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Leveraging socio-technical systems to tackle grand challenges: Reflections on human-robot teams, hybrid workplaces, med-tech, and digital transformation

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ABSTRACT

The world is increasingly volatile, uncertain, complex, and ambiguous with global challenges such as the UN's Sustainable Development Goals presenting new design issues. In this paper, we argue that socio-technical systems principles and tools can be applied to address these wicked problems. We illustrate this and consider challenges of applying these ideas using four examples: designing human-robot teams, designing future hybrid workplaces, integration of surgical technologies (med-tech) in public healthcare systems, and digital transformation within policing. We call for socio-technical systems thinking to be applied to grand challenges to foster collaboration, develop shared language, and enable multi-disciplinary solutions. We suggest that this can be effectively supported through adopting the role of expert facilitators. We discuss the extension of socio-technical systems thinking to enable identification of outcomes and impacts relating to SDGs; to broaden the conceptualisation of stakeholders and system boundaries; to utilise project management tools and to integrate socio-digital skills.

Practitioner summary: Expert facilitators enable socio-technical system (STS) thinking to be applied to wicked problems. STS principles and tools should be extended to include Sustainable Development Goals outcomes and impacts. 'Stakeholders' are increasingly diverse and project management tools can identify and engage these groups. Technological innovation requires new socio-digital skills and training.

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1. Introduction

Socio-technical systems (STS) theory emerged around 75 years ago (e.g. Trist and Bamforth 1951) and has since been applied widely in practice and research (e.g. Baxter and Sommerville 2011; Imanghaliyeva et al. 2020). Fundamentally, STS thinking considers organisations as complex systems, comprising many interdependent (social and technical) factors (Cherns 1976; Clegg 2000). Changes to part of the system will have consequences (intended or unintended) elsewhere in the system and design is more effective where both social and technical factors are considered in advance (Hendrick 1997).

Academics and practitioners have applied STS methods and principles to many contemporary issues, including cyber security (e.g. Malatji, Von Solms, and Marnewick 2019); industry 4.0 (Sony and Naik 2020); sustainable development (Bolis et al. 2023), smart working (Bednar and Welch 2020) and augmented job design (Parker and Grote 2022). In so doing, scholars have used and improved existing frameworks, generated new approaches, and developed predictive tools (Clegg et al. 2017; Hughes et al. 2017; Salmon et al. 2022; Thatcher, Nayak, and Waterson 2020). The breadth of activity demonstrates the flexibility and potential of STS thinking to approach eclectic problems at all scales (Davis et al. 2014). However, despite immense potential, STS thinking in practice is not yet mainstream. For example, Google search trends data for STS terms from 2004 to 2024 remains stable but relatively low (Google 2025). STS theorists and practitioners must therefore consider the challenges (and concomitant opportunities) of applying STS principles across more stakeholders and problem areas.

One such challenge could be the perceived relevance of established STS theory to our rapidly evolving environment (e.g. Imanghaliyeva et al. 2020). The world is increasingly *v*olatile, *u*ncertain, *c*omplex, and

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ambiguous (VUCA) (Benett and Lemoine 2014). We must therefore respond to increasing disruptions, including pandemics, artificial intelligence, climate change, political instability, supply chain fragmentation, shifting societal norms, and changing work patterns. The pace and complexity of these changes requires a corresponding evolution in our approach to proactively address global challenges such as the UN's Sustainable Development Goals (SDGs) or future workplace design.

In this paper, we use four case examples to identify and explore the challenges involved in applying STS thinking to complex problems involving technological disruption or innovation. We extend knowledge by explicitly considering the implications of addressing SDG-linked problems and consider how these may differ from traditional design problems. We set-out to identify possible extensions to STS principles, relevant approaches and methods that may support STS adoption in a VUCA world.

1.1. Approach and structure

In the background section, we first reflect on contemporary challenges and why an STS approach is particularly suited to addressing them. We then discuss the value of applying an STS approach and scaling it up to address wicked problems.

Next, in our illustrative examples section, we reflect on four examples from our collective experience. Each illustrates different challenges and opportunities relating to work systems experiencing change or redesign due to technological disruption or innovation: (1) human-robot teams, (2) the design of future hybrid workplaces, (3) the integration of surgical technologies (med-tech) in public healthcare systems, and (4) digital transformation within police organisations. These diverse examples illustrate challenges with applying STS thinking in practice to these SDG-linked problems and implications for extending our use of STS principles. In turn, we identify approaches and methods to support STS adoption, including multi-disciplinary teams, unifying language, and common goals. In so doing, we highlight the changing notion of stakeholders and the emerging importance of *socio-digital skills* (Hughes and Davis 2024) relevant to various challenges.

In our discussion section, we then propose an agenda that builds on STS thinking to provide a common platform and shared language to enable multi-disciplinary teams to address wicked problems. We argue there are opportunities to reframe our roles from disciplinary experts (i.e. creating the solutions) to expert facilitators, thereby extending the reach and impact of STS thinking. We propose learning from project management experts about engaging with and meeting stakeholder expectations. We extend conceptualizations of socio-technical systems by explicitly identifying socio-digital skills as a key contingency and enabler within organisations. Finally, we advocate ergonomists' professional skills training should build capability to address grand challenges. We conclude by noting limitations and calling for collective action to address the challenges of our VUCA world.

1.2. Background: socio-technical systems thinking and grand challenges

The UN's SDGs call for rapid action to end poverty, protect the planet, and ensure universal peace and prosperity (Singhal, Davis, and Voss 2024). They epitomise the scale, complexity, and breadth of 21st century societal challenges that businesses must help address. However, SDGs require sustained and systemic change across society and are beyond individual organisations or nations to accomplish (George et al. 2016). Accordingly, SDGs mirror other grand challenges facing organisations (e.g. Artificial Intelligence, ageing populations, geopolitical disruption), as 'wicked' problems requiring collaboration across diverse stakeholders, disciplines, and individuals (Bansal and Sharma 2022; Colledge 2017; George et al. 2024; Hughes et al. 2024), and are likely to involve technological innovation alongside behaviour or social change. The problems themselves are often dynamic, multifaceted, difficult to define, and interconnected, making them complex to approach, let alone to solve (Hughes et al. 2017).

Such wicked problems are quintessentially socio-technical problems, comprising many interdependent social and technical components that interact in expected and unexpected ways (Cherns 1976; Hendrick 1997). STS may refer to single organisations, teams, multi-team systems, industry clusters, events, or whole industries. Regardless of scale, each system includes interconnected social (e.g. people, culture, goals) and technical (e.g. technologies, processes, infrastructure) elements that together enable the system to operate (Davis et al. 2014). Technical components could include software, hardware, or emergent tools such as AI, machine learning, or chatbots, together with offices, work sites, utilities and supporting physical structures, formal and informal production practices, working arrangements, HR policies, knowledge management systems, and processes used to operate the organisation and its subcomponents. Social factors can span individuals' attitudes, knowledge, motivation, skills, organisational culture and sub-cultures, norms, corporate strategy, task goals, performance related targets and Key Performance Indicators. Organisational systems can be represented using these inter-related elements to consider the interdependencies and causal effects of changes in different components (e.g. Figure 1).

STS theorists argue that 'design is systemic' (Clegg 2000, 465) and that systems perform better when their design and operation are jointly optimised (McKay et al. 2020; Pasmore et al., 2019). In practice, this means that when designing a change to a system to address any problem, whether wicked or seemingly simple, decisions and actions will likely affect or require changes elsewhere within the system (Davis et al. 2014). For instance, introducing a new workplace technology or a change to environmental regulation (process) will necessitate unanticipated or consequential changes to job roles and training (people), culture, and infrastructure (e.g. Shepherd, Clegg, and Stride 2009). Some such changes will be predictable and intended, though others may be unforeseen and potentially even undesirable. Contemporary STS thinking emphasises the complex inter-relationships that exist between a system's networks, actors, and structures, both vertically and horizontally within tasks, activities, or groups (Ang et al. 2024).

Socio-technical principles (Cherns 1976; Clegg 2000) are increasingly utilised to understand wickedness inherent in grand challenges (Hughes et al. 2024), including sustainability, health or medical technology, ageing populations, smart cities, artificial intelligence, and industry 4.0 (Colledge 2017; Costa, Diehl, and Snelders 2019; Lawhon and Murphy 2012; Marcon et al. 2022; Singhal, Davis, and Voss 2024; Smit, Scott, and Pitt 2023; Westbrook et al. 2007). Certainly, ergonomics has a proud history of working to balance developments in technologies, work practices, and organisational change with safety, human experience, and social outcomes – seeking ways to develop design solutions that satisfy multiple stakeholders' needs (in itself, an often-intractable problem) (van Eijnatten 1997; Mumford 2006). While the complexity, scale, and scope of wicked problems such as climate change or artificial intelligence may extend beyond the traditional notion of STS (Thatcher, Nayak, and Waterson 2020), we contend that the STS mind-set and principles remain relevant in convening the necessary stakeholders to understand and then collaboratively pursue the transformational change needed to tackle grand challenges (Hughes et al. 2024).

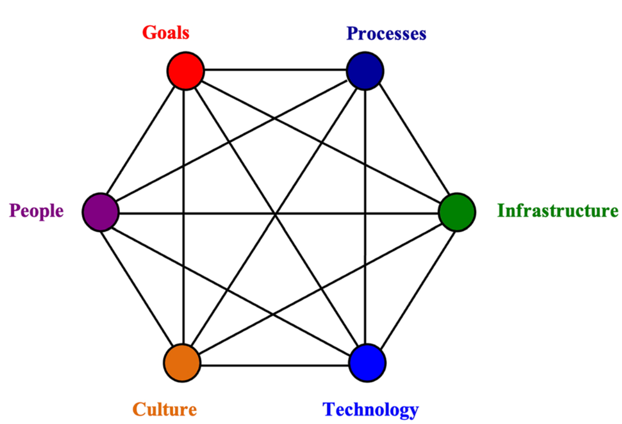


Figure 1. Socio-technical system, illustrating the interrelated nature of an organisational system (adapted from Challenger, Clegg, and Robinson 2010, 74).

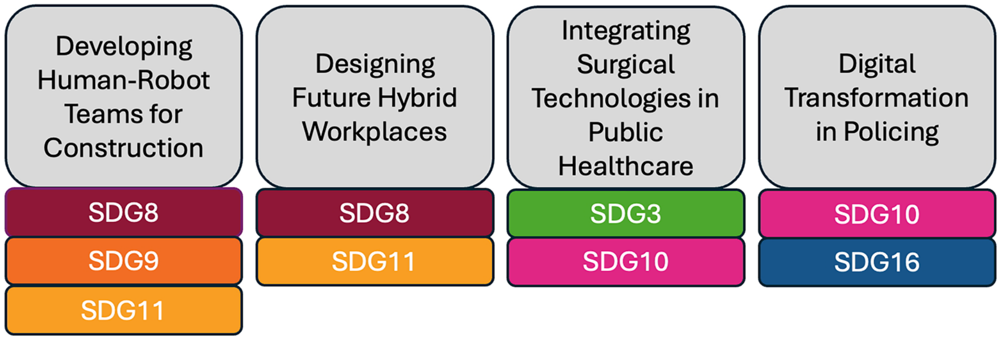
We extend these ideas by arguing that the challenge of delivering impactful change is further compounded by the wickedness of collaboration itself, since this too has socio-technical ramifications. To deliver against challenges like the SDGs, the different stakeholders must share a common language. This requires tools, methods, and allied investment. In this paper, we demonstrate how tools readily used in ergonomics and project management can support this agenda, as can broadly applying STS principles and extending them to reflect the expanding scope of design challenges.

2. Examples of STS application to grand challenges

Next, we provide four examples of applying an STS approach to contemporary challenges driven by technological disruption or prospective innovation. Each example addresses a range of SDG areas (see Figure 2), such as promoting peaceful and inclusive societies (SDG16) through digital transformation in policing. Together, these examples demonstrate the breadth of stakeholders involved in contemporary design challenges, the difficulties in establishing system boundaries, the new skills demanded, and the value delivered by a shared socio-technical language.

2.1. Developing human-robot teams for construction

Our first example concerns the challenge of integrating AI and robotics within the construction industry. Emerging technologies present significant potential benefits for productivity, quality, efficient use of resources, sustainability, and inclusivity by reducing physical demands. However, significant challenges exist in integrating robotics within real-world construction sites, maintaining 'decent work' (i.e. not deskilling or producing undesirable human roles), and minimising



SDG3: Ensure healthy lives and promote well-being for all at all ages

SDG8: Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all

SDG9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation

SDG10: Reduce inequality within and among countries

SDG11: Make cities and human settlements inclusive, safe, resilient and sustainable

SDG16: Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels

Figure 2. SDGs addressed by the four examples.

potential costs such as reduced employment. These challenges reflect similar design contingencies expected in mainstreaming robotics and AI elsewhere.

This example reflects on the journey of researchers developing solutions for the construction industry. We illustrate how the team considered, understood, and applied STS thinking to design human-robot teams for construction. The Quenda-bot project, initiated in 2021, developed a robot capable of drilling and installing long screws into mass timber boards, addressing the challenges of repetitive and strenuous construction tasks (Le et al. 2023). Initially, the project addressed *technical* aspects of robot design and development. This followed the research team's previous practice when designing fully autonomous robots that worked *for*, but not *with*, humans. However, Quenda-bot had to be smart enough to use the building's digital design data to know where to place each screw, but would still not be smart enough to navigate a dangerous construction site unsupervised. Consequently, Quenda-bot would only succeed if designed to collaborate with people within a human-robot team (Ang et al. 2023).

Human-robot teaming (HRT) came with social considerations not germane to fully autonomous robot designs and so STS researchers joined the project design team to address these. This occurred because the project leaders recognised the importance of integrating social and technical aspects into the design and development of robot technologies. By engaging a multidisciplinary team – comprising researchers and engineers in robotics, STS, and project management – the opportunities for the Quenda-bot were much improved. This eventually resulted in an integrated human-robotic construction team that could install 300 mm long screws faster and more accurately than experienced human workers. Whilst the importance of integrating STS concepts became apparent to the project design team, incorporating them in the development project proved challenging as they did not match the existing practices and mindset of the multidisciplinary team (Ang et al. 2023). So, the team first had to align their understanding of terms that had different disciplinary meanings, such as human factors, joint optimisation, variance controls, and autonomy.

Developing this shared understanding involved significant effort by the STS researchers to introduce the roboticists to the philosophical paradigms underlying STS theories and design principles. In subsequent versions of Quenda-bot and other intelligent robots, the team incorporated artificial intelligence (AI) technologies, such as large language models (LLMs), to enhance the robots' capabilities and enable more natural interactions with human team members. The rapid advancement of AI technologies posed new challenges, such as ensuring transparency, predictability, and ethical development of AI-enhanced HRTs. In safety-critical work environments such as construction, there are implicit assumptions of individual accountability and threatened sanctions that maintain a safe workplace.

However, these assumption are challenged when the team includes robots with no understanding of these concepts.

Authentic stakeholder collaboration throughout the development process was found to be lacking, partly due to the short duration of the Quenda-bot project but also because of the topic sensitivity in the unionised but otherwise fractured Australian construction industry (Ang et al. 2023). The team did engage with industry members, however these were not construction workers who could have provided valuable insights into the ergonomic challenges and requirements of the construction site (Ang et al. 2024). The Quenda-bot example shows that designers can create more viable robotic opportunities, that enhance ergonomics, reduce physical strain, and optimise human-robot collaboration in dynamic work environments by considering the social and technical aspects – however, this depends on first establishing a common language and mind-set (Ang et al. 2023; Le et al. 2023).

2.2. Designing future hybrid workplaces

Our second example reflects on the challenge of designing future hybrid workplaces where the very nature of 'workplace' is being disrupted by technological possibilities. This challenge centres on emerging tensions between shifting societal expectations, where technology enables inclusive employment practices, more efficient use of city space, and reduced transport usage, alongside competing economic, business, and social interests in how and where work is conducted.

Davis et al. (2022a) describe the deliberations involved in redesigning work systems and workplaces to accommodate the rapid shift to hybrid working post-COVID in various public and private sector UK organisations. The rapid growth in hybrid working, enabled by advances in collaborative technologies for remote and asynchronous working, has transformed the notion of a workplace (see, Galanti et al. 2021; Wheatley et al. 2024; Wu et al. 2024) and created a contested design problem. Designers must now resolve conflicting visions of work across stakeholders at various levels where identifying the system boundary may be difficult (e.g. where does the workplace start and stop if it could include home, public and client spaces?).

Methodologically, an STS Scenarios Tool (STSST) was employed (Hughes et al. 2017) to analyse problems, alongside stakeholder interviews and informal design discussions with management groups to understand the contexts, map the socio-technical systems, support the ideation of future workplaces for each organisation, and to understand staff experiences. The project team configuration was underpinned by the STS principle of user involvement, extended to consider wider stakeholder groups (Bednar and Welch 2020; Clegg 2000; Hughes et al. 2017; Winby and Mohrman 2018), and the project was steered by a multi-disciplinary research team, including psychologists and ergonomists, engineers, information scientists, and business professionals.

STSST workshops and interviews identified expectations, requirements, and goals for the future workplace. An initial lesson here concerned the difficulty in defining scope and goals for the future workplace, with considerable variation in the mental models of 'hybrid working' between intra-organisational and external stakeholders (employee groups, technical services, external providers). For example, while the same terms were used by different groups, the operationalisation was markedly different. One person's idea of hybrid working may be predominantly remote with quarterly office visits, while another person may expect to work in the office day-to-day with the option to work from home if needed (Davis et al. 2022a). Furthermore, there was a lack of shared understanding or acceptance regarding the role of 'place' in any future workplace. For example, these ranged from adapting traditional office buildings and configurations to provide technologies to enable hybrid meetings, to radical downsizing of office provision, with employees using local co-working spaces instead and a reduced corporate base for client activities (see, Davis et al. 2022a; Davis et al. 2022b). The STSST provided a structured approach to explicitly elicit the conflicting goals, needs, and values present both within and between stakeholder groups and the trade-offs and contingencies present in different design configurations.

Unravelling the implications of different design preferences and choices was complex and only possible by incorporating multi-disciplinary expertise. For example, architects, technology specialists, human resources, legal teams, health and safety, property management, and other specialisms worked through the simultaneous changes resulting from a seemingly simple implementation of a hybrid working policy change. For example, for employees to spend some time working from home, it would be vital to enable access to core corporate information systems and provide office space to support hybrid meetings. Assessing the potential for unintended consequences on different employee groups, highlighted through STSST deliberations, required diverse datasets, including social network analysis, physical location data, and staff surveys.

Mapping the envisaged workplaces as STS and exploring the implications of differing design choices with stakeholders identified challenges regarding defining the system's boundaries. Stakeholder discussions showed the future workplace is nebulous in physical location (e.g. workplaces within homes or public spaces), technological boundaries (e.g. blurring between work and personal messaging platforms), and temporality (e.g. when the workday begins and ends). This inevitably increased the range of stakeholders to consider, including spouses and children, private landlords, home insurers, domestic furniture suppliers, local government, transport providers, and local communities. Implementing a more inclusive and extensive approach to stakeholder mapping influenced the design goals within some organisations. For example, a financial services firm with strong connections to their local area prioritised redesign of their corporate office to maintain footfall of employees into the town (to support dependent local businesses and services). Opportunities for the public to use the office building were also considered, so that their corporate social responsibility would be aligned with their hybrid working approach. Our approach of considering design as an 'extended social process' (see, Clegg 2000) aligns with following the path of change wherever it leads. However, our initial design discussions and stakeholder mapping had not foreseen the breadth or scope of the system change that redesigning the physical workplace for new ways of working would take.

2.3. Integrating surgical technologies (med-tech) in a public healthcare system

Our third example considers integrating accelerated surgical technology in the UK's public healthcare system, the NHS. Surgical care accounts for over one-third of hospital admissions in the UK with over 10 million annual operations. Innovation in domains such as machine learning, augmented reality, and genomics can facilitate earlier detection, quicker diagnosis, and more effective treatment of surgical conditions with safer and earlier recovery (Department of Health & Social Care 2024). Successfully mainstreaming promising technologies in complex health systems can improve public health and reduce treatment inequalities. However, widespread deployment of new technologies in high-risk processes within tightly regulated and bureaucratic health systems presents challenges.

This example focuses on the experience of a multidisciplinary Health technology Research Centre (HRC) tasked with accelerating the development and deployment of surgical innovation in the NHS. The HRC community comprises surgeons, health economists, innovation consultancies, engineers, clinical trialists, technology companies, and allied health service professionals. It has a strong track record in piloting novel technologies, with a number of pioneering examples. Despite increasing technological possibilities, clinicians are concerned about the slow pace of mainstream adoption across the NHS due to non-technological barriers. The HRC recognised that so-called 'plug and play' technology that satisfies existing socio-technical boundaries and parameters is easier for the NHS to implement, even if it is less innovative. Over time, our involvement has demonstrated, through a range of inter-disciplinary case examples, that many of the overarching challenges faced by the HRC are inherently socio-technical and must be understood to enable progress, because: (a) the focal technologies inevitably influence aspects such as surgical processes, culture, and training; and (b) diverse stakeholders must collaborate to enable the right technologies to deliver against the right surgical problems.

In particular, the STS researchers' role as interlocutors is helping the HRC to identify that there are system design *choices* in operationalising new surgical technology (Hughes et al. 2017), which may have broader implications for its mainstreaming. For instance, STS researchers are helping surgical leadership to map the socio-technical choices they make regarding particular technology implementations, and elucidating implicit assumptions and operational trade-offs. In one case, the surgeon described adapting existing surgical roles that were essential to enable effective delivery and manage risk. Some technologies initially require longer theatre time or specialist surgical environments, which might have unintentionally increased rather than reduced waiting times. Sometimes, new technology might require the surgeon to interact with health professionals who were not previously involved in the surgery. For instance, technology that enables invasive radiology for renal cancer ablation brings a previously laboratory-based radiologist to the forefront of a patient-facing surgical environment (Wah et al. 2014). Another case requires a new real-time, intraoperative consultation between a neurosurgeon and a neuropathologist when conducting brain tumour resection surgery (Fotteler et al. 2021). These technologies are changing relational norms and power balances between collaborating professionals, who each have different needs and role-related goals from the surgical procedure.

Achieving effective surgical outcomes with mainstreamed new technologies requires socio-technical integration, and an understanding of technology implementation as a dynamic and iterative process (see, Clegg 2000). The examples above show how surgical technology can necessitate new *socio*-digital skills (Hughes and Davis 2024) – that is, being able to operate the technology from a technical perspective might not be enough to achieve surgical success. Stakeholders may need to establish new etiquette, common language, and social norms to enable effective collaboration. In many of the HRC's cases, effective technology adoption and implementation requires creating new roles, and potentially overhauling long-established working practices and culture. Alongside this, stakeholders' competing goals can be difficult to reconcile – not least, because procurement and investment decisions are often made in professional circles far removed from surgical practice.

This example demonstrates the role of STS researchers as expert facilitators of system re-design in response to surgical innovation, and the mechanisms through which this facilitation occurs. The interlocutor role is key to connecting and empowering stakeholder groups, by understanding their (sometimes competing) needs, and collaborating with HRC colleagues to develop socio-technical tools to capture system readiness for different technologies, alongside better refined understanding of the system changes required to 'jointly optimise' the system. While this work is ongoing, by engaging the HRC community in the value of STS thinking, the STS researchers are developing understanding and capability within these stakeholder groups to examine old problems in new, more holistic ways, enabling projects that better equip those involved in surgery to embed and mainstream technological innovation.

2.4. Digital transformation in policing

This final example draws on experience participating in the digital transformation of a large UK policing organisation with over 8,000 employees, serving around 2 million citizens, and covering a diverse population and geographic area (Gritt, Forsgren, and Pandza 2024). In this organisation, digital transformation is driven by advancements in digital technologies, changing public behaviours and expectations, and the need for public services to deliver more for less. These drivers put pressure on police to transform through implementing new technologies, which in turn influence changes in organisational structure and culture. Developing a digital culture where technologies are used effectively to increase productivity, and threats posed by new technology are recognised, is key to securing peaceful and inclusive societies. Achieving this in a public institution with limited resources and the need to maintain operational performance and critical functionality is challenging.

The researchers used systems mapping and stakeholder engagement activities to understand the digital transformation process, identify the challenges, and work with the organisation to design a way forward. The activities consisted of: (1) regular meetings between the research team and the senior leadership team to understand the changing context, the digital transformation journey, and the goals; (2) focus groups with users across a range of roles to map how digital transformation was evolving in practice and how the goals were understood from different perspectives; (3) semi-structured interviews to understand experiences of those involved in the digital transformation process; and (4) feedback sessions with organisational stakeholders, to identify challenges and ways forward.

During the focus groups, interviews, and feedback activities, it became clear that while the focus of the digital transformation was on one organisation, policing is part of a network of stakeholders consisting of the wider criminal justice system, other public services, government, and the public, which presents challenges to stakeholder mapping and engagement. Furthermore, while identifying the system's main goal seemed straightforward in a police context (i.e. to enforce the law and maintain public safety), shifting social expectations and technology disruption make this more difficult to define. Police are navigating the traditional activities of policing such as face-to-face contact with the public, patrolling neighbourhoods, arresting individuals, and conducting investigations, while also contending with an increasingly digital society, and online security threats and crimes, which require new skills and changes in organisational and individual mindsets. Capturing the sheer scale of requirements and factors challenges our existing STS tools to define where the 'digital transformation' starts and ends, where the system boundary lies, and who is considered as user, stakeholder or customer.

Stakeholder management as part of the design process is particularly challenging. This example reinforces the view that digital transformation goes beyond the implementation of new digital technologies and requires a fundamental shift in the design of the whole socio-technical system to create new value propositions and generate a new organisational identity (see, Wessel et al. 2021). In the policing context, external pressures from key stakeholders such as the government and society are pushing for digital services that can provide greater value and outcomes for the public, while providing increased efficiency for police. The hard politics (with policing having local and national political oversight/interest) and public interest adds a dimension to acceptance of change and system requirements that we had not foreseen. Managing this change process – within a dynamic environment of constantly evolving technologies, changing public expectations of a system deeply rooted in traditional values, and strong organisational culture – creates tensions for police and presents a wicked design problem with seemingly intractable trade-offs (Gritt, Forsgren, and Pandza 2024).

In the focal police organisation, digital transformation of processes and practices was in its early stages and was largely initiated by the COVID-19 pandemic. For example, police had to innovate quickly to ensure service delivery, and redesign processes such as criminal justice, community engagement, and support services (Gritt, Forsgren, and Pandza 2024). Through system mapping, it became apparent that through the digital transformation process, new socio-technical systems were emerging in parallel with the existing systems. As the digital transformation process was emerging (Gritt, Forsgren, and Pandza 2024), there was not a single IT implementation but instead continuous change and development. Consequently, police were having to reconfigure their work and negotiate tensions without a clear end-point (e.g. it was unclear when digital transformation would be complete, or indeed if it could be). While the principle of design being an extended process is well established (Clegg 2000), managing stakeholder expectations and bounding design tasks without discrete end-points is challenging. Our observation is that education and stakeholder or user capability become central to sustaining change and refining the design brief. For example, creating knowledge networks, user groups, and peer support provided opportunities for police staff to share information regarding emerging technologies, to support each other in understanding how to utilise rapidly changing digital tools, and to identify emerging requirements.

The experience of digital transformation in the police underlines challenges relating to politics, stakeholder management, and continuous and ill-defined changes that are likely present when embarking on design involving public institutions required to facilitate peaceful and inclusive societies.

3. Discussion

We now reflect on the lessons from our examples regarding the extensions of STS principles and applying approaches to respond to the array of technological disruptions, the VUCA environment, and the wider challenges posed by the SDGs. We start by considering a point raised in the first three examples regarding the need to facilitate inter-disciplinary collaboration and develop a shared language to enable optimum outcomes. Next, we discuss the need to extend our thinking regarding stakeholders, reflected in all four examples, and consider what we can learn from project management. Then, we argue that STS thinking needs to be broadened to recognise the socio-digital skills inherent in many contemporary problems – a reflection that runs through all four of our examples. Finally, we outline the role of education in providing the skills to enable expert facilitation and implementation of STS principles. Running through this discussion, we recognise that the scale and ongoing nature of change inherent in grand challenges requires extending our conceptualisation of STS principles and ergonomists' own roles. We turn first to the challenge of collaboration.

3.1. Facilitating inter-disciplinary collaboration and developing common language

Our examples demonstrate opportunities to apply STS thinking and tools to design activity shaping the future of work and to address grand challenges contributing to the SDGs. Our experience is that STS methods remain impactful and the work of Cherns (1976), Mumford (1983), Clegg (2000), and others still bear relevance to today's VUCA world. We recognise that addressing grand challenges and wicked problems may often feel too complex or beyond our influence, being the domain of policy interventions, industry-level initiatives, or social change. However, small scale and individual actions can aggregate to create meaningful change (c.f. Hughes et al. 2021) and provide exemplars for transdisciplinary approaches to such problems that may influence others. There is both an opportunity and a responsibility to identify ways to contribute towards the SDGs and to add technical expertise, either directly towards the solutions or to influence how such solutions are developed. In other words, we should actively embracing the role of expert facilitator where this adds value over and above the contribution of technical content knowledge.

Expert facilitation is key to creating the conditions for collaboration – our examples illustrate the necessity of this, and it is clear that most complex problems cannot be dealt with by individual disciplines working in isolation (Hughes et al. 2024). A perennial challenge facing those working across diverse disciplines in academia and practice is how to establish a shared understanding and common language to enable effective collaboration. All too often, such work is multidisciplinary rather than truly interdisciplinary (Klein 2017).

As our human-robot teams and other examples show, this is a natural starting point for many design teams. That is to say that individual disciplines conduct their work largely independently before trying to join these parts at the end, often ineffectively. STS thinking calls for a truly blended interdisciplinary approach instead (c.f. Clegg 2000; Davis et al. 2014; Fisher et al. 2015). As our examples demonstrate, this requires integration and synthesis throughout the process, to harness the benefits of all disciplines optimally. To do so, requires active management and facilitation, to establish shared understanding with common reference points. We argue that adopting an STS approach to working provides a shared mind-set and language to enable this – essentially extending the notion of design process to collaboration itself, implicit in STS principles (Hughes et al. 2021).

It has been argued that different disciplines are often addressing similar conceptual challenges at a macro level, but that different levels of abstraction make this less transparent (e.g. Keil 2006). For instance, both engineers and management specialists recognise the concept of a filter to eliminate negative aspects from a system. However, engineers may use gauze as a filter to remove contaminants from a fluid, whereas management specialists may use process approval gateways as a filter to weed out ineffective practices. By considering problems at a higher level of abstraction like this, common ground can be found to enable different disciplines to communicate effectively. We have tools at our disposal to facilitate this in practice. For instance, Clegg's (2000) STS principles offer guidance for designing human work in complex STS. Similarly, the creative problem-solving tool TRIZ is used in engineering to enable macro design principles to be applied to specific problems by identifying how they resemble, or differ from, previous problems that have already been solved elsewhere (e.g. Altshuller 2002).

These high levels of problem abstraction afforded by STS thinking therefore enable a shared understanding between disciplines. Within the four examples presented, the use of scenarios planning techniques, stakeholder education, and benchmarking exercises are techniques that can help to establish common understanding. This is important as, at a micro level, this enables transactive memory systems (e.g. Lewis and Herndon 2011), while at a macro level this enables shared mental models (Mathieu et al. 2000). Transactive memory systems at the micro level are where those working together understand the roles that their colleagues perform and how these fit with theirs, even if they lack the specialist expertise to undertake that work themselves. Shared mental models at the macro level are where everyone understands the overall principles governing each other's work equally well.

For instance, in the human-robot team example, at a micro level the engineers were focused on the robots installing screws effectively, while the project managers were focused on optimising the coordination between robots and construction workers to complete the project efficiently. However, the introduction of socio-technical specialists enabled the engineers and the project managers to view both the robots and construction workers as a cohesive human-robot team. Specifically, all members were then able to view the project as integrated working towards a common goal of completing the project efficiently and effectively while maintaining stringent safety standards. Similarly, in the surgical technology example, at a micro level surgeons were focused on treatments and patient care, while healthcare managers were focused on cost-benefit analyses. However, applying a socio-technical approach helped these professionals and other stakeholders consider system readiness earlier at the design stage, thereby delivering a smoother and integrated service for patients.

Our argument is aligned with STS principles that are explicit regarding the centrality of values and mindsets to the process of design and the need for transdisciplinary education to enable this (see Clegg's (2000) process and meta principles). Our contention, however, is that as the scale and scope of design challenges increase, the role of ergonomists becomes more central to establishing the shared mental models, language, and ways of working of the multi-disciplinary design team, as much as providing disciplinary technical knowledge into the design itself. The role becomes one of convenor, interlocutor, project manager, and guide too.

3.2. Extending our conceptualisation of stakeholders

The centrality of user-engagement and user-led design have long been advocated within STS thinking (e.g. Cherns 1987; Clegg 2000; Mumford 1983). However, our examples illustrate the wide range of individuals, groups, and organisations with an interest in contemporary design challenges (Davis et al. 2022a). For example, seen within the future hybrid workplace example where stakeholder groups were diverse within the organisations themselves and then extended through the wider local economy. In the police example, stakeholders could extend to politicians, charitable groups, civic society and local residents. In many cases, these actors may be more distal to the design process and may have no obvious representative or advocate with whom to engage. Nonetheless, their perspectives and interests are important.

The process of identifying relevant parties, establishing direct and indirect needs and impacts, managing conflicting interests, and navigating political processes and cultural sensitivities becomes more difficult as design problems increase in complexity. For example, see the burgeoning Corporate Social Responsibility literature regarding stakeholder management in complex sustainability or social issues (e.g. Fritz et al. 2018). We saw in digital transformation in policing, how external politics and community expectations can present challenges to defining requirements and outcomes. Political and external communications management are not explicitly considered within STS design principles, with the emphasis upon internal organisational processes, structures and politics (see Clegg 2000; Mumford 1983). However, contemporary challenges are increasingly likely to present these external stakeholders and relationships to manage.

STS principles and tools have much to offer in practically approaching these activities in general, offering advice regarding stakeholder engagement, establishing metrics relating to key outcomes, resolving conflicting needs, and recognising the political aspects of design processes (e.g. Clegg and Shepherd 2007; Mumford 2006). However, we argue that there is an opportunity to upgrade STS principles and methods to better reflect the broader stakeholder needs and interests present in contemporary challenges, where organisational or system boundaries may be permeable and the contingencies wide ranging. We saw the potential for system boundaries and interested parties to increase rapidly when considering both future hybrid workplaces and digital transformation in policing. There is a need to adapt common STS frameworks and tools to make them scalable to incorporate larger groups of stakeholders in such cases, breaking out of the organisational or accident/event mind-set. Concurrently, STS design processes may need to be extended to include a wider range of voices or outcomes, or new guidance created to support ergonomists in such activities.

In so doing, it is possible to look to other disciplines to increase the utility of our own tools. For instance, the project management discipline offers guidance on stakeholder engagement and management. Whilst traditionally applied to the implementation of solutions rather than their development, the project management literature is clear about the role and importance of stakeholders. The tools and techniques of stakeholder identification, assessment, and prioritisation are well established (e.g. Eskerod and Jepsen 2016) and provide a means to agree where the STS boundaries are and what is expected of any intervention. There are also case studies of different approaches, comparing the more traditional management *of* stakeholders with the more democratic and STS aligned management *for* stakeholders (Huemann, Eskerod, and Ringhofer 2016).

Project management may also offer further lessons from its long consideration of what success looks like. For example, it is important to differentiate between process success ('how') and outcome success ('what') (Eskerod and Jepsen 2016). Stakeholders are primarily concerned with outcomes and are unlikely to be experts in processes. Accordingly, project managers are seen as facilitators and projects are 'conceived as processes of pursuit and discovery' that 'necessarily unfold in disorderly and circuitous ways' (Kreiner 2020). The project management mindset may help to extend the notion of 'evaluation' within STS principles, but also the social construction of the design process itself.

Part of this project management mindset involves a focus on managing the stakeholder engagement process and developing it through distinct stages (see Figure 3): identifying stakeholders, understanding their needs, analysing their contributions, prioritising them, engaging with them, and monitoring the relationship. Most of this work is done in the very early stages of a project to ensure that the goals are established by involving key constituencies. These early discussions with stakeholders also clarify the project's expected benefits, or the set of (measurable) changes that the project will create once completed. Benefits realisation management (see Figure 4) also has a defined process and stages, establishing the need for change, developing options for action, choosing actions, making change (the purpose of projects), monitoring outcomes, measuring benefits, and assessing value.

If, as a community, we are to be ambitious in tackling high impact, complex, and wicked problems, then we also need to reconsider our conceptualisation of whom may be our stakeholders and what we mean by political processes within design (c.f. Clegg 2000; Davis et al. 2014). We need to look further outwards when considering whom to bring into design activities and consider how we extend our tools to increase their reach, learning from complementary disciplines and bodies of knowledge such as project management.

3.3. Socio-digital skills

Many of the challenges and disruptions that we have referenced are either driven by technological change, are mediated by it, or will involve new technologies within the response or solution. Applying STS principles to guide technology design is well established; however, in each of our presented examples, it was apparent that socio-technical changes in the system necessitated new skill requirements for workers or users. Furthermore, these could not merely be considered as upgrades to 'technical' *or* 'social' skills. Rather, the technologies embedded in the systems of focus changed the way that people interacted with the system itself. That is, they needed to develop new ways of receiving, seeking, or processing information; or they presented the user with different or new social cues, which would affect the way they undertook their work activities. For instance, within our future hybrid workplace example, an employee hosting a meeting online instead of face-to-face would rely on different social cues. In the online environment, raised hands help turn-taking in communication, and emojis verify emotions, which may otherwise be absent. Alternatively, a hybrid worker might be entirely competent at the *technical* aspects of using collaboration software, but would struggle to understand the social implications of how and when to use it. In this way, the system necessitated and facilitated 'socio-digital' learning for employees and system users (Hughes and Davis 2024). In our experience, this benefitted from specific and targeted training.

Certainly, learning has been implied in earlier STS research (Ang et al. 2024). Leach, Wall, and Jackson (2003), for instance, describe how humans working with complex machinery will learn to read technical cues to anticipate breakdowns. However, despite the central importance of this phenomenon, the mechanisms of socio-digital learning remain underexplored and conceptually under-developed. Nevertheless, our examples highlight the importance of socio-digital learning as an enabler of effective socio-technical systems. This is particularly important as contemporary

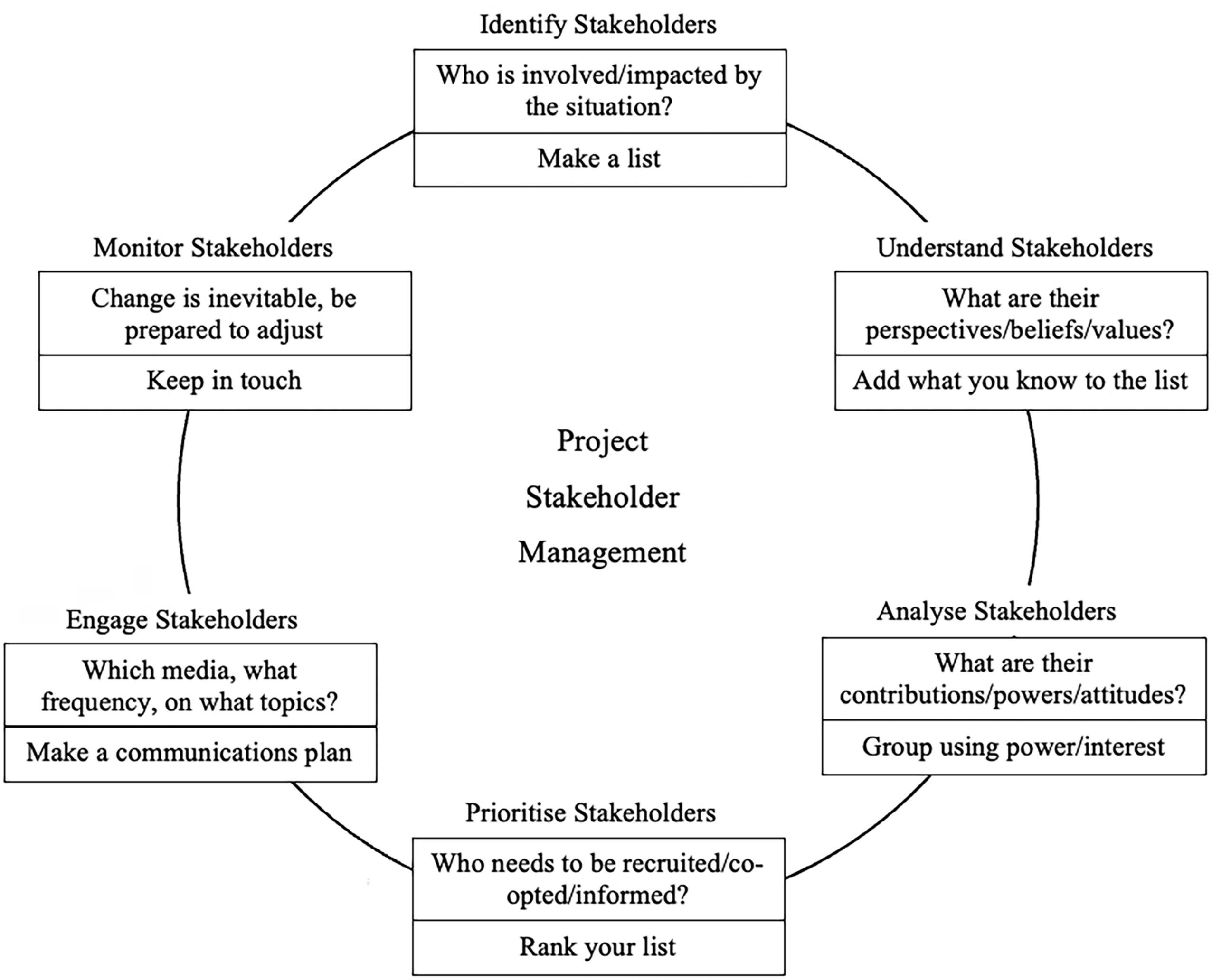


Figure 3. Stakeholder management. Adapted from Project Management Institute, Inc. (PMI). (2021). *A Guide to the Project Management Body of Knowledge (PMBOK ® Guide) (7th Edition)*. Project Management Institute, Inc. (PMI).

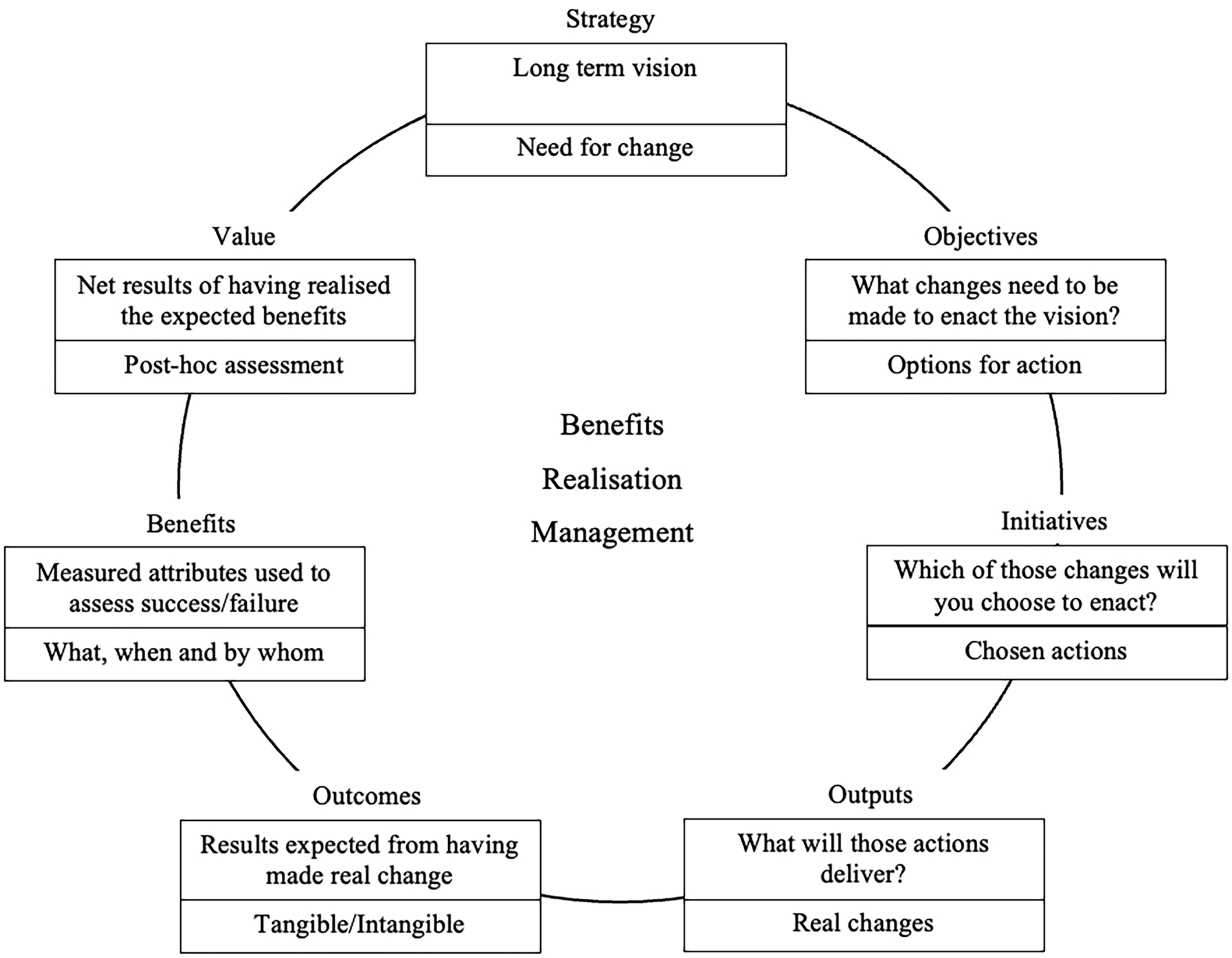


Figure 4. Benefits realisation management. Adapted from Project Management Institute, Inc. (PMI). (2019). *Benefits Realisation Management - A Practice Guide*. Project Management Institute, Inc. (PMI).

technology is likely to continue to evolve following introduction (Parker et al. 2025), introducing the need for ongoing socio-digital skills development. We have observed the centrality of peer networks and informal learning to support the development of shared competencies and skills, for example, within the police. This suggests that social structures and groups within organisations may provide opportunities to develop socio-digital capabilities, in addition to more formalised training. Supporting effective adaptation to the digital, social, and environmental disruptions we are facing presents opportunities to develop new socio-digital education resources and training packages to upskill workers and wider stakeholders, and processes to integrate these within design practice.

3.4. Professional skills

We have argued for ergonomists and the wider STS community to actively tackle grand challenges and SDGs, to take up the role of expert facilitator to aid collaboration, to upskill in stakeholder management, and to identify and develop new socio-digital skills. This call-to-action requires both domain and content knowledge (e.g. regarding SDGs, STS tools) as well as professional skills and competencies.

There are implications here for Human Factors and Ergonomics (HFE) training. While systems thinking, collaborative design practices, and user-centred design are central to degree syllabi, there are opportunities to challenge students further in considering their own professional role in design. Our human-robot team example demonstrates the need for practitioners to be comfortable and confident in both creating shared language and mental models within multi-disciplinary design teams, but also to engage in training technical experts in socio-technical principles. Requiring students to collaborate with a multi-disciplinary design team, communicate effectively across diverse disciplinary groups, or design project management processes would embed mind-sets and skills aligned with expert facilitation. While there are challenges and risks to opening HFE modules or courses to other degree disciplines, the practical learning opportunities would be significant (Oakman et al. 2020). Similar multi-disciplinary experiences can be provided through extra or co-curricular activities such as design competitions or business challenges (Singhal, Davis, and Voss 2024; Davis et al., 2023). The benefits of multi-disciplinary educational activities accrue beyond our own discipline. This can provide an opportunity to maximise our community's impact and influence towards addressing complex challenges. Exposing students and professionals to our approaches, demonstrating and sharing tools on joint activities, illustrating the value of collaboration through cases, and creating spaces for students to share their experiences and perspectives could be transformational. This approach to education could create a community of STS advocates across disciplinary and professional domains.

Many university courses are incorporating sustainability and social issues (Martin, Legg, and Brown 2013). Professional competencies (e.g. Chartered Institute of Ergonomics and Human Factors 2024) can be extended to support this endeavour, for example, by explicitly including sustainability, stakeholder impact assessment, or SDGs when referring to optimising performance and engaging or defining design requirements. This would reflect the burgeoning interest within the field (e.g. Sigahi et al. 2024) and keep training provision relevant to the challenges faced in practice (c.f. Salmon et al. 2025; Davis et al. 2020). Furthermore, the role of HFE practitioners in providing relevant training and education can be extended to consider the role of education of stakeholders more directly during design (in addition to during implementation) and to identify attendant socio-digital skills requirements.

4. Conclusion

In presenting our arguments for extending and applying STS thinking to grand challenges, we have reflected on our own practical experience of implementing STS approaches and tools to four domains. While these examples illustrate our ideas and demonstrate the logic of our thinking, we cannot claim that these are sufficient evidence alone. We have referenced literature and theory supporting our ideas, but further empirical work is required to test proposed extensions and to explore contingencies, particularly regarding socio-digital skills. Our reflections also concern the experiences of researchers based solely in Western contexts. So, to truly embrace the challenges of the SDGs, we should explore the additional implications and opportunities arising from applying our ideas in emerging economies and non-Western contexts.

There are several avenues for future research stemming from the issues we discuss. Most notably, researchers should test and evaluate different forms of stakeholder management (including those we propose) in the design of contemporary sociotechnical systems that involve extended groups of external stakeholders. There is a need to conduct additional research to identify differing contingencies and strategies to manage the overt political influences present within both complex public institutions, but also present more widely when considering SDG-related design challenges. Last, studies should identify the specific socio-digital skills requirements that artificial intelligence and evolving work technologies introduce, the potential for these to co-evolve with new technologies and how this may be integrated within socio-technical design principles.

In summary, we argue that ergonomists must be bold in helping address the grand challenges of our VUCA environment. There are opportunities to increase our impact and influence as a community by embracing a role of expert facilitators – leveraging the power of an STS approach to foster collaboration, develop shared language, and enable inter-disciplinary solutions to these wicked problems. This requires humility and an acceptance that, as professionals, we may not always be seen as the originator of a solution. Rather, we may achieve impact through convening the right mix of skills, identifying the salient voices, and creating the conditions for solutions to be discovered. We can extend and refine our STS principles and tools to: (a) directly consider outcomes and impacts relating to SDGs, (b) broaden our conceptualisation of stakeholders and system boundaries, and (c) integrate concomitant socio-digital skills requirements present in our fast-changing world.

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Ethics statement

The manuscript does not present new primary data collection with human participants. The various published studies underpinning the described illustrative examples received ethical approvals from the respective university research ethics committees of the principal investigators as detailed in the individual studies.

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