (STS) explores how the introduction of new technology in organizations impacts people, including how multi-skilled people work together as self-organized units to optimize social and technical systems (Jackson 2019). STS advocates that the design and performance of any organizational system can only be understood and improved if both 'social' and 'technical' aspects are integrated and considered as interdependent parts of a complex system incorporating people, technology, infrastructure, culture, processes or procedures, goals, and metrics or measures (Emery 2016). Optimal performance in such systems requires attendance to both the social and technical aspects of work organization (Jackson 2019). Since the need for socio-technical balance was first recognised, over 50 years ago, STS thinking has evolved (Mumford 2006). The next paragraphs introduce the thinking offered by several recent key STS researchers such as Davis et al. (Davis et al. 2014; Davis 2019), Pasmore et al. (Pasmore et al. 2019) and Maguire (Maguire 2014) who were writing 20–25 years after Levin first published on his TLD model.

Davis, Jayewardene & Clegg's (Davis et al. 2014) socio-technical framework, known as the Socio-technical Hexagon model, identifies six core components of socio-technical systems: goals, people, infrastructure, technology, culture, and processes. This model emphasizes the importance of considering the interplay between different components when analyzing and understanding complex systems. They argue, in what they describe as a "call to bravery", that STS thinking should be applied to new domains, new technologies and even in a predictive way to consider what is likely to happen given our understanding of the socio-technical system's intrarelationships.

Meanwhile Pasmore et al. (Pasmore et al. 2019) offer a forward-looking view of STS for organizations of the future. Their views for organizational design in the face of rapid technological advancement suggest that while technological progress is exponential, organizational design has lagged behind, creating a widening gap between technical solutions and the ability to effectively utilize them (Pasmore et al. 2019). They present a participative STARlab (socio-technical action research) model, that outlines three levels of design work: strategic, governance and ecosystem design. Their implementation of a 2-day STARlab with thirty invited participants concluded that STS change management needed to be continuous, to be more inclusive of stakeholders in the ecosystem, to anticipate variances (being predictive of potential outcomes) and would benefit from using design thinking tools.

Subsequently, Maguire (Maguire 2014) discusses the application of STS principles to 21st-century technologies, including information integration, pervasive systems, artificial intelligence (AI) and cloud computing. He suggests that AI, particularly intelligent agents, could present themselves to users as human-like characters or avatars, cueing responses through their use of language, assumption of social roles, or physical presence (Maguire 2014). Maguire also highlights the importance of considering human factors in technology design and the need for users to learn the skills to make the best use of AI developments (e.g., as intelligent agents, human-robot interactions) while appreciating their benefits and limitations. AI's interactional properties with its environment also enables its capability to learn and change its behaviour based on the cues from the environment (Glikson and Woolley 2020). However, as far as we know, these postulations have not yet been well observed and researched in practical scenarios from an STS and TLD perspective.

Interconnectedness of Theories and Frameworks

The works of Levin, Davis et al., Pasmore et al., and Maguire emphasize the importance of considering both social and technical aspects when designing and implementing new technologies in organizations. Levin's TLD model (Levin 1993a, b, 1997) developed more than three decades ago does align with contemporary STS thinking, viewing technology as shaped by social, cultural, and political factors. The Socio-technical Hexagon model by Davis et al. (Davis et al. 2014) complements Levin's theories by providing a schema of six interrelated elements to better understand the broader socio-technical context of the organisation in which technology transfer occurs. Their views imply that those involved with innovation and technology transfer require access to cultural knowledge encapsulated in technological artefacts. This is as true for those designing these technological artefacts as it is of those using them. The acquisition of skills and understanding comes through a learning process. Technology such as machines and tools have cultural meaning embedded in them and cultural discontinuities can present barriers to this learning process (Levin 1997). This is because the individuals involved in the design and production of technology operate under specific social and cultural conditions likely to encompass individual, professional and organisation culture. Traditional STS and Levin's TLD do recognise that to successfully use these artefacts, users must have access to this inter-cultural knowledge. This implies a need for a dialogue between designer and user to minimise the potential for cultural discontinuities and the risks these entail to the successful adoption of new technologies. These views emphasize the importance of communication and understanding between technology designers and users, which is achieved through mutual learning and dialogue, or as Greenwood & Levin describe it "keeping the conversation going" (Greenwood and Levin 2007).

Levin highlights that co-generative learning occurs with organizational innovation and development through a participative process using action research, where outside experts are embedded within teams (Levin 1993a, b), and critical systems thinking is employed to inquire into important assumptions in understanding and 'givens' that may be relevant (Levin et al. 2007). This would include learning across boundaries of work and disciplines, resulting in participative transformation and learning within teams and across organisations. Pasmore et al.'s STARlab model (Pasmore et al. 2019) extends Levin's theories by explicitly addressing the engagement and interconnectedness of different organizational levels and the need for continuous adaptation in the face of rapid technological change. Both Levin and Pasmore et al. highlight multi-stakeholder participation and collaboration through action research, for innovation with successful technology acceptance and transfer. Maguire's discussion of STS principles applied to developing technologies like AI further reinforces the importance of considering human factors and the social implications of emerging technologies (Maguire 2014).

In the context of advancing technologies like robotics and AI, STS theories suggest that the development and deployment of such (quasi) autonomous agents should have an integrated focus on technical aspects, social implications and the values embedded in the technology. These concepts are critical in addressing industry challenges such as productivity stagnation and labour shortages. Human-robot teams offer a solution to boost productivity while ensuring worker well-being and safety. Therefore, STS integration into the HRT design and development process aims not to replace humans but to enhance their capabilities through collaborative intelligence (Wilson and Daugherty 2018), (quasi) autonomous technology and people working together. The successful development and integration of HRTs requires an extended socio-technical approach that addresses the interplay between technology, people, culture, and processes, as well as continuous learning and adaptation to optimize performance and human well-being.

In the next section, the research questions and qualitative research methodology are outlined. A single unique case study was applied to trace the inception, design and development of a prototype human-robot team (HRT).

Research Questions

This study investigates the interplay between Morten Levin's theories on technology transfer as a socio-technical learning and developmental process (TLD process), and socio-technical systems (STS) theories. Three research questions have been formulated.

1. How does having an STS mindset change the way a multi-disciplinary team works on researching, developing and testing HRTs?
2. What are the challenges in a multidisciplinary team in HRT development?
3. How do STS and Levin's theories serve to enable innovations and Technology Transfer to occur in a HRT development process?

Research Methodology

To illustrate the synergies and potential challenges from Levin's theories of technology transfer coupled with STS concepts, this study employs a qualitative methodology, using a case study focusing on the interactions for the design and development of human-robot teams (HRTs) for construction tasks. The qualitative approach allows for in-depth exploration of the complex social phenomena within real-life contexts (Yin 2014), making it suitable for investigating the socio-technical aspects of HRT development and deployment.

Case Study and Participants

The case study focuses on a collaborative endeavour involving a construction engineering organisation and a small multidisciplinary research team comprising of robotics personnel, working together to develop and use collaborative robots with workers in the construction industry (Le et al. 2023). Two of the authors are action researchers and used this perspective as a way of thinking, while conducting this case study. They worked with the multidisciplinary research team, tasked with applying a socio-technical systems lens to the design and development process using standardised methods for the collection and analysis of data, as recommended by Levin (Levin 2012). While action research was not explicity used in conducting this case study the two authors used a reflective process to interpret what was happening during the collaborative development of technology to help in a construction automation project. The multidisciplinary robotics team at UNITECH developed the prototype Quendabot (Fig. 1), an intelligent robot developed for installing screws for mass timber construction work. This case study was selected as it enabled the firsthand study of socio-technical phenomena in human-robot collaborative technologies within the context of the construction industry. Purposive sampling was employed to select participants who could provide rich insights into the HRT development process (Patton 2014). 60-minute interviews were conducted with industry experts, leaders, project engineers and timber construction consultants and the HRT development team members to gather their views on design and development, as well as their experiences as humans working alongside collaborative

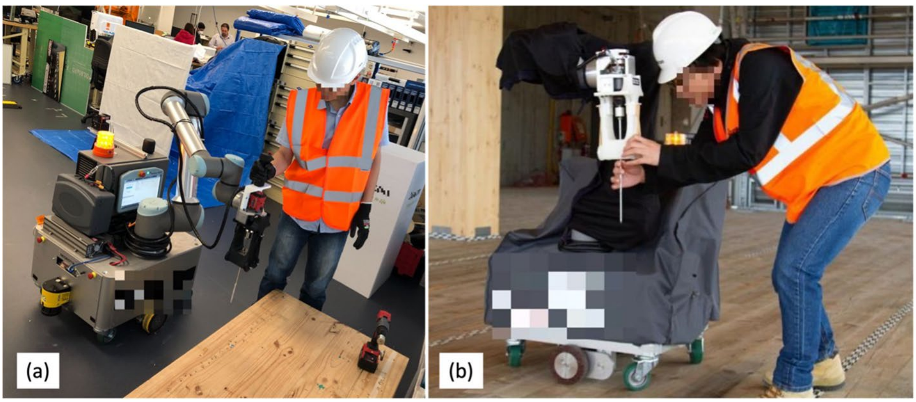

Fig. 1 The Human-robot team comprising the construction worker and Quendabot at (**a**) simulated timber construction site; (**b**) actual construction site

robots. Follow-up on the progress of the case and ongoing developments of the HRT team was possible, aligning with the STS concept of iterative and continuous systems.

Case Synopsis

Researchers at UNITECH, in collaboration with MODA (building site) and AURORA (project engineers identified as 'Lead Project Engineer' and '2nd Project Engineer', and 'Timber Consultant'), developed an autonomous robot, Quendabot, for timber building construction. A simple user interface allows workers to monitor the operation of the Quendabot and view real-time data. At the point of prototype deployment on site, a human operator was needed to feed the screws to the robot as the self-feeding mechanism was not completely developed yet due to time constraints.

This innovation addresses the challenges of repetitive and strenuous tasks involved in Mass Engineered Timber (MET) construction, enhancing both safety and efficiency. The Quendabot project was initiated at the request of AURORA whose role as construction engineers on recent MET projects led them to see a role for such technology. The UNITECH HRT development team, led by a Robotics director, comprises hardware and software engineers, postdoctoral researchers and other collaborating academics (STS Director) focusing on technical and socio-technical aspects. Team meetings are held regularly to discuss developments, achievements, and next steps, with the Robotics Director typically leading discussions.

Quendabot is regularly showcased to industry visitors at the UNITECH Robotics Engineering Lab where the HRT development team demonstrate the human-robot teams completing construction tasks in a lab environment.

Data Collection

The case study was selected as it was possible to interview personnel involved in the development and use of Quendabot on site. The data collection in the case study approach includes semi-structured interviews, videos, photographs, and document analysis. Semi-structured interviews provide flexibility for participants to express their views while ensuring that key topics are covered (Baskarada 2014). The flexible data collection design enabled the researchers to follow up on some of the former interviews to look into the progress of the case and ensure that key aspects from original data collected are not missed. As the data is analysed, emerging results are used to shape the next set of questions.

Videos and photographs served as visual data sources, capturing the interactions and dynamics within the HRT development process. Document analysis involved reviewing relevant project documents, such as design specifications, progress reports, and meeting minutes, to gain further insights into the socio-technical considerations and decision-making processes.

Data Analysis

The data analysis followed an abductive approach, combining observation-based and rule-based thinking to provide a nuanced approach to iterative analysis and interpretations (ISO 2009). The qualitative analysis software NVivo 14 was used to manage and organize the

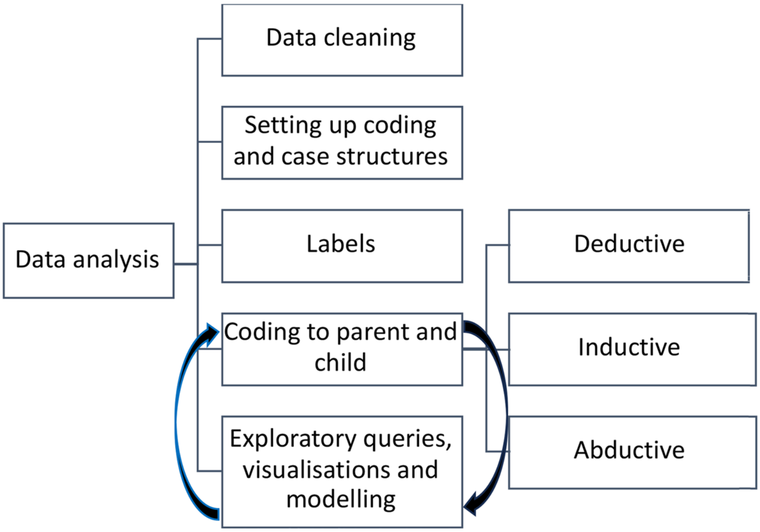

Fig. 2 Data coding and analysis process

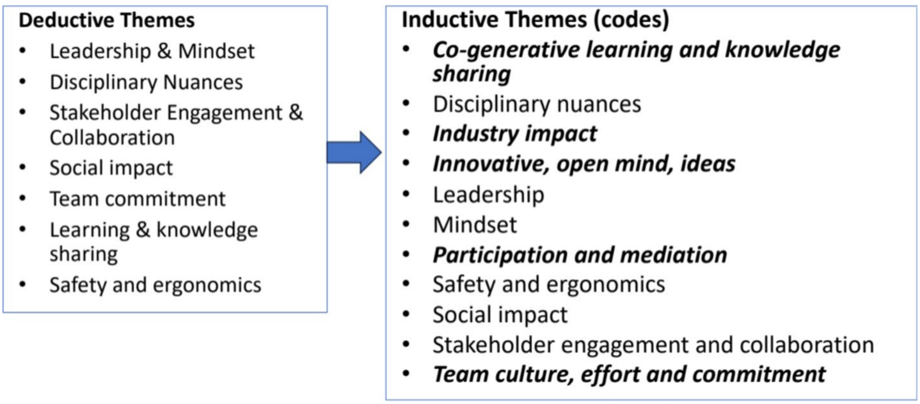

Fig. 3 An example of the deductive and inductive themes

interview data transcripts. This facilitates the coding process and the exploration of emerging themes.

The coding and analysis process (Fig. 2) involved a combination of deductive and inductive coding. Deductive codes are derived from the literature review and the research questions, while inductive codes emerged from the data itself (example in Fig. 3). The analysis approach emphasizes the importance of subjective yet professional analysis based on interpretation and the socio-technical systems perspectives (Srivastava and Hopwood 2009; Alvesson and Sköldberg 2017). Data by way of verbatims as the participants' spoken words are included in the findings as evidence, illustration, explanation to deepen understanding and to give participants a voice (Corden and Sainsbury 2006). Video and photo analyses

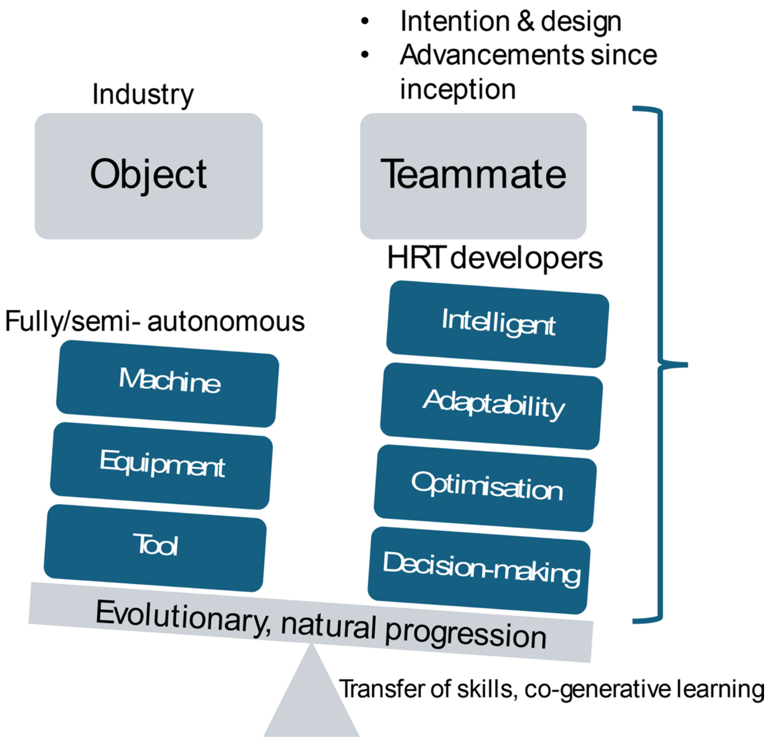

Fig. 4 Contrasting views between industry and human-robot team developers regarding the role of intelligent robots

were conducted as a secondary data source, providing additional reference for context and insights into the HRT development process.

The analysis recognizes the dialectical relationship between ideas and their impact on each other, as well as the reflexivity in the research process, substantiating the researchers' role and presence in the data analysis (Alvesson and Sköldberg 2017). The multidisciplinary co-authors of this paper bring a shared purpose but with asymmetrical and divergent insights, enriching the analysis and interpretation of the data.

Findings and Discussion

Aligned with Levin's TLD model, the case study demonstrates the innovation approach as research-driven, and involves a lead agent (Lead Project Engineer at AURORA) handling the mediation with multiple external stakeholders and strategic consultants (Timber Consultant and 2nd Project Engineer as the Case Timber Construction Consultants). The Timber Consultant also represents the users, due to his extensive experience as a contractor and former carpenter. Meanwhile the technology supplier is UNITECH, a university robotics research team comprising the Robotics Director, Software Engineer, Hardware Engineer and STS Director. The case study contrasts with Levin's original TLD model and much of the STS literature in that the organisation or system being studied is not the end-user but the coalition of AURORA, UNITECH and MODA, considering socio-technical issues at the design stage to establish what ought to be rather than coping with what is. We discuss further aspects of STS elements with the following findings.

Impact of an STS Mindset on Multi-Disciplinary Teams

The adoption of an STS mindset has a significant impact on the way multi-disciplinary teams work on researching, developing, and testing Human-Robot Teams (HRTs). By STS mindset we mean the recognition by all members of the coalition, but particularly the multidisciplinary research team, that the robotics project sits at the centre of a web of interrelationships, that have both technical and human-social aspects, all of which are situated within an open environment from which new interrelationships can emerge at any time. In this context, the project involves the development of Quendabot as a human robot team. The multidisciplinary team in the case study comprises of engineers with knowledge of robotics, users in the construction sector and researchers with a systems background (especially sociotechnical systems) who are helping the team to appreciate the importance of using sociotechnical systems theory.

Leadership and Mindset

The findings reveal that visionary leadership, and an open-minded, forward-thinking mindset are essential for driving innovation in HRTs for construction, for instance, "*We need some drivers or future-thinking leaders who have the vision for the future. Without them, it's very difficult to make it happen.*" (Robotics Director). This is further supported by the statement, *"I think just being open minded and having that, that perseverance, towards driving excellence and driving innovation*" (STS Director). Leaders with a clear vision can inspire and guide multi-disciplinary teams to push boundaries and embrace new technologies. This is in line with Levin's original critical success factor for technology transfer, the company-based innovation process (Levin 1993a, b) and its goal of the learning organisation (Levin 1997), reflected here in the strategic framing set by the team leardership.

Bridging Disciplinary Differences

An STS mindset helps bridge the differences between various disciplines involved in HRT development, such as engineering, AI, IT, Construction and Project Management. The STS Director indicated that engineers tend to have an "*engineer's mentality*" and focus on objective technical aspects, while an STS perspective considers broader and subjective social implications. Recognizing and accommodating different communication styles and priorities can facilitate better collaboration and understanding among team members, as suggested by STS Director, *"Engineers will like to draw pictures. The managers will not draw pictures, but they may have a lot of dialogue, so, depending on who is at the party."* For the members of the multidisciplinary team, who are often deeply inculcated in discipline specific language usage and communication styles, maintaining an STS mindset prompts them to think twice about what they are saying, and to whom.

Balancing Research and Industry/Social Impact

The findings suggest that an STS mindset encourages multi-disciplinary teams to balance academic research excellence with practical industry impact. Whilst publishing papers is important, focusing on developing solutions that benefit the construction industry and end-users is equally crucial, as suggested, *"Although we do not publish as many papers as we expect, but I think research needs to generate benefits to the industry and people working in the industry."* (Robotics Director). This mindset also emphasizes the benefits of considering human factors and social impact, such as wellbeing, ergonomics and user experience, in HRT design. This can be seen through the comments, *"I think the robotics will only bring less fatigue, less stress on the human body and the guys working in allow them to do slightly modified tasks."* (Timber Consultant) and *"We're not taking away jobs, we're, letting the robot do unsafe tasks"* (Robotics Director).

Collaborative Engagement with Stakeholders

An STS mindset promotes collaborative engagement with stakeholders, particularly industry partners, from the early stages of HRT development. Focusing on engagement and developing solutions that benefit the construction industry and end-users is crucial as commented by STS Director, *"That means that we are engaging with the people who are going to apply the solution, at the beginning of the process so that they continuously give us inputs. And we can work to develop something that they will use better."*.

While participants agreed that this was an important aspect, in practice this principle was not always well executed. 2nd Project Engineer expressed concerns about the limited involvement of the physical trades in the Quendabot project, which he felt reduced opportunities for valuable feedback and learning opportunities. *"It was very closely managed by the people who built it, programmed it and were seeking to get the innovative results out of it. It could have been a higher level of involvement between the guys that do it from a physical perspective."* (2nd Project Engineer). This is partly due to the fact that carpenters and other physical trades are most often independent contractors in the Australian construction sector, adding significant complexity to their ongoing engagement as stakeholders.

Through actively seeking to understand the needs and problems of construction companies, multi-disciplinary teams are more likely to develop targeted solutions that address real-world challenges. Early and continuous engagement fosters trust, buy-in, and a sense of shared ownership, leading to more successful HRT implementations, as posited by Levins' TLD model (Levin 1997). Levin's emphasis on the social and cultural aspects of technology transfer is demonstrated, with the implication that effective communication and understanding across different organizational and cultural contexts are important. This remains true even though the case organisation sits further up the supply chain than in Levin's original TLD model.

Co-generative Learning and Engagement

The findings reveal that getting industry partners involved from day one, to understand their problems, gather requirements and continuously seek their input is key. This means early engagement and open conversations and with stakeholders like construction companies are needed to get their buy-in.

Multiple comments were raised about these aspects from both the research and engineering perspectives, for instance, *"It's not about us telling them what we can do. It's more about they tell us what they want"* (Robotics Director), *"Early discussions, early engagement with anything, absolutely anything. Early engagement, as always is the key piece of the puzzle, bringing them into the table early and saying, here's the plan."* (Lead Project Engineer at Aurora). This was also demonstrated through the comments HRT Hardware Engineer, *"So it's very good if their team is working with researchers, not just the very big guy (seniors) that come to our labs.* These statements strongly suggest that researchers and industry partners need to work closely together, be open, and not hide problems from each other.

Additionally, as robots become more learning-oriented, teaching humans how to effectively interact with them will become increasingly important, "*it's important for humans to know how to teach robots. They have to understand what they're learning and what the robots are actually learning.*" (Software Engineer). This leads to the next theme where robots are viewed as collaborative partners. An STS mindset that considers robots as collaborative partners rather than mere tools can foster a more human-centric approach to HRT development *"I think the mindset of it is just treating a robot like another human, like if they were a new person on the work side"* as commented by the Software Engineer, leading to better integration and acceptance of robots on construction sites.

Challenges Faced by Multidisciplinary Teams

The themes reveal that Levin's theories provide a valuable foundation for understanding innovation and technology transfer through having an STS mindset in multidisciplinary teams. Contemporary sociotechnical systems face unique challenges, particularly resistance from stakeholders and end-users, conflicting organisational and stakeholder priorities and expectations, and emergence of AI-driven technologies in human-robot teams.

Resistance from Stakeholders

One of the primary challenges is resistance from stakeholders and end-users, including construction companies and unions. This resistance typically stems from concerns about job displacement and changes to established work practices. These quotes by Timber Consultant illustrate the resistance and perceptions observed in the field, *"The other guys who just want to use their drill every day of the week, because that's what they know." "Some (xxxxx) people have a very narrow perception of it. It's taking jobs and all those sorts of (xxxxx) things. The reality is, I don't think the robots ever done anybody out of work, all it's done is created a diverse working environment and people who learn different skills.*".

Overcoming this resistance requires careful communication, education, and collaboration with these stakeholders to address their concerns and demonstrate the benefits of human-robot collaboration.

Managing Scope and Expectations

Another challenge is managing the scope and expectations of industry partners in the HRT design. Software Engineer commented that, "*We engineered this robot to go beyond these kinds of limitations that the robot has. If it was a proper project run by a partner, they would have better scoping*." (Software Engineer). Better scoping and clear communication of project goals and limitations can help manage expectations and ensure a more successful collaboration between the research team and industry partners.

Limited Resources

Limited resources, both in terms of funding and time, can also hinder the development and scalability of HRT projects. These constraints can lead to compromises in robot design and functionality, as well as a lack of continued development and improvement. These comments illustrate the issue, *"In terms of why the robot was not designed in the ideal way, it is mainly because we have the limitation of the resources."* (Robotics Director). Securing adequate funding and dedicating resources to further development are essential for realizing the full potential of HRTs in construction.

Risky Integration of HRT into Existing Construction Processes and Workflows

STS principles hold that ideally, new technologies ought to be integrated with the social systems for a unified and holistic approach. However, the case study indicates that integrating robots into existing construction processes and workflows presents challenges to the designers of such technologies. 2nd Project Engineer raises concerns about the ability of robots to handle dynamic and unstructured construction environments, where problem-solving and adaptability are crucial, for example, *"I think that's where the robot is limited is when it comes across a problem, something's in its way, and it just stop and wait for somebody to solve its problem in the early days."* (2nd Project Engineer). *"There's the risk of if the robot breaks down whilst it's working, then you're delaying work on site. So delay becomes a critical aspect of what we do for the robot to not have any downtime."* (Lead Project Engineer). Robotic system downtime or breakdowns can cause delays and disrupt construction schedules, which are often tight and interdependent. For HRTs, ensuring robot reliability, maintainability, and seamless integration into construction workflows is crucial to mitigate these risks and minimize disruptions.

Different views of robots: The Robot as a Team-Mate in Human-Robot Teams (HRTs)s

The findings reveal contrasting perspectives between industry participants and HRT developers regarding the role of robots in HRTs as illustrated in Fig. 4. Industry participants tend to view robots as an object, such as a tool, equipment, or machine, or as a fully autonomous technology that will naturally progress and evolve as commented by Timber Consultant, *"It's just a natural progression in the arsenal of tools that we have at our disposal…. As we get more skilled in being able to program to do more complex tasks, that will be the way to evolve."*. In contrast, the HRT development team perceives robots as teammates, capable of decision-making, optimization, adaptability, and intelligence. This difference in perspective can be attributed to the designers' insight, intention, and proximity to the advancements in technology, including AI capabilities, since the inception of the Quendabot project. These differences in how robots are perceived were highlighted where different stakeholders attributed different descriptions to the robot, including "alien," "machine," "worker," and "colleague" based on their familiarity and experience with the robot (Sauppé and Mutlu 2015).

The challenges identified demonstrate the importance of effective stakeholder engagement, clear communication, adequate resource allocation, and thorough planning for the successful development and integration of human-robot teams in the construction industry. Addressing these requires a multi-faceted approach that considers the technical, social, and organizational aspects of HRT projects. Despite the different contexts, these themes are typically in line with TLD and STS thinking. However, contrasting views can spur innovation and new ways of sociotechnical thinking. This was found in the theme of 'robot as teammate' and will be discussed in the next section.

Emergence of a New Sociotechnical Dynamics

From the findings, we observed that the integration of AI into HRTs introduces a new type of sociotechnical working relationship and associated dynamics between humans and robots. In the AI field, as robots become proactive and intelligent agents, they challenge the traditional notions of human-robot interaction (Glikson and Woolley 2020). Robots as social entities or "co-worker" affects people's perceptions regarding their social relationships (Sauppé and Mutlu 2015). This shift leads to changes in human behaviours and attitudes towards robots, invokes different communication modes and cues, changed expectations of agency, autonomy and self-determination, and the possibility of alternative work processes and routines (Sauppé and Mutlu 2015).

The rapid advancements in AI challenge and extend Levin's theories of technology transfer and STS thinking. With the increasing sophistication of AI systems, the STS concept of the co-generation of knowledge and collaborative learning between humans and other humans have moved into the domain of humans and robots, through machine learning. Furthermore, robots powered by AI have the potential to be proactive initiators rather than mere followers or responders, leading to a more dynamic and interactive technology transfer process.

Collaborative Intelligence – Incorporating Levin's Theories of Co-Generative Learning into STS Theories

The integration of AI into HRTs obliges an update to traditional STS theories The human-robot team can be viewed as an autonomous and adaptive subsystem, where team decisions are made jointly, and problems are solved within the unit, based on each agent's capabilities to optimize performance and outcomes. This leads to incorporating *"collaborative intelligence"* in STS theory, emphasizing the symbiotic relationship between human and artificial intelligence in socio-technical systems. As Wilson & Daugherty (Wilson and Daugherty 2018) (p.123) observe *'Organizations that use machines merely to displace workers through automation will miss the full potential of AI. Such a strategy is misguided from the get-go. Tomorrow's leaders will instead be those that embrace collaborative intelligence*, *trans-*

forming their operations, their markets, their industries, and—no less important—their workforces'.

Challenges and Opportunities for AI-Driven HRTs

Ethical Considerations

The incorporation of HRTs that are enabled by AI acting as (quasi) autonomous agents raises ethical dilemmas that need to be addressed. As AI systems become more autonomous and exhibit independent decision making behaviours, issues of responsibility, accountability, transparency, and fairness become critical. These would be in addition to the issues of safety, both physical (injury, accident) and psychosocial (trust, dependability, reliability) that already pertain to the use of industrial robots. For instance, the ethical aspects fundamental already to robotic design center on the ethics of safety—both physical and psychosocial. Physical safety involves valuing human life and wellbeing by reducing or eliminating risks of injury from accidents, repetitive strain, and heavy lifting, as well as minimizing human involvement in menial, dangerous, and dirty construction environments. Psychosocial safety, on the other hand, encompasses factors such as trust, dependability, reliability, and autonomy within human-robot teams. Responsible AI development includes considering AI systems as artefacts, where humans set the purpose in alignment with societal, moral, and legal values (Rodríguez et al. 2011; Ahmad et al. 2022). This would need further exploration beyond this report on a single case study.

Stakeholder Engagement and Organizational Dynamicss

The rapidly evolving nature of technologies poses challenges for stakeholder participation and inter-organizational dynamics in HRT development and implementation. Engaging stakeholders and managing organizational change in the context of AI-driven HRTs requires adaptive approaches that can keep pace with the dynamic technological landscape. An STS mindset that acknowledges the complex web of socio-technical interractions taking place in an ever-changing environment is a good starting point for such conversations.

Conclusions

This study delved into Levin's theories on technology transfer as a socio-technical learning and developmental process (TLD process), and socio-technical systems (STS) theories, within Human-Robot Team (HRT) development. The unique case study demonstrated how a multidisciplinary team has navigated HRT design and development and provided insights into fostering co-generative learning, driving organizational innovation, and facilitating technology transfer in contemporary contexts.

The research uncovered divergent viewpoints between industry participants and HRT developers regarding the role of intelligent robots in HRTs. While industry players often see robots as tools, visionary leaders and HRT designers regard them as decision-making teammates capable of optimization, adaptability, and intelligence. These differing perceptions of emerging technologies suggest the need for a paradigm shift, urging those working with robots to embrace them as collaborative partners rather than mere tools. The infusion of AI into HRTs introduces a new dimension into socio-technical dynamics, challenging traditional human-robot interaction norms. As robots evolve into potentially proactive agents, they are likely to reshape human behaviours, communication modes, and work processes. This paper proposes integrating "*collaborative intelligence*" into STS theory to address these emerging dynamics, emphasizing the symbiotic relationship between humans, AI and robots.

Levin's (1993a, 1997) emphasis on incorporating cultural knowledge into technological transfer resonates with current STS's holistic approach to HRT development. Collaboration, flexibility, and adaptability are crucial in technology transfer programs to navigate changing conditions and unpredictable technological landscapes. Additionally, integrating new technology into strategic plans, leveraging local competencies, and fostering continuous learning optimize HRT performance. Challenges from the case study such as stakeholder resistance, resource constraints, and integration issues reveal the importance of effective stakeholder engagement, clear communication, and thorough planning for successful HRT development and technology transfer. This study has broader implications for technology development and transfer initiatives, emphasizing skill leveraging, adaptability, and collaboration.

However, limitations like single-case focus and evolving AI technologies may affect generalizability over time. Future research could explore AI-driven HRTs in diverse industries to grasp socio-technical dynamics comprehensively. Developing STS principles and frameworks for HRTs enabled by AI that consider responsible and ethical deployment, skill leveraging, adaptability, and collaboration and organizational dynamics, are crucial areas of investigation. Lastly, while the original STS concepts by Emery and Trist (Mumford 2006) implied self-organizing teams, the question of whether intelligent robots could prompt the evolution of a new form of self-organizing teams with humans and robots jointly deciding how to allocate tasks dynamically during the execution of a complex processes in construction, has yet to be explored in socio-technical systems research.

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Data Availability The raw data that support the findings of this study are not openly available due to ethical reasons of participant confidentiality, anonymity and privacy. Summaries of the data are available from the corresponding author upon reasonable request. Data are located in controlled access data storage at University of Technology Sydney.

Declarations

Ethics Approval and Consent to Participate This study has been approved by the University of Technology Sydney Human Research Ethics Committee (ETH22-7525) with informed consent from participants. All information is kept confidential, anonymous and private. We confirm that we understand Journal of Systemic Practice and Action Research is a transformative journal. When research is accepted for publication, there is a choice to publish using either immediate gold open access or the traditional publishing route. We declare that the authors have no competing interests as defined by Springer, or other interests that might be perceived to influence the results and/or discussion reported in this paper. The results/data/figures in this manuscript have not been published elsewhere, nor are they under consideration (from all Contributing Authors) by another publisher. We have read the Springer Nature Portfolio journal policies on author responsibilities and submit this manuscript in accordance with those policies. All of the material is owned by the authors and/or no permissions are required.

Competing Interests The authors declare no competing interests.

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