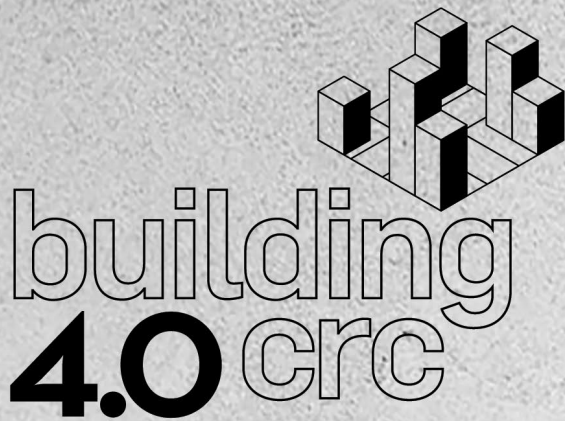
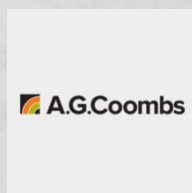
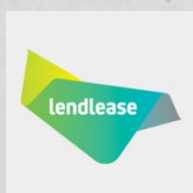
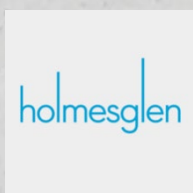




PROJECT #49: IMPLICATION OF INDUSTRY 4.0 TECHNOLOGIES ON WORK PRACTICES

FINAL REPORT



AUTHORS AND CONTRIBUTIONS

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KEY TERMS

Augmented Reality (AR)	Augmented Reality is a technology that overlays digital information, such as graphics, instructions or data, onto the physical world in real time. In the building and construction industry, AR is often used to support tasks such as on-site guidance, visualising hidden infrastructure, training, and safety checks, enabling workers to combine digital insights with direct physical interaction.
Desirability, Viability, Feasibility (DVF) Framework	The DVF framework is a decision-making model used in innovation and design to assess whether a solution should be pursued. Desirability considers whether a solution meets human needs and is wanted by users; Viability examines whether it is commercially and organisationally sustainable; and Feasibility assesses whether it can be technically built and implemented. Successful innovation typically requires alignment across all three dimensions.
Embodiment	Embodiment refers to the role of the human body, its senses, movements and physical presence, in shaping how people think, learn and act. In work contexts, embodiment recognises that knowledge and expertise are often developed through bodily interaction with tools, materials and environments, rather than solely through abstract or cognitive processes. Embodied Interaction refers to interactions with technology that are grounded in physical action, spatial awareness and bodily movement. Embodied learning is an approach to education and skill development that emphasises learning through physical activity, sensory experience and hands-on practice. Embodied expertise is knowledge that is enacted through the bodily actions, involves muscle memory, sensory awareness, and actions developed through repetition and experience.
Extended reality (XR)	Extended Reality is an umbrella term that encompasses technologies which blend physical and digital environments, including Augmented Reality (AR) and Virtual Reality (VR). XR technologies are used to support training, design review, remote collaboration and simulation by immersing users in digitally enhanced or fully virtual environments.
Generative AI (GenAI)	Generative AI refers to artificial intelligence systems capable of producing new content, such as text, images, code or recommendations, based on patterns learned from large datasets. In construction, GenAI may be used to assist with documentation, design exploration, quality checking or decision support, though its use requires careful consideration of safety, accountability and human oversight.
Human-Computer Interaction (HCI)	Human-Computer Interaction is a multidisciplinary field that studies how people interact with digital technologies and how those technologies can be designed to better support human needs, capabilities and values. HCI combines insights from design, computer science, psychology and social sciences to create systems that are usable, effective and ethically aligned with real-world practices.
Human-Centred Design	Human-Centred Design is an approach to innovation that prioritises the needs, experiences and capabilities of the people who will use a system. It involves engaging users throughout the design process to ensure solutions are intuitive, inclusive and aligned with real work practices, rather than being driven solely by technical or commercial considerations.

EXECUTIVE SUMMARY

Industry 4.0 technologies, such as Artificial Intelligence (AI), robotics, digital twins, automation, and Extended Reality (XR), offer significant potential to improve productivity and workplace safety, and address skills shortages in the B&C industry. However, the implications of these technologies on future work practices are unclear. This project seeks to mitigate this uncertainty by providing recommendations about the choice and use of Industry 4.0 technologies, and about the appropriate training to best prepare for Industry 4.0 workplaces.

Realising the promise of Industry 4.0 depends on innovations being feasible, viable and desirable. Feasibility asks whether a technology can be built, purchased and maintained with existing expertise, funding and resources. Viability concerns whether there is a sound business case and whether the innovation will improve productivity and profitability. Desirability focuses on whether the technology addresses real problems and delivers clear benefits for workers, management and clients. To understand how Industry 4.0 technologies will affect work practices, it is not enough that they are technically and commercially sound; they must also respond to genuine needs in the workplace. By concentrating on what makes work more desirable in practice, we can better anticipate and shape the impact of Industry 4.0 technologies on building and construction workplaces.

This document reports on the insights of an 18-month study conducted with workers, educators, executives, regulators, and industry bodies across the Building and Construction (B&C) industry. By focussing on human-centred needs, it complements other Building 4.0 CRC projects that have examined technological feasibility and business viability. The project aimed to understand the implications of Industry 4.0 technologies on B&C workplaces and to make appropriate choices about the types of technologies that will improve work practices. The project addressed four primary goals:

1. Identify emerging technologies and their likely impact on future work practices.
2. Use these insights to plan for the transition to new ways of working.
3. Inform interventions for upskilling the workforce and managing the risks of deskilling.
4. Identify opportunities for technology to enhance both productivity and working conditions.

This report draws upon the theoretical and methodological disciplines of Human–Computer Interaction (HCI) and Industrial Relations (IR). HCI investigates the use and design of interactive technologies to improve user experience, while IR navigates complex employment relationships to ensure workplaces are efficient, safe and fair. By combining these perspectives, this project looks beyond what technology can do, to understand what workers across the industry *need* and *desire* for their work practices. As such, people (i.e. workers, managers, leaders, regulators etc) are at the centre of this research, contributing to knowledge about how Industry 4.0 technologies must support work satisfaction, safety, and meaningful work if they are to positively impact work practices.

The study followed the Double Diamond research framework, which consists of four iterative phases:

- **Explore:** identifying industry concerns and foundational knowledge through stakeholder interviews and desktop research
- **Define:** establishing future scenarios and mapping the "innovation system" to identify macro-level dynamics and leverage points
- **Develop:** translating abstract insights into low-fidelity speculative prototypes to simulate workplace impacts and provoke reflection
- **Deliver:** synthesising findings into a final report with evidence-based recommendations and guiding principles.

The project utilised **design futuring** (asking people to imagine possible futures) and **systemic design** (analysing how different parts of the industry interact) to ensure findings accounted for the complex, interconnected reality of the B&C sector.

The project began by identifying the core “desires” and “concerns” experienced by specific job roles (these are fully discussed in section 2.1). The study found that:

- **Project Managers** desire tools to track project progress and enable flexible work, but fear safety risks from remote robotics or untrained workers using AI tools
- **Apprentices/New Starters** seek practical learning tools like AR but worry that automation will take away the "fun" problem-solving aspects of their jobs
- **Skilled & Manual Workers** want robotics to prevent physical injury and automated paperwork to free up time for practical work, but fear job losses and becoming an "appendage of the machine"
- **Trainers/Educators** value VR/AR for demonstrating practical knowledge but are concerned about the cost of continuous retraining and students using AI to cheat
- **Business Leaders** focus on productivity and cost-effectiveness but worry about investing in expensive technologies with little return or creating fragmented information sharing
- **Surveyors/Inspectors** desire customized tech to assist with their skills but fear burnout from increased workloads and being held accountable for AI "hallucinations".

These desires and concerns were used to create seven principles that reflect the values of B&C work and to guide understanding about the implications of Industry 4.0 technologies on the workplace. (these are fully discussed in section 2.2). The guiding principles are as follows:

P1 Strive for work satisfaction: Prioritise fulfilling, safe, and high-quality work over quantity.

P2 Authentically empower people: Involve workers and experts in the decision-making.

P3 Learn the ‘why’: Design technologies and curricula that encourage critical thinking.

P4 Design for the human body: Use technology to complement physical skills and "hands-on" learning.

P5 Bring services together: Ensure digital tools support coordination and shared visibility across different trades and services.

P6 Encourage reflection and innovation: Provide workers with time and space to improve their work practices.

P7 Respect prior knowledge: Actively involve experienced workers in the design of emerging technologies to leverage their tacit expertise.

Findings from interviews, workshops, system maps and prototype evaluations were analysed to identify 13 actionable recommendations (summarised in Table 1 and fully discussed in section 3). The recommendations describe specific actions, while the guiding principles explain the underlying values that support them. recommendations (summarised in Table 1). The findings are structured around four themes:

Theme 1: Productivity Through Job Satisfaction

Participants emphasised that an excessive focus on efficiency alone leads to an undesirable workplace. They expressed a strong preference for forms of productivity that make work safer, easier, or of higher quality, rather than simply faster. It is recommended that:

- innovation mindsets be embedded into formal training (R1)
- investing in dedicated time for collaborative reflection (R2)
- designing AI tools that prompt users to verify information (R3)
- use safety, sustainability and quality for technology implementation (R4).

Theme 2: Industry Cohesion

While remote technologies have improved work-life balance for many, they have also created new risks of fragmentation and isolation. Participants expressed concern that individualistic digital tools (like AI guides) could separate people on-site and cause them to miss crucial contextual information. Recommendations are:

- maintain camaraderie, establish predictable in-person days for flexible workers (R5)
- incorporate teamwork and critical thinking into training pathways (R6)
- prioritise interoperability so that digital tools support collaboration across teams (R7).

Theme 3: Embodied Learning

This theme highlights the deeply physical nature of work in the B&C industry. Workers feel a strong sense of pride and value in creating tangible outputs. This value could be diminished with new technologies (such as robotics or GenAI), making workers feel like a mere "appendage of the machine". Recommendations are:

- invest in technologies like AR and physical simulations that complement human skills (R8)
- involve workers directly in the implementation of new tools (R9)
- ensure workers expertise is respected (R10)
- seek support from Governments and Technology suppliers (R11).

Theme 4: System-Wide Coordinated Education

There is need for a unified approach to training that accounts for the interconnected nature of modern construction. Existing training systems often fail to address the realities of Industry 4.0 and worker readiness (younger workers may adopt technology at a different pace than experienced staff). Recommendations are:

- advocate for an industry-wide technology education strategy (R12)
- assign leadership roles to ensure no segment of the workforce is left behind (R13).

Outcomes of this research was published in three academic papers. Paper 1, “**Systemic Futures Dialogue: Bridging Speculative and Systemic Design**” (see full paper in section 5), introduces the Systemic Futures Dialogue, a novel design framework that combines speculative and systemic design to address complex sociotechnical challenges within the construction industry. Paper 2: “**Reclaiming Productivity: Critical Perspectives on Speculative Futures**” (see full paper in section 6) focuses on evaluating the desirability of Industry 4.0 technologies by examining the human experience of work. The paper shows how abstract systemic insights can be translated into concrete, experienceable scenarios to provoke reflection on the future of work. Paper 3 “**Workplace Training for Construction 4.0**” (see full paper in section 7) focuses on the role of training to address the challenges that Industry 4.0 technologies pose to traditional work practices. It adopts an industrial relation perspective to provide insights about how to manage work transitions into new work practices mediated by emerging technologies, mitigating deskilling through upskilling and responding to specific risks of automation, and use of technology to enhance both productivity and working conditions.

Overall, the findings from this report offer guidance about the procurement, implementation and use of Industry 4.0 technologies to manage their implications on work practices in Building and Construction Industry.

Recommendations

Productivity Through Job Satisfaction		
R1	Teach innovation and continuous improvement in training courses.	P1, P6
	Training courses should actively teach innovation and continuous improvement – not just technical skills. Stakeholders should work together so that training programmes include an innovation mindset.	
R2	Encourage and invest in time for reflection and innovation.	P1, P2, P5, P6
	Workers need time to time to pause and think about what is working. Time spent reflecting is an investment, not a cost, and effective use of expertise within the organisation.	
R3	Design technology (especially AI) with reflexivity as a goal.	P1, P3, P6
	Technologies should encourage employees to check, question and verify information, to interrogate the reasoning behind AI recommendations and to reflect on their own decisions and work practices.	
R4	Focus on improving safety, sustainability and quality challenges	P1
	Use Safety, sustainability and quality as criteria when selecting or purchasing new technologies. These are likely to build trust, increase adoption and improve both work satisfaction and long-term performance.	
Industry Cohesion		
R5	Continue to support flexible working, particularly for those with young families.	P2, P5
	Remote and flexible work helps employees manage family and caring responsibilities, supports healthier work-life balance and show that workers are trusted to manage their time and location.	
R6	Education in project management, critical thinking and teamwork across roles.	P3, P5
	Invest in training that helps employees understand the responsibilities of people in other roles, to understand how their work links to (become aware of upstream and downstream activities).	
R7	Cohesion and collaboration are a key consideration for technology implementation.	P2, P5
	New technologies should support communication and teamwork (rather than encouraging solo work), integrate smoothly with other systems and make it easy to share information between teams.	
Embodied Learning		
R8	Invest in teaching strategies and/or technologies that support learning by doing.	P4
	Continue to invest in training methods and technologies that help people learn by doing. Augment conceptual knowledge with embodied knowledge that encourages learners to see tangible results.	
R9	Use a human-centred approach to education design and delivery.	P2, P7
	Education and training should match the needs, experiences and learning styles of employees, recognising that employees learn in different ways and bring valuable prior knowledge to their roles.	
R10	Design technology with the end user's strengths in mind.	P2, P4, P7
	Choose and shape technology that builds on workers’ strengths The employees' experience and understanding of their work is an asset which should be leveraged by new technologies.	
R11	Subsidise access to innovative technologies.	P2, P7
	Work with government and technology suppliers to ensure new technologies are accessible to businesses and workers. Advocate for subsidies, grants or tax incentives	
System-Wide Coordinated Education		
R12	Co-design for system-wide technology education with Government as the convener.	P5
	Partner with government and other key stakeholders to co-design a single, coordinated strategy for technology education across the construction system.	
R13	Leaders educate work-force groups at a different stage in their career.	P2, P5
	Work with education providers, unions and government to clearly define who leads training for different stages of a worker’s career and technological readiness.	

Table 1: A summary of the 13 recommendations, grouped according to four key themes (Productivity Through Job Satisfaction, Industry Cohesion, Embodied Learning, System-wide Coordinated Education) and aligned to the relevant principles (P#)

Full details of the recommendations are discussed in Section 3 (page 21).

1. PROJECT OVERVIEW

1.1 INTRODUCTION

Industry 4.0, enabled by technologies like artificial intelligence (AI), extended reality (XR), digital twins and prefabrication systems, promises a variety of opportunities to improve productivity across the Building and Construction (B&C) industry. However, attempts to implement these technologies have not always resulted in improved productivity or better working conditions. Additionally, societal and industry-wide challenges, such as skills shortages, the cost of technology investment, fragmented information sharing, and a complex industrial relations setting, have added to the challenges of Industry 4.0 adoption. Together, these issues contribute to the difficulty in understanding and planning for the impacts of Industry 4.0 on working practices.

This report brings together insights from a project that included a series of collaborative design research activities spanning 18 months. This project augments other B4.0 CRC projects that address the technical feasibility and the business viability of Industry 4.0 technologies, by identifying the factors that make Industry 4.0 technologies *desirable*, by ensuring the innovations solve a real problem that benefits the people using the technology. The use and adoption of desirable Industry 4.0 technologies contribute to a positive transition to inclusive and productive work practices.

The project involved participation from industry partners across commercial construction, building services, prefabrication, regulation, education, and labour unions. Their insights helped to identify the systemic forces that can influence innovations and to highlight the opportunities for emerging technology to improve productivity and working conditions.

The research approach was interdisciplinary and involved researchers from Human-Computer Interaction (HCI) and Industrial Relations (IR). HCI examines how people use, experience, and interact with technologies in their everyday environments. HCI researchers are concerned with ensuring technologies meet human-centred needs and aspirations. Industrial Relations (IR) examines the social, organisational, and regulatory dynamics that govern work, focussing on the relationships between employers, employees, unions, and the state, and the conditions under which work is performed.

The transition to new work practices was mediated by identifying characteristics of desirable technologies. HCI and IR perspectives were combined to understand what workers and industry leaders desire for their productive and satisfying work - beyond what can be feasibly built or what is viable from a business perspective. This integrated approach enabled us to foreground the human element of work and identify the conditions under which innovation becomes genuinely desirable from the perspective of those who use these technologies.

This document begins by reporting the project's objectives (section 1.2) and study design (section 1.3). We present the major desires and concerns for key job roles in the B&C Industry (section 2.1) and then the seven guiding principles to support desirable work-practices (section 2.2). The findings are summarised and presented as key recommendations (section 3). The report ends with three scholarly research papers that provide a thorough account of the various aspects of the research.

1.2 OBJECTIVES

This project addresses the B&C's industry need to understand the implications of Industry 4.0 technologies on work practices and working conditions and thereby plan for the transition of work practices arising from these technologies. It investigates the challenges related to acquiring, retaining and transitioning skilled workers arising from introduction of Industry 4.0 technologies. It explores how new technologies in the B&C industry might impact the working conditions of employees, and in turn how this will impact industrial relations. The objectives of this research project are to:

- provide insights about the new and emerging technologies that are likely to be used in the building and construction industry and their likely impacts on future work practices and working conditions
- use the insights to understand and plan for transition in new work practices arising from these technologies
- use the insights to understand impacts on skills and training, and informing interventions to upskill the workforce, manage the risks of deskilling and acquiring retaining and transitioning skilled workers
- use the insights to understand impacts on working conditions and industrial relations, identifying opportunities for emerging technologies to both enhance productivity and working conditions.

We use the Desirable, Viable, Feasible (DVF) framework¹ to position this project as part of a broader agenda of innovation. **Desirability** concerns *people*, focussing on what makes sense to people to ensure technological innovations address genuine user-needs. **Viability** concerns the *business*, focussing on what is likely to be a sustainable to ensure financial sustainability and profitability. **Feasibility** concerns *technology*, focussing on what is technically possible and can be built within the foreseeable future.

Whilst it is impossible to predict exactly which Industry 4.0 technologies will be adopted, it is possible to prepare for changes by ensuring fundamental aspects of what makes work safe, satisfying and productive are supported. The project contributes to this goal by specifying knowledge about what makes workplaces in the B&C Industry desirable and relevant to worker needs. This knowledge becomes a valuable resource in planning for changes to work practices arising from Industry 4.0 innovation.

The insights of this project are intended to complement other B4.0 CRC projects which are focused on technological feasibility and business viability. Figure 1 shows a selection of B4.0 projects² which are indicatively mapped to the DVF (Desirable, Viable, Feasible) framework, showing that this project #49 is primarily concerned with the Desirable attribute. When considered together, the recommendations across these projects will support organisations to develop innovation portfolios that are *desirable* for workers, *viable* for organisations, and *feasible* from a technological standpoint.

¹ Introduced by Tim Brown "Design thinking" (2009) and extend by IDEO www.ideo.com/pages/design-thinking

² Details of related B4.0 CRC projects are available at <https://building4pointzero.org/projects/>

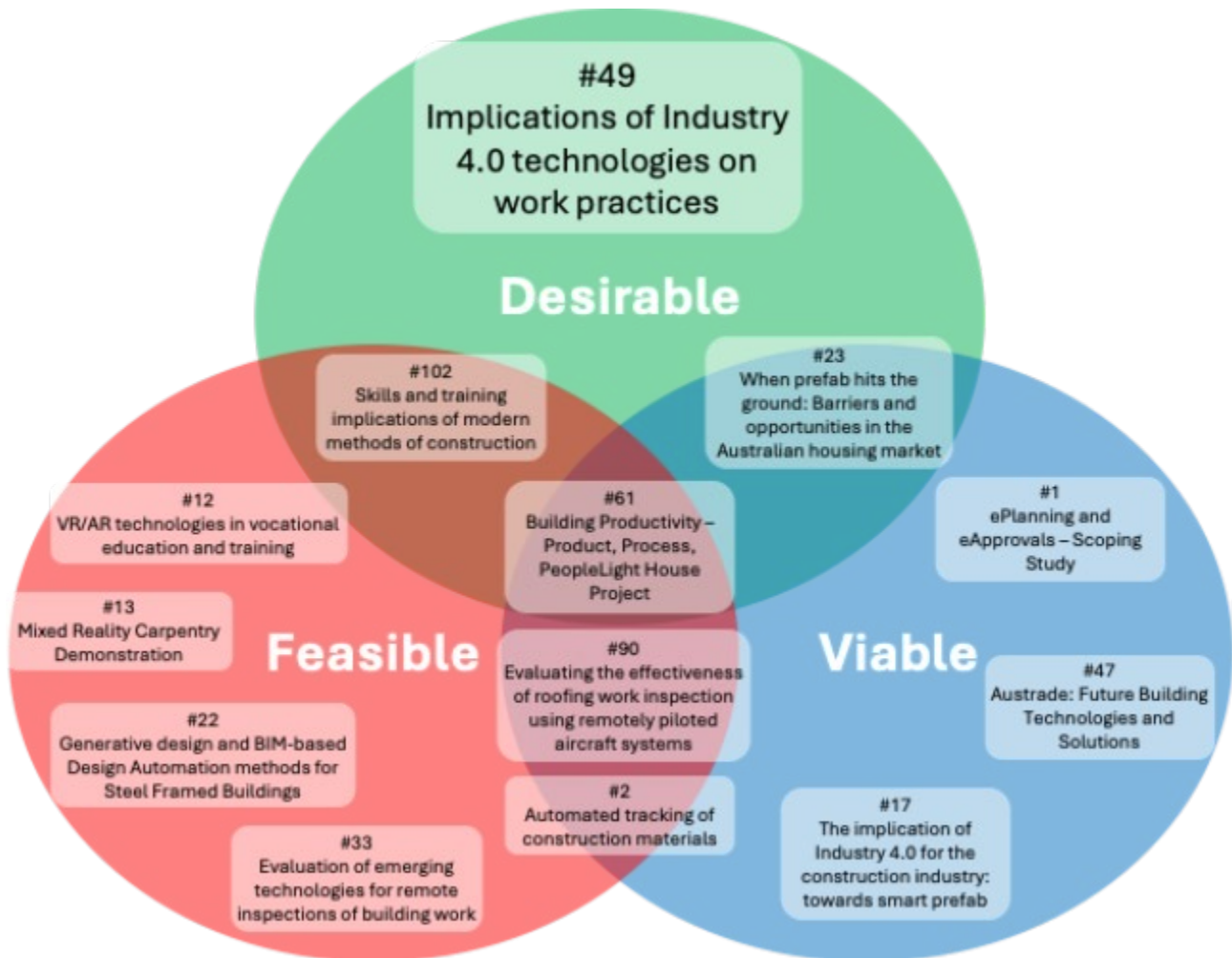


Figure 1 :A selection of B4.0 projects which are indicatively mapped to the DVF (Desirable, Viable, Feasible) framework, showing that this project #49 is primarily concerned with the Desirable attribute

1.3 STUDY DESIGN

Mitigating the risks of negative work practices associated with Industry 4.0 technologies is done by identifying desirable technologies. To understand what people across the building and construction (B&C) industry want from the future of their work, we used a mix of practical, workshop-based methods.

One of these was **design futuring**, which is a structured way of thinking about possible futures. Design futuring involves asking people to imagine how their work might change and what they would like, or want to avoid. We did this by using activities such as creating scenarios, sketching out future workflows, and running group discussions.

We complemented this with **systemic design**, which focuses on understanding how all the different parts of the industry connect and influence each other. Rather than looking at one issue in isolation, systemic design considers the bigger picture, working to understand how regulations, organisations, technologies, and people interact. This approach helps ensure that new technologies take into account real-world constraints like regulatory requirements, workforce capabilities, and organisational practices.

Together, these approaches allowed us to explore not just what future technologies might look like, but how they would function in the complex, interconnected reality of the B&C industry.

Inspired by the Design Council, we followed the Double Diamond approach³ (Figure 2) to structure the project across four phases: Explore, Define, Develop and Deliver.

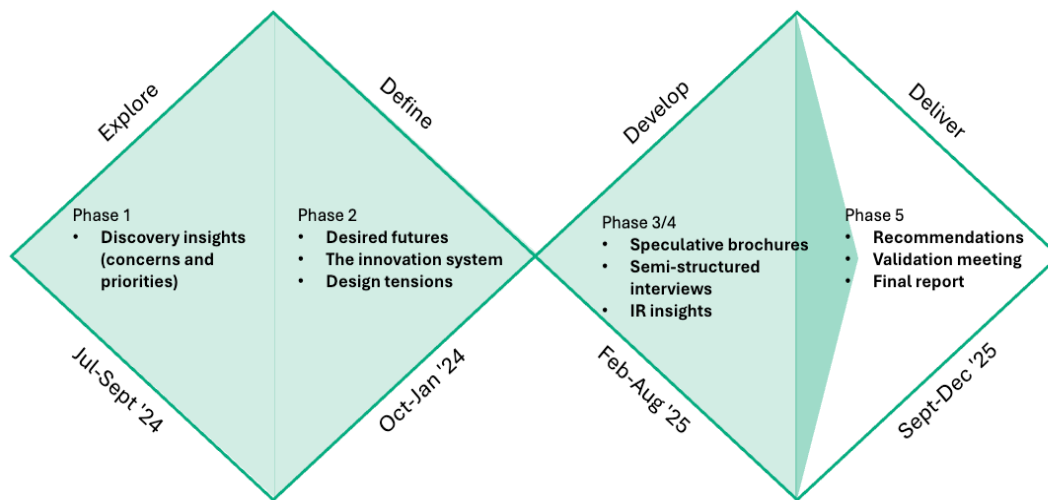


Figure 2: Research approach: the double diamond

In the Double Diamond method, designers initially diverge to explore a wide set of possibilities before converging on the most meaningful problems and solutions. We used this method to identify industry challenges and worker perspectives and then narrow the focus to the insights and opportunities most critical for shaping desirable futures. The approach is deliberately iterative: insights generated in each phase informed the design of subsequent artefacts and research activities, enabling the team to move from broad system exploration to concrete, actionable recommendations.

Each phase consisted of specific activities and outputs, discussed below and summarised in Figure 3. The research was approved by the University of Melbourne Human Ethics Committee (project #30719).

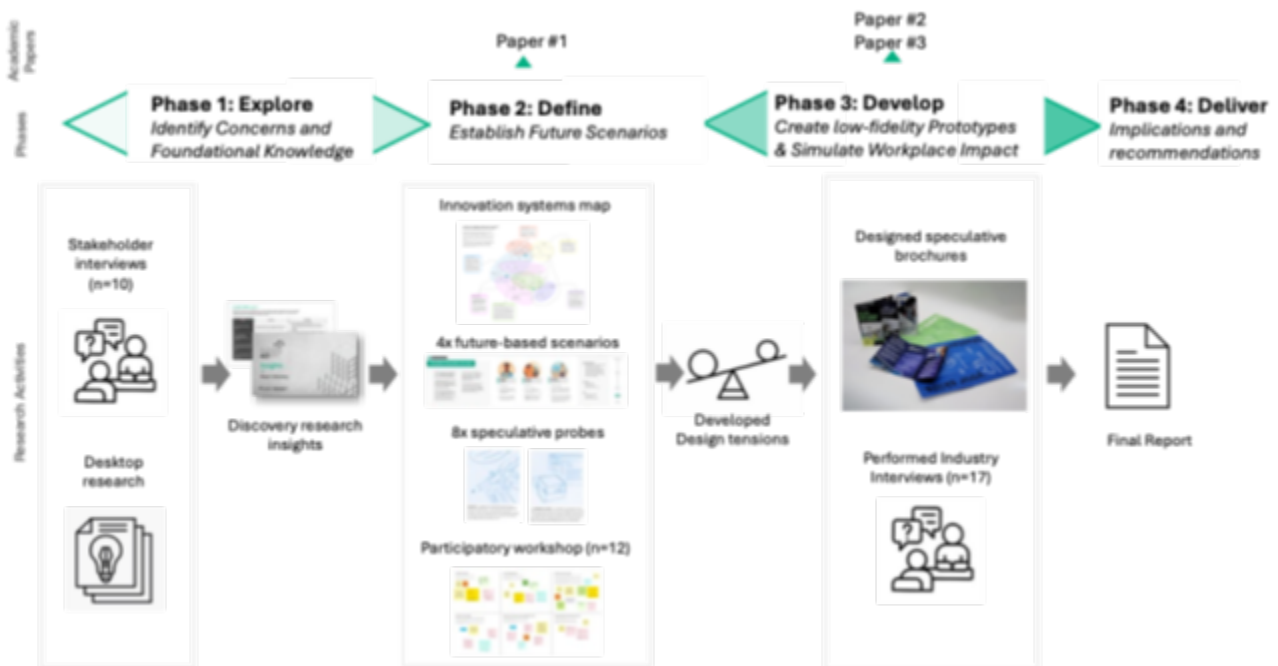


Figure 3: Research activities and outputs

³ <https://www.designcouncil.org.uk/our-resources/the-double-diamond/>

1.3.1 Phase 1: Explore – Identifying Concerns and Foundational Knowledge

The first phase focused on building a foundational understanding of current challenges, values and lived experiences across the B&C industry. This phase was intentionally divergent, designed to surface a wide range of perspectives across the industry.

We conducted semi-structured interviews with 10 stakeholders spanning regulatory bodies, construction companies, education providers, and innovation leaders. These interviews explored current priorities and concerns for the future of work in the industry, as well as perceptions of emerging technologies. By engaging stakeholders across different parts of the system, this phase enabled the identification of shared concerns and values informing technology development and adoption across the industry.

These high-level exploratory insights were supplemented by desktop research and validated in a subsequent workshop with six industry stakeholders. The final output of the phase was a set of “discovery research insights” that informed the bases of the subsequent phases.

1.3.2 Phase 2: Define – Establishing Future Scenarios

Building on insights from Phase 1, the second phase shifted toward sensemaking and convergence, focusing on defining key challenges and tensions within the system.

This phase employed systemic design and systems mapping techniques to identify macro-level dynamics, including reinforcing and balancing feedback loops, structural constraints and potential leverage points for change. These insights informed the development of future-based scenarios and speculative probes, which explored plausible and alternative futures for work under different technological and organisational conditions.

In a participatory workshop, 12 industry participants from across the B&C sector were asked to respond to the systems map, future-based scenarios, and speculative probes. The research team analysed the difference between the participants’ proposed present-day solutions to systems challenges and their desired futures to articulate a set of **design tensions**.

The results are published in paper 1: “Systemic Futures: Integrating Critical Speculation and Systemic Design Pragmatism” (see full paper in section 5)⁴. This paper introduces the **Systemic Futures Dialogue**, a novel design framework that combines speculative and systemic design to address complex sociotechnical challenges within the construction industry. The paper reports on the integration of macro-level systems mapping with micro-level speculative prototyping to bridge the gap between present-day pragmatic solutions and long-term desirable futures. It identifies **systemic futures tensions**, which highlight contradictions between immediate industrial goals and collective aspirations for the future of work. The paper provides a methodological guide for researchers to conduct critical, participatory design that questions how new technologies might reinforce or disrupt existing social patterns.

1.3.3 Phase 3: Develop – Prototyping and Simulating Workplace Impact

The third phase focused on translating abstract system insights into concrete, tangible artefacts that could be evaluated by industry participants. Drawing on findings from Phases 1 and 2, the research team developed **three low-fidelity speculative design prototypes** in the form of brochures that represented alternative futures of work.

These prototypes were designed to provoke reflection on desirable and undesirable futures, surface implicit assumptions about work, and support deeper discussion about trade-offs and priorities. The prototypes were evaluated through **in-depth interviews with 17 industry participants**, enabling the

⁴ This paper was presented at the ACM Designing Interactive Systems Conference (DIS '26) in Singapore on 13-17 June 2026 (<https://doi.org/10.1145/3800645.3812901>)

research team to assess how different futures resonated across roles and career stages, and to identify consistent patterns in participants' desires and concerns regarding emerging technologies.

The results are published in paper 2: "Reclaiming Productivity: Critical Perspectives on Speculative Futures" (see full paper in section 6)⁵. This paper focuses on evaluating the desirability of Industry 4.0 technologies by examining the human experience of work. The paper shows how abstract systemic insights can be translated into concrete, experienceable scenarios to provoke reflection on the future of work. It explains how the three low-fidelity speculative prototypes were developed and provides details about each brochure. The paper then presents the results of the interviews. The paper argues that technological innovation that solves human-centred problems is effective in creating positive workplaces. It presents three key findings:

- **Prioritising Job Satisfaction:** While there is intense systemic pressure for efficiency and labour reduction, participants expressed that "good productivity" must also make work safer, easier, and higher quality.
- **Human-Centred Value:** Participants voiced that an excessive focus on efficiency may lead to an undesirable future. They valued autonomy and "space to think" for genuine innovation.
- **Pride in Craft:** The research highlighted the importance of embodied pride, with workers finding deep satisfaction in creating physical, tangible outputs that they can personally point to as their own work.

1.3.4 Phase 4: Deliver – Implications and Recommendations

The final phase synthesised insights across all prior phases into a single, integrated analysis. Findings from interviews, workshops, system maps and prototype evaluations were consolidated to identify guiding principles and evidence-based recommendations. These aim to help people make technology design, implementation and investment decisions that are grounded in worker experiences and aligned with long-term productivity, safety and workforce resilience objectives.

The results are published in academic paper 3 "Workplace Training for Construction 4.0" (see full paper in section 7)⁶. This paper focuses on the role of training to address the challenges that Industry 4.0 technologies pose to traditional work practices. It adopts an industrial relation perspective to provide insights about how to manage work transitions into new work practices mediated by emerging technologies, mitigating deskilling through upskilling and responding to specific risks of automation, and use of technology to enhance both productivity and working conditions. The paper provides the methodological and policy framework required to ensure that technological innovation supports human capability and long-term job satisfaction. in the context of Industry 4.0 challenges for the B&C industry.

1.4 ENGAGEMENT

The research involved participation across a wide cross-section of the B&C workforce, capturing the diversity of practices, pressures, and expectations across the industry.

1.4.1 Stakeholders

The project drew heavily upon the experience of key sponsors, who formed the project's working group. They contributed to the system mapping, scenario validation, and the evaluation of speculative prototypes, making valuable insights, spanning diverse perspectives: a major regulatory authority; an

⁵ This paper was presented at the 4th Annual Symposium on Human-Computer Interaction for Work (CHIWORK '25) in Linz, Austria on 22-25 June 2026 (<https://doi.org/10.1145/3808045.3808064>)

⁶ This paper has been submitted to the journal "The Economic and Labor Relations Review" for review

industry peak body; a building services company; a technical education institute; and a real estate and development organisation.

1.4.2 Participants

The project also engaged industry practitioners across key groups (Figure 4), ranging from early-career employees to senior executives to participate in our research activities.

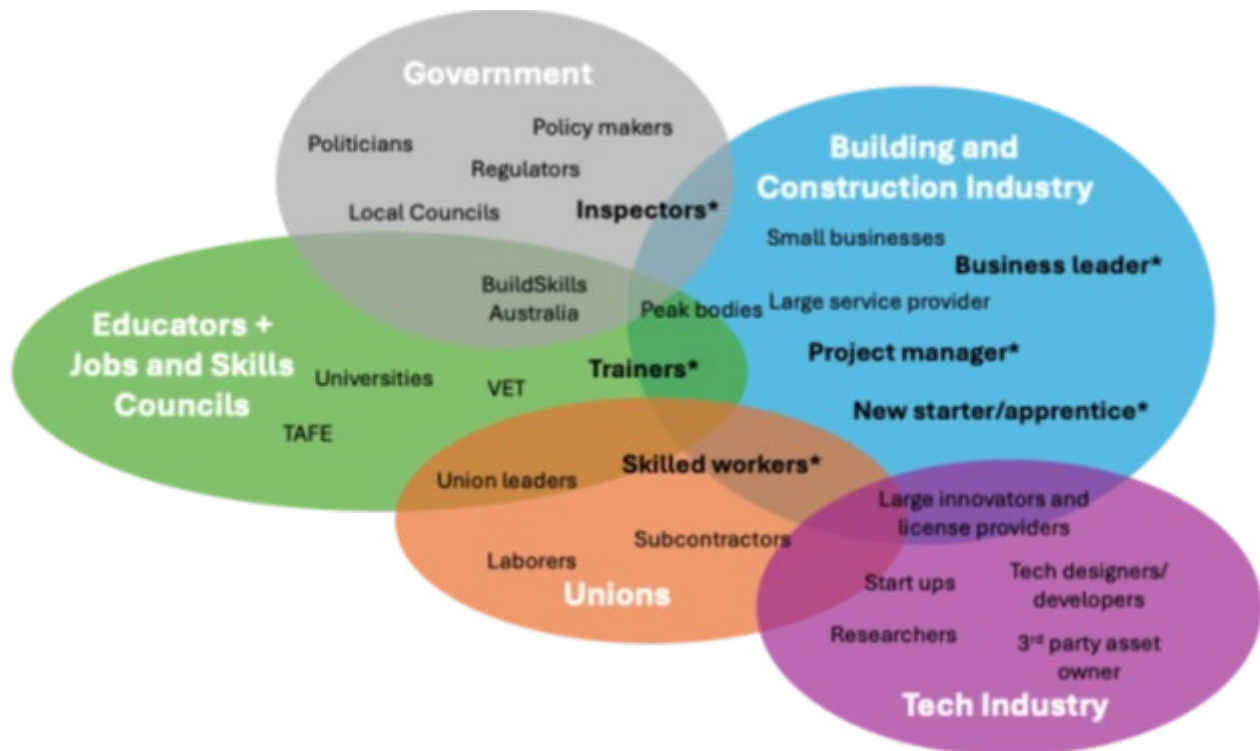


Figure 4: Map of key stakeholder groups

Note: The asterisk (*) identifies roles which are the focus of this project and featured in section 2.

Participants averaged over **25 years of industry experience**, with perspectives shaped by both traditional trade pathways and modern digital construction environments. This expertise included:

- **Skilled workers:** carpentry, plumbing, welding, on-site supervision
- **Knowledge work and design:** architecture, engineering, drafting, project coordination
- **Business leadership:** commercial construction executives, operations leads, digital transformation managers
- **Regulatory and compliance roles:** building surveyors, inspection managers, union health and safety representatives
- **Education and training:** vocational educators, curriculum developers.

1.4.3 Limitations

This research involved a relatively small number of participants from a select group of industry players, all of which were based in Victoria. Although the number of participants is consistent with comparable qualitative research, these limitations should be taken into account when considering the findings and outcomes.

2. JOB ROLES AND GUIDING PRINCIPLES

This section consolidates insights from interviews, workshops, and collaborative design activities. These insights are then translated into a set of guiding principles and practical recommendations for human-centred technologies, strengthening workforce capability, and aligning the broader system around safe, satisfying, and productive work practices. Workers, trainers, regulators, union representatives, and business leaders articulated a clear set of aspirations and concerns that illustrate the types of futures they desire and ones they want to avoid.

2.1 JOB ROLES AND THEIR DESIRES AND CONCERNS FOR EMERGING TECHNOLOGIES

Across job roles, participants expressed both enthusiasm and caution regarding emerging technologies. This section gives an overview of participants' desires and concerns for the future, based on their job roles. Table 2 shows a summary the 'Desires' and 'Concerns' of Industry 4.0 technologies, according to job roles in the B&C Industry. These desires and concerns inform the design principles and recommendations presented later in the report.

2.1.1 Desires

- **Safer, easier, more satisfying work:** Project managers and skilled workers wanted tools that reduce administrative burden, improve coordination, and enable more time for high-value tasks. Apprentices and new starters sought technologies that support “learning by doing”, such as AR, while business leaders emphasised productivity, safety, and quality gains.
- **Recognition of skill and pathways for growth:** Skilled tradespeople, inspectors and trainers stressed the importance of applying their embodied expertise. They wanted technologies that augment, not replace, the craft skills and judgment developed over years.
- **Connection, communication and cohesion:** While remote technologies offer flexibility, workers voiced concerns about fragmentation, loss of shared context, and reduced human connection if technology replaces teamwork rather than strengthening it.

2.1.2 Concerns

- **Shortcut culture and deskilling,** particularly among younger recruits relying on GenAI for answers without understanding the “why” behind tasks.
- **Safety risks,** especially if untrained workers use AI/AR tools for decision-making on live sites.
- **Loss of autonomy and job identity** if robotics or automation remove opportunities to contribute physically to the built environment.
- **Fragmentation and duplication,** arising from non-integrated digital tools across services.

Desires and Concerns

Role	Desires	Concerns
Project Manager	- Technologies that help them track how a project is progressing and streamline communication across services. - More time for family because they have the tools to make work more productive. - Flexible work options enabled by remote technologies, so that they can care for their family at home when needed.	- Younger recruits taking short-cuts by creating the answer using GenAI rather than understanding why they need to do certain processes. - Remote controlled robotics that could compromise safety on a job site. - Safety and quality risk of having untrained workers on site using AI/AR tools to tell them how to do the work. - Overreliance on technologies.
New Starter/ Apprentice	- Feel a sense of pride in their work, having contributed to a physical building that they can point at and show people. - AI automating all the tedious repetitive work (e.g. QA checking) so that they can focus on the fun problem-solving aspects. - Technologies like AR that teach them new skills in practical ways.	- GenAI or robotics taking all the “fun” work and feeling as though they have not personally contributed to the final building. - A lack of opportunities because robots and GenAI has taken the entry level jobs. - Sitting at a desk all day and not getting to see what they are building.
Trainer	- Ability to show their students a real job site using VR technologies. - Enhance their ability to demonstrate practical knowledge with AR/VR tools, e.g. showing how cladding reacts to fire and therefore why the industry has certain safety standards.	- The time and money it will take to continuously “train the trainer” on new technologies, (e.g. new AR programs for education) - Students looking up the answers to quiz questions using GenAI rather than learning the content and thinking for themselves.
Workers (skilled & manual labour)	- Robotics that make their work safer so they can avoid injury over time and take care of their body. - Technologies that teach them new skills in practical and visual ways. - Paperwork that is automated so that they can spend more time doing the practical work.	- Job losses and de-skilling due to emerging technologies. - A lack of autonomy done and disregard for their skill set. - Becoming an appendage of the machine. Losing control of and pride in their work. (i.e. baby-sitting a robot instead of applying a craft. - Falling behind or feeling undervalued because they do not have the opportunity to learn new technology or skills.
Business Leader	- Technologies that make building projects more productive and cost effective. - Improved safety outcomes. - Technologies that are quick to implement and people want to use.	- Technologies that make information sharing more fragmented and less streamlined. - Investing in expensive technologies with little return. - Good technology not adopted due to misconceptions about its use.
Building Surveyor /Inspector	- Customise technology to suit their inspection/surveying needs. - Preservation of human interaction: on-site is best but also value visual technologies to connect with people when they’re on the road. - Technologies that help them apply their skills and knowledge developed over a long period of time. - GenAI support for filling out repetitive forms so they can spend more time applying their skills.	- Job losses due to automated inspection technologies. - Burn out due to pressure to complete more jobs in less time using emerging technologies. - Mental health risks if they do not have enough human-to-human contact. - Being held accountable for technology that fails, especially in the risk of GenAI hallucinating.

Table 2: Summary of ‘Desires’ and ‘Concerns’ about the introduction of Industry 4.0 technologies, according to job roles in the B&C industry

2.2 GUIDING PRINCIPLES FOR DESIRABLE WORK-PRACTICES

The following principles provide a practical guide for decision-makers across the building and construction industry. They can be used to shape the design, implementation and investment of new and emerging technologies, helping to create safer, more productive and more satisfying workplaces. Developed in collaboration with workers, trainers, inspectors, business leaders and regulators, these principles distil what people across the industry value in their day-to-day work and what they hope to see in the sector's future. They are grounded in desirable work practices, a critical pillar for successful technology innovation and adoption, alongside business viability and technical feasibility. Together, the principles offer a foundation for guiding Industry 4.0 transformations that are human-centred and resilient over the long term.

For each principle, two examples of application are provided: a “Technology Application”, which illustrates how the principle can guide a building and construction activity, and an “Education Application”, which shows how it can be embedded in training.

2.2.1 Principle 1: Strive for work satisfaction

Work satisfaction is a core priority for desirable work practices and an indicator of healthy long-term productivity. For many people, maximising the quantity of work output, without sufficient consideration of work satisfaction describes an undesirable workplace. Yet productivity can be satisfying if the technologies that enable people to be more productive make their work safer, of higher quality, or less tedious. Application of new technology without meaningful and satisfying training/retraining further distances workers from the product of their labour.

Technology Application	Education Application
Prefabrication facility managers ask workers how satisfied they are alongside traditional productivity measures (output/time). When work satisfaction is low, they involve workers in creating improvements that support healthier long-term productivity over time.	Curriculum developers incorporate material about satisfying productivity and the steps to support self-improvement. They create opportunities for trainers to show how finding a better way to complete a task using technology can make work more satisfying by being safer, easier, or higher quality.

2.2.2 Principle 2: Authentically Engage and Empower People

Worker involvement must be inclusive and authentic for effective application of Industry 4.0 technologies. Decisions that superficially engage workers risks eroding trust over time. Feedback needs to be heard and actively addressed.

Technology Application	Education Application
Implementation of robotics involve advice safety experts. Employees actively share the outcome of the experts' involvement and explain how the new technology will make work safer as a direct response to their challenges.	Education leaders involve students and industry leaders in crafting education opportunities, showing how the feedback gathered has been incorporated into the curriculum.

2.2.3 Principle 3: Learn the ‘why’

Aim for technologies and education that help people to think critically about the information the encounter in the workplace, so that they can make smarter, safer decisions at work. Avoid “knowledge shortcuts” by ensuring people understand the reason behind an action or an answer.

Technology Application	Education Application
GenAI tool explains the reason behind complex or risky answers and encourages users to double check their work. These could be paired with AR technologies to ‘show’ with visualised physics why an action or answer has been suggested.	Curriculum developers and trainers deliberately create opportunities to test students' knowledge without the aid of GenAI tools.

2.2.4 Principle 4: Design for the human body

Many people in the B&C industry learn and find satisfaction through making, and by using their hands and senses to create tangible outputs. Given the significance of physical skills in B&C, Industry 4.0 technologies should aim to complement, rather than replace physical skills, and prioritise practical learning.

Technology Application	Education Application
AR headsets designed can be used to remind employees to use their human senses, like touch, to teach quality craftsmanship. Reminders might reduce over time as the learner increases their expertise in the craft.	Trainers seek opportunities to show students theoretical knowledge through practical application. Knowledge about safety-critical systems and processes is supported through technologies like AR, such that students can still get an embodied experience of theoretical ideas.

2.2.5 Principle 5: Bring services together

New digital tools should support coordination across trades, management, and regulation. When information becomes fragmented, safety and quality are at risk. Industry 4.0 technology should aim for integration and shared visibility, to connect people across areas of expertise to establish a shared understanding of a common goal.

Technology Application	Education Application
Developers of emerging certification platforms ensure that these have a trusted version history and transparent workflow that helps services and inspectors proactively plan their jobs. They apply service design to understand the touch points across the life cycle of a building (from design to demolition).	Trainers exemplify best practices for sharing digital information across different services. For example, by demonstrating what a file (e.g. BIM) looks like that they might receive from someone and best practices on how to contribute to this.

2.2.6 Principle 6: Encourage reflection and innovation

Innovation that leads to improved productivity requires time to pause, think, and improve. Support moments that let workers reflect on what is working and what could be done better. When people are given space to process information and experiment, innovation becomes a natural part of everyday practice rather than an afterthought squeezed between deadlines.

Technology Application	Education Application
If implementing GenAI tools, organisation leaders might develop policy and education processes that encourage their employees to pause, critically reflect, and make informed decisions about how and why they are using these technologies in their workflow.	Trainers encourage students to reflect on their work practices and give them opportunities to apply these improvements in class.

2.2.7 Principle 7: Respect prior knowledge

Workers bring years of tacit expertise gained through direct experience with materials and environments. Technologies that acknowledge and extend these learnt skills are more likely to be used.

Technology Application	Education Application
Developers of emerging technologies actively involve skilled workers in their design process, prioritising solutions that enhance their experience and practical knowledge of materials.	Curriculum developers work with experienced tradespeople and trainers to shape future courses, drawing on their lived experience of how people learn, struggle or thrive in the industry.

3. FINDINGS AND RECOMMENDATIONS

In this section we present a summary of the key findings and translate them into recommendations. Each recommendation offers practical actions to help address the implications of Industry 4.0 on work practices in the B&C Industry.

The findings and recommendations are structured around four themes: *Productivity Through Job Satisfaction, Embodied Learning, Industry Cohesion, and System-Wide Coordinated Education*. The recommendations are aligned to the guiding principles. While the recommendations describe the specific actions that should be taken, the guiding principles inform why these actions are important and can be used to inform further decisions during implementation. The recommendations are also aligned to key stakeholders (industry leaders, educators, unions, technology developers and government) who have primary responsibility for the actions and able to progress their implementation. The recommendations are summarised in Table 3, grouped according to key themes and aligned to guiding principles and stakeholder roles.

Subsequent sections give a description of the findings that have informed the recommendations. To clarify the recommendation and facilitate its application, each recommendation is accompanied by key success factors that highlight the organisational, cultural and systemic conditions required for the recommendation to have meaningful and sustained impact.

Recommendations

Theme	Recommendations	Principles	Stakeholders				
			Educators & Jobs Councils	Unions	B&C Industry	Government	Technology Industry
Productivity Through Job Satisfaction	R1: Teach innovation and continuous improvement in training courses.	P1, P6	✓	✓	✓		
	R2: Encourage and invest in time for reflection and innovation.	P1, P2 P5, P6			✓	✓	
	R3: Design technology (especially AI) with reflexivity as a goal.	P1, P3, P6			✓		✓
	R4: Focus on improving safety, sustainability and quality challenges	P1		✓	✓	✓	✓
Industry Cohesion	R5: Continue to support flexible working, particularly for those with young families.	P2, P5			✓		
	R6: Education in project management, critical thinking and teamwork across roles.	P3, P5	✓				
	R7: Cohesion and collaboration are a key consideration for technology implementation.	P2, P5	✓	✓	✓		
Embodied Learning	R8: Invest in teaching strategies and/or technologies that support learning by doing.	P4	✓	✓	✓		✓
	R9: Use a human-centred approach to education design and delivery.	P2, P7	✓	✓			
	R10: Design technology with the end user's strengths in mind.	P2, P4, P7					✓
	R11: Subsidise access to innovative technologies.	P2, P7				✓	✓
System-wide Coordinated Education	R12: Co-design for system-wide technology education with Government as the convener.	P5	✓	✓	✓	✓	✓
	R13: Leaders educate work-force groups at a different stage in their career.	P2, P5	✓	✓	✓	✓	✓

Table 3: Recommendations grouped according to key themes in findings and aligned to guiding principles and stakeholder roles

3.1 PRODUCTIVITY THROUGH JOB SATISFACTION

3.1.1 Findings

- Participants voiced that an overemphasis on efficiency alone presents an undesirable future for the B&C industry.
- Participants valued finding better ways to do a job. However, time pressures and strict processes often make it hard to pause and reflect.
- Importantly, having autonomy and space to think were seen as key to genuine innovation that would support productivity.
- Across roles, participants expressed a preference for forms of productivity that enhance work satisfaction, particularly when technologies make work safer, easier or of higher quality, rather than simply accelerating output.

3.1.2 Participants' Voices

“ I think the technology has got great advantages provided. It actually looks after the mental well-being as well, you know, that that kind of the social aspect. Hopefully people will be producing more, they have more time for themselves.

Trainer [P12]

“ I think, obviously, if you can get something done quicker, or eliminate something altogether so that you don't have to do it. But also, maybe there's like an aspect of, You may still have to do something, but it's. Somehow it's done in a more rewarding way, or it Less frustrating to do it. Not that, you know, not necessarily quicker, but just easier.

Project Manager [P15]

“ Would I have a future where we've got a whole bunch of, tech supporting, supporting a better lifestyle for project managers. Or you know, a whole bunch of sort of agentic sort of buddies helping humans be, be better at their job or maybe doing part of their job for them.

Business Leader [P3]

“ Getting caught doing all the other admin stuff, a lot of time prevents you from doing enough checks. So doing, having these running all the time and doing those checks for you is gonna it will prioritize your quality, but it will, it will give you a better output, a fun product.”

Newstarter [P5]

“ It's funny, I talked to all the apprentices and stuff and they do the exact same thing. They all. Go out and build a few houses with their boss and stuff like that, and they always, and I still do it, you know, I'll take my wife every single time I go for a drive around a certain way because I'm like, I'll build that house down there. And then it's a satisfaction of going, yeah, like, I built that one, I built that one, I built that one. and I feel like the apprentices, they, you hear them, and they all do the exact same thing. Like they're quite proud of their work, or everything they've built. Like they've all got folders on their phone of everything they've done in their whole career so far, which I think is awesome”

Trainer/Skilled Worker [P13]

“ If I'm gonna utilise technology, it's got to make my life easier. So a building surveyor who generally will issue building permits, similar to New South Wales's building certifier, they are liable pretty much for everything, they have the highest insurance, so it doesn't matter even if they, I suppose, morally didn't make any mistake, but it was a shortfall. Generally people will still try to sue them, sort of thing. And so they're gonna want to look at that and go, well, how's this, like if I utilise this, what's my protection if something fails?”

Inspection Manager/Skilled Worker [P9]

“ So it's a bit of a chicken and the egg type thing that, we're too busy to actually implement it, but if we implemented it would make us less busy [...] So if we can actually dedicate some time to start adopting and implementing some of these, that will actually release more time [...] and so I think it will be a snowball effect if you can invest that time and effort [...] But it is hard work because you're busy doing what you're doing, [...] you go to your comfort zone of things and ways you know how to do things and then as soon as you start stepping out of that to these new areas, you're not as confident or, committed quite often.”

Building Surveyor/Business Leader [P6]

3.1.3 Recommendations

R1: Teach innovation and continuous improvement in training courses.

The findings of this project make clear that workers across the B&C industry value opportunities to find better, safer and more satisfying ways of doing their jobs. Yet time pressures and rigid processes often prevent them from stepping back to reflect or innovate. Embedding innovation mindsets into formal training, led by educators, unions and industry partners, helps cultivate these capabilities early and positions new entrants to challenge inefficiencies and propose improvements throughout their careers. This aligns with the guiding principles [P1] *Strive for work satisfaction* and [P6] *Encourage reflection and innovation*, which emphasise that productivity must enhance human experience, not diminish it. By equipping the workforce with structured ways to recognise problems, test ideas and iterate on practice, employers can strengthen both long-term productivity and job satisfaction.

Stakeholders	Education, Unions, B&C Industry
Example	- Trainers might teach methods like Lean Construction to support a culture where students feel able to identify improvements that will make work more satisfying. - Training courses themselves have a shift in the design and flexibility of training programmes, perhaps a new VET qualifications structure, or the addition of a new stream to existing qualifications to accommodate this kind of “student-centred” training.
Success Factors	- Curriculums have “innovation mindset” as a learning goal. - Organisations and trainers encourage new starters to propose new ways of carrying out a task.
Guiding Principles	[P1] Strive for work satisfaction [P6] Encourage reflection and innovation

R2: Encourage and invest in time for reflection and innovation.

Participants highlighted an apparent paradox: whilst acknowledging that achieving innovative solutions would reduce workload in the long run, current workloads leave little space to innovate. Workers need opportunities to “slow down to speed up” to innovate, e.g. moments where workers are encouraged to slow down for self or collaborative reflection rather than a continuous drive to produce outputs in an unchanging way. Government incentives could reinforce this shift by rewarding demonstrable workplace innovation from the bottom-up, not just top-down. This recommendation is grounded in the guiding principles: [P1] *Strive for work satisfaction*, [P2] *authentically empower people*, [P5] *bring services together* and [P6] *encourage reflection and innovation*. The recommendation recognise that desirable and resilient innovation happen when workers feel heard and when teams coordinate to improve their shared environment. Investing in reflection time is not a cost. It can be a catalyst for bottom-up productivity gains across the sector.

Stakeholders	B&C Industry, Government
Example	Business leaders might create opportunities for their team and extended contractors to reflect on what worked or did not work, finding collective improvements. Government could reward business that innovate.
Success Factors	• Leaders authentically listen and follow up on feedback being applied. • There are metrics for the outcome of innovation.
Guiding Principles	• [P1] Strive for work satisfaction • [P2] Authentically empower people • [P5] Bring services together • [P6] Encourage reflection and innovation

R3: Design technology (especially AI) with reflexivity as a goal.

Workers expressed concerns that emerging technologies, particularly Generative AI (GenAI), may encourage shortcuts and diminish critical thinking. Designing tools that prompt users to reflect, verify information and understand the reasoning behind answers directly addresses these fears. This recommendation advances the guiding principles: *[P1] Strive for work satisfaction*, *[P3] Learn the ‘why’*, and *[P6] Encourage reflection and innovation*. Reflexive technologies help safeguard quality and safety by ensuring that automated insights enhance, rather than bypass human judgment. In doing so, they position AI as a partner in decision-making rather than a replacement for domain expertise. This shifts the goal away from automating jobs out of existence, placing workers in other roles they may not be trained for. Instead, this approach aims to improve the human effort in their existing role, rather than handballing their skills to another area of the system.

Stakeholders	Tech industry, B&C industry
Example	Designers and Engineers developing GenAI tools for the construction industry consider how they use its conversational functionality to help people reflect on and improve their work practices.
Success Factors	• Technologies are design with their users to ensure self-reflection happens at appropriate moments.
Guiding Principles	• [P1] Strive for work satisfaction • [P3] Learn the ‘why’ • [P6] Encourage reflection and innovation

R4: Focus on improving safety, sustainability and quality challenges.

Participants across all job roles consistently framed “good productivity” as work that is safer, easier, or of higher quality. Workers want technology that helps them avoid mistakes, reduce physical strain and produce better buildings, not simply complete tasks faster. Prioritising safety, sustainability and quality improvements as core design and investment criteria ensures technology supports these outcomes that stakeholders and workers from across the industry can agree with. This aligns with the guiding principle *[P1] strive for work satisfaction*, recognising that satisfaction is linked to doing meaningful, high-quality work with reduced risk. Elevating these criteria also builds trust in new technologies and strengthens their likelihood of adoption at scale.

Stakeholders	Tech industry, B&C industry, Unions, Government
Example	Business leaders at technology companies include safety, sustainability and quality improvements as key measures of success for their technology development. Peak bodies communicate success stories of organisations who focused on safety, sustainability or quality.
Success Factors	• The benefits of focusing on safety, sustainability and quality are clearly communicated in a unified way.
Guiding Principles	• [P1] Strive for work satisfaction

3.2 INDUSTRY COHESION

3.2.1 Findings

- Remote work technologies help participants have a healthier work-life balance.
- Participants noted how remote technology also causes fragmentation as they are tempted to focus on getting their own tasks done without the distraction of others in the office.
- Participants were also concerned that although GenAI tools helped people self-serve answers to questions, this might mean they miss crucial contextual information by asking their site manager.
- Participants felt a strong sense of comradery in contributing to a shared output.

3.2.2 Participants' Voices

“ We've got families, we've got other priorities, [...] more about ourselves, our health, our family. You know, dropping kids off at school, that kind of stuff. So I'd be looking for anything that could sort of help me minimise [working overtime].

Project Manager [P4]

“ A major part of our job is communication. Like, without communication, we can't, we can't run a job. So having this, I feel like [AI guides] would separate people on site. Yes, it would give you access to all this information, but it will separate [people].

Newstarter [P5]

“ I am guilty sometimes. I just want to have an easy day at work. I just want to model and that's all I want to do. I just want to work through, you know, that particular task, but it's not like that every single day, there are days where you have to collaborate.

Newstarter [P16]

“ I think [teamwork is] a really important part of the culture of our construction industry, and I'd worry that if that were to fragment because people aren't on site, then the outcome won't be as good.

Business Leader [P2]

“ It's doing something that doesn't directly benefit me, but I know is making the process for someone else downstream easier. [...] it's productivity for them, might not be for me, but that tech is still obviously beneficial if it's helping out down the road.

Project Manager [P15]

“ Most of them will say none of them are desirable, for the fact that, you know, nothing beats that human human interaction and everybody wants to keep their job if they're happy in their job. I think [human contact] would definitely be the priority because a lot, a lot of our staff still believe that.

Inspection Manager/Skilled Worker [P9]

“ More and more [people are] being employed in remote places or they're moving out [...] Yeah, in the past they've often said, oh, we feel like we're a bit like forgotten about the times, you know, they give them a heap of jobs and they go and no one ever calls [them] I've always called them, but like, yeah, I think past experiences, they were just left to their own. But now it's just so much easier to take a Teams meeting or we can sit in the car and we still see them.

Inspection Manager/Skilled Worker [P11]

3.2.3 Recommendations

R5: Continue to support flexible working, particularly for those with young families.

Remote technologies have enabled healthier work-life balance for many workers, especially those managing family commitments. However, participants also emphasised that remote work and a focus on individual tasks can fragment communication with colleagues, so it is important an effective balance. This recommendation reflects the guiding principles: *[P2] authentically empower people* and *[P5] bring services together*, ensuring workers feel trusted to manage their personal circumstances while organisations still maintain strong team cohesion. Establishing predictable in-person days and modelling flexible practices creates a culture where workers feel both supported and connected.

Stakeholders	B&C Industry
Example	Project managers and business leaders role model a culture where people feel comfortable supporting their family through flexible working, while also showing the value of purposefully coming together as a team in person. This perhaps looks like having a day where everyone agrees to come into the office so that people can plan for these days in advance.
Success Factors	• Clear communication about why it is important to work on site. • Supporting people if they do need to work from home on certain days. • Encouraging a collaborative culture and providing technology to help people collaborate when they do need to be remote.
Guiding Principles	• [P2] Authentically empower people • [P5] Bring services together

R6: Education in project management, critical thinking and teamwork across roles.

The research showed that many workers lack visibility into how their tasks connect with upstream and downstream processes, leading to inefficiencies, rework and safety risks. As the industry shifts toward Modern Methods of Construction (MMC) and offsite production, this system-level understanding becomes increasingly important due to tighter interdependencies and greater reliance on digital coordination through approaches such as Design for Manufacture and Assembly (DfMA) or, Building Information Modeling (BIM), and emerging technologies like robotics and drones. Offsite and manufacturing environments also present an opportunity to attract new entrants, offering safer, more controlled working conditions and more varied career pathways. Embedding project management, critical thinking and teamwork skills across training pathways supports both new entrants and the existing workforce to operate effectively across manufacturing and onsite contexts, enabling the development of multi-skilled operatives and strengthening safety, coordination, and productivity across the project lifecycle.

Stakeholders	Jobs and Skills Councils, Educators
Example	• Develop a curriculum that incorporates project management and critical thinking skills across all certifications so that different pathways have an understanding about how their role fits into a broader project. • Develop a purpose-driven VET qualifications system/training framework for a construction industry utilising MMC (offsite/prefab/modular construction/advanced building materials, and new technologies) that prepares learners for multiple, related occupations while retaining industry relevance.
Success Factors	• Curriculum reflects the need for roles across the industry to understand how they integrate within a larger project. • Leaders cultivate a culture of psychological safety where workers feel safe to speak up.
Guiding Principles	• [P3] Learn the 'why' • [P5] Bring services together

R7: Cohesion and collaboration are a key consideration for technology implementation.

Workers expressed significant concern that digital tools, especially GenAI, could isolate individuals, reduce communication, and compromise contextual understanding. Designing technologies that reinforce collaboration, integrate with existing systems and encourage human-to-human information sharing directly addresses these risks. This recommendation aligns with the guiding principles: [P2] *Authentically empower people* and [P5] *Bring services together*. By prioritising interoperability, clear data flows, and collaboration nudges, technology developers and employers can better support cohesive, cross-disciplinary work practices.

Stakeholders	Educators, Jobs and Skills Councils, B&C industry, Unions
Example	- Technology developers consider how their product will integrate with other services beyond their main customer. For example, by creating APIs that integrate with popular tools and making it easy to convert file types without any loss of information. - GenAI developers consider how they design their system so that it encourages users to ask their team for important contextual information. - B&C companies have a clear policy and guidelines for how their people should use GenAI and when they should ask their team for contextual information.
Success Factors	- The importance of cohesion across different services is recognised by companies leading technology development. - Business leaders have a point of view on when GenAI should be used and when their people need to be asking each other questions directly. - There is a culture in organisations where people feel safe to ask questions.
Guiding Principles	[P2] Authentically empower people [P5] Bring services together

3.3 EMBODIED LEARNING

3.3.1 Findings

- Workers across the B&C industry feel a strong connection and pride in creating a physical output that they can point at and say they made.
- Participants voiced how technology like robotics or GenAI diminishes their ownership and pride in contributing to the final building. They felt that, since they are not using their body to construct the building, they have not really contributed to the final outcome.
- Those with an automation mindset believe that humans introduce error into a computerised system. However, there is also agreement that skills learnt by using the body and human senses in a certain way over time is valuable.
- There was a sense that people who are attracted to the B&C industry learn visually and through making.
- Participants voiced a desire to ensure that people across the industry with different opportunities have equal access to education and the ability to learn skills for their work.

3.3.2 Participants' Voices

“ I'll take my wife every single time I go for a drive around a certain way because I'm like, I built that house down there [...] it's a satisfaction of going, [...] I built that one, I built that one, I built that one. And I feel like the apprentices [...] they all do the exact same thing. Like they're quite proud of their work [...] they've all got folders on their phone of everything they've done in their whole career so far.

Trainer/Skilled Worker [P13]

“ [The craft] is more romantic [. . .] I can still smell wood being cut and I don't know, the smell of fresh concrete [. . .] symbolises a space and a place for me where this [remote hub with robotics] doesn't feel like [. . .] you're gonna get close to it.

Business Leader [P7]

“ So, although I'm not a hands-on person, I still really get a lot of satisfaction from that physical side of [projects]

Project Manager [P15]

“ I'll drive past the job and I've got my girlfriend in the car and I go “oh yeah, I remember working here, I did this, I did that,” [...] it's more rewarding [than] if you say, “oh yeah, a robot did that.

Newstarter [P8]

“ I don't think I would get much job satisfaction with it, [. . .] [it] feels like I'm setting the machine up to go. I don't know, it almost feels like if you're making a cake or something, if you buy a cake mix in a box, it feels like the work's already done for you. But if you do it from scratch, you have more satisfaction from it.

Trainer/Skilled Worker [P13]

“ Most of the kinaesthetic or the tradie blokes [...] if we watch a video of someone else doing it once, we seem to understand it better than reading a book or something like that. But if you've got the AR glasses showing you as you're doing it, I think it would be great.

Trainer/Skilled Worker [P13]

“ Our training unit, I think they put 10,000 people through a year and I think it's, it's a 60% or 80%, it's a staggering amount of people who need some type of assistance in numeracy and literacy when they're looking at a brochure or a manual, you know, how to read that, [the help required is] quite high.

Trainer/Skilled Worker/Business Leader [P10]

“ It's almost like an audiobook. So if you look at an audiobook, it's great. So if you go for a run, or, you know, if you go for a walk, you can listen to an audiobook. But it doesn't help with your reading skills.

Inspection Manager/Skilled Worker [P9]

“ It hasn't been done correctly, or the engineers haven't considered X, and they haven't utilised the knowledge and the skill and the experience, which is sitting dormant on the shop floor to say, “Do you think this will work?” They're not getting involved. And then people are just feeling, you know, disenfranchised, disheartened, and they realise they've got no control over their work life.

Union Leader/Skilled Worker [P10]

3.3.3 Recommendations

R8: Invest in teaching strategies and/or technologies that support learning by doing.

Across job roles, participants described the deeply embodied nature of construction work, where people learn through doing, sensing, and physically engaging with materials. Workers take pride in contributing to tangible outputs, and many expressed that overly automated processes diminish their sense of ownership. Investing in AR, physical simulations and practical training strategies preserves and strengthens this embodied learning culture. This recommendation aligns with the guiding principle *[P4] Design for the human body*, ensuring technology complements rather than replaces physical skill. Supporting hands-on learning also helps close skill gaps for workers who prefer visual or kinaesthetic modes of learning. This recommendation is aligned with other work conducted by Vocational Educational and Training sector⁷.

Stakeholders	Educators, Jobs and Skills Councils, Tech industry, B&C industry, Unions
Example	• Incorporate AR technologies into education delivery. • Integrating existing elements of competency-based practical “learning by doing” in education delivery with a shift toward “student-centred” approaches that teach important soft-skills and project management strategies.
Success Factors	• Trainers need to be upskilled in emerging technologies like AR, to do this there will need to be a cultural shift mindset of existing trainers and teachers, like students, embracing a growth mindset and being granted the time to learn new teaching methods. • AR/tech supported education courses need to be easy to maintain over time. • Practical learning done through AR/immersive tech should mimic real-world movements as closely as possible.
Guiding Principles	• [P4] Design for the human body.

R9: Use a human-centred approach to education design and delivery.

The findings highlight significant variation in learning styles and access challenges across the workforce. A human-centred approach ensures training programs reflect these needs by involving learners in course design and conducting user research to remove barriers. This promotes psychological safety and ensures training resonates with real-world work practices. The recommendation should be guided by the following principles: *[P7] Respect prior knowledge* and *[P2] Authentically empower people*, both of which emphasise honouring the lived experience workers bring to their roles. Tailored education can improve learning outcomes and supports equity in skill development across the industry.

Stakeholders	Educators, Jobs and Skills Councils, Unions
Example	Include students while designing education courses and perform adequate user research to understand their challenges and goals for accessing resources.
Success Factors	• Performing adequate user research. • Deep understanding of access challenges for different groups of people. •
Guiding Principles	• [P2] Authentically empower people • [P7] Respect prior knowledge

R10: Design technology with the end user's strengths in mind.

Participants emphasised that technologies gain acceptance when they recognise and enhance workers’ tacit expertise, not override it. Including workers in the design and testing of emerging technologies ensures tools build on existing strengths and help individuals perform their work more

⁷ For example, “Unlocking the Potential of VET” (Dec 2024) report from the Qualifications Reform Design Group to the Department of Employment and Workplace Relations (D24/7227879)

safely and effectively. This should be informed by the guiding principles: *[P4] Design for the human body*, *[P7] Respect prior knowledge* and *[P2] Authentically empower people*. Designing with these principles in mind fosters trust, reduces resistance and increases adoption, especially among experienced workers whose identities are closely tied to their craft. Although this recommendation is primarily intended for the developers in the technology industry, the B&C industry can advocate for stronger human-centred features in their technology.

Stakeholders	Tech industry
Example	Include workers in the design phase of emerging technologies. Specifically ask how their acquired skills helps them use the technology and in vice versa, how the technology helps to augment these skills by making work safer or easier.
Success Factors	- Authentic inclusion of end users in the design and testing of technologies. - Respect for the end user's tacit knowledge.
Guiding Principles	[P2] Authentically empower people [P4] Design for the human body [P7] Respect prior knowledge

R11: Subsidise access to innovative technologies.

Unequal access to emerging tools risks widening capability gaps across the sector. Many workers expressed concern that without access to training and technologies, they might fall behind or feel undervalued. Subsidies or tiered pricing models might ensure technologies such as GenAI, AR and robotics reach smaller businesses and training institutions. This recommendation is directed to the Tech Industry and Government and is informed by the guiding principles: *[P7] Respect prior knowledge* and *[P2] Authentically empower people*. Recognising that equitable access enables all workers to build confidence and capability as the industry transforms.

Stakeholders	Tech industry, Government
Example	- Subsidies for access to innovative technologies such as GenAI, AR and onsite robotics to put technologies in the hands of users. - Tech companies providing discounts for smaller-scale businesses to promote whole system adoption.
Success Factors	- Identify the best-fit technology to subsidise through rigorous research. - Clear purpose for why certain technologies would be subsidised and who is set to benefit. - Benefits should go to entities who can demonstrate accessibility challenges.
Guiding Principles	[P2] Authentically empower people [P7] Respect prior knowledge

3.4 SYSTEM-WIDE COORDINATED EDUCATION

3.4.1 Findings

- Participants indicated their support for diverse training methods capable of catering for various ages and skillsets within the industry. This requires a considered effort to engage people from different career stages and preferences for information delivery.
- Some participants made note of burdens on employers in conducting training. Concerns as to cost weren't explicitly referred to, but could be inferred through remarks as to time pressures.
- Many participants indicated views that existing training systems either ignore altogether, or fail in addressing, realities of the modern industry. There is a need for a qualification structures that reflects the changes in new technologies and production systems taking place. This includes both TAFE and higher education degree studies.

- Participants voiced that workers often fail to appreciate the context of the project more generally and the consequences a particular approach in one area may have for other areas. This indicates a potential need for workers to receive training from experts/trainers across the system rather than in their siloed discipline, noting the potential role unions can play in supporting equitable access to education and the safe use of emerging technologies on-site.

3.4.2 Participants' Voices

“ I just think for some of those technologies, our younger crew will pick that up and really like work with that shit, but the older guys will really struggle with it. They've got the experience. It's needed, but do they, will they really need it, you know, and then? And they're very set in their way too, you know, like to introduce those new technologies as part of their onboarding and recruitment, they'll really struggle with. Whereas our young, they'll pick that up and really great and probably enjoy doing that.

Inspection Manager/Skilled Worker [P11]

“ Learning new skills takes time and effort, and we don't have the time. And so if it's, if it's tools and systems that don't require the deep learning and the deep understanding, then, that's a bonus for a business in that, you don't have to invest in that, that upskilling and the training and the time.

Building Surveyor/Business Leader [P6]

“ cause I might have been a carpenter first, then going on to be a site supervisor. I can't see a lot of them adapting to this kind of change. But if someone's gone a different route and gone the university route all the way through them and become a builder, I think they could adapt to it really well.

Trainer/ Skilled Worker [P13]

“ Not every way suits each individual, everyone has different needs, but I think that things could be done differently to support both ways rather than just having it one way.

Building Surveyor [P14]

3.4.3 Recommendations

R12: Co-design for system-wide technology education with Government as the convener.

Participants stressed that fragmented training approaches do not reflect the interconnected nature of modern construction work. A coordinated education strategy would ensure consistency, clarity and responsiveness across the system. Government is best placed to convene this effort, bringing together key stakeholders to align objectives, roles and success measures. This recommendation should be supported by the guiding principle [P5] *Bring services together*, recognising that effective education requires collaboration across organisational boundaries. A unified strategy helps ensure training keeps pace with technological change and supports a resilient, future-ready workforce.

Relevant Stakeholders	Government, Educators, Jobs and Skills Councils, Unions, B&C industry, Tech industry
Example	A series of workshops with key stakeholders from Government, educators, unions, and industry to define education objectives, success measures, and action owners.
Success Factors	- Clearly defined roles and responsibilities. - Clear unifying purpose and objectives of the task force. - Increased funding to support the resourcing and delivery of education and training in these modern construction methods and/or introduction of new technologies. - Engage co-design specialists.
Guiding Principles	[P5] Bring services together

R13: Leaders educate work-force groups at a different stage in their career.

Workers at different career stages have distinct learning needs and levels of technological readiness. Participants highlighted that younger workers may adopt technologies quickly, while more experienced workers may require additional support to integrate new tools into established practices. Assigning clear leadership roles (e.g. TAFE leading foundational training, unions guiding mid-career safety education, and industry partners supporting advanced upskilling) ensures each workforce segment receives relevant and effective learning. This recommendation should be informed by the guiding principles: *[P5] bring services together* and *[P2] authentically empower people*, ensuring each group feels supported rather than overwhelmed by change. This structured, system-thinking approach ensures cohesive development across the entire workforce and helps prevent skill gaps from widening over time.

Relevant Stakeholders	Government, Educators, Jobs and Skills Councils, Unions, B&C industry, Tech industry
Example	• TAFE/tertiary education leading new-starters and introducing technologies at the pace of this generation. • Unions leading mid-career trade-workers' safety training for technology innovation. • Tech/B&C industry supporting different stakeholders to craft inclusive training programs. • B&C industry and TAFE leading project management development.
Success Factors	• Support and link to the findings and recommendations of The Qualifications Reform Design Group already researched and proposed. • Authentic inclusion and transparent leadership from convening organisations • Clearly defined roles and responsibilities. • Systems thinking approach to understand how education in one area might positively impact the rest of the system. • Human-centred understanding of students and their education needs.
Guiding Principles	• [P2] Authentically empower people • [P5] Bring services together

4. CONCLUSION

4.1 SUMMARY OF FINDINGS

This study demonstrates that the successful adoption of Industry 4.0 technologies in the Australian building and construction (B&C) industry depends not on technological capability alone, but on the extent to which new technologies are feasible, commercially viable, and desirable to the people and organisations expected to use them. Through a human-centred, speculative and systemic design approach, the study surfaced tensions and opportunities associated with the future of work across the industry, and used co-created design artefacts to make these possibilities tangible for industry participants.

A central finding is that technological transformation must be accompanied by transformation in workforce capability and learning systems. Participants consistently emphasised the importance of technologies that support safer, more satisfying and higher-quality work, while reducing administrative burden, improving coordination and strengthening opportunities for embodied and practice-based learning. At the same time, they expressed concerns about deskilling, reduced autonomy and human connection, and the potential for technology to disrupt valued forms of craft expertise and workplace learning.

Training and skill development therefore emerge as a critical enabler of Construction 4.0. The fragmented structure of the sector, the prevalence of SMEs, and the diversity of the workforce require learning systems that are flexible, accessible and responsive to different roles, capabilities and project contexts. Rather than assuming that digital technologies will automatically improve productivity, innovation should be understood as part of a broader socio-technical transition in which workforce capability, organisational practices and technology develop together.

Overall, the study provides a foundation for more human-centred approaches to digital transformation in B&C. It suggests that desirable technological futures are those that augment workers' capabilities, preserve valued forms of expertise and autonomy, strengthen collaboration, and contribute to safer, more productive and more fulfilling workplaces. The design principles and insights developed through the study provide a basis for further research and for industry, government and education stakeholders to critically assess how emerging technologies can contribute to these outcomes.

4.2 LIMITATIONS

Several limitations should be considered when interpreting the findings. First, the study was conducted primarily through relationships with industry partners and participants based in Victoria. Although considerable effort was made to engage people from diverse roles across the architectural, engineering and construction sectors, the findings should not be assumed to represent the full Australian B&C industry. Differences in regulatory environments, project types, workforce composition, industrial arrangements and technology adoption across jurisdictions may shape both the challenges identified and the desirability of particular technological futures.

Second, the study relied on a relatively small pool of 17 in-depth participants. This is appropriate for qualitative and speculative HCI research, where the objective is to develop rich insights into participants' experiences, aspirations and concerns rather than statistical representation. Nevertheless, the depth of the interviews necessarily limited the number of roles and sub-sectors that could be represented. The study therefore provides a detailed but necessarily partial view of an industry encompassing highly diverse occupations, organisational structures and working

environments. In particular, not every role across the building and construction lifecycle could be included.

There were also limitations arising from the design process itself. Participants could not all be involved at every stage: a core group of industry representatives helped guide the co-design process, while subsequent participants primarily responded to the resulting speculative artefacts. This discontinuity may have influenced how particular tensions were framed. Time and resource constraints also meant that some activities were combined within workshops that, in retrospect, might have been more productively separated. These methodological refinements could be investigated in future applications of the framework.

Finally, the speculative artefacts deliberately emphasised uncanny and relatively optimistic futures to provoke reflection. This helped challenge assumptions about trade-offs between values such as productivity, job satisfaction and craft expertise, but may have underrepresented more dystopian possibilities. The use of sliders to represent tensions may also risk suggesting that values necessarily exist in a zero-sum relationship.

4.3 FUTURE WORK

Future research should extend this work from broad industry-level perspectives towards more focused investigation of specific stages, occupations and technological challenges across the building and construction lifecycle. The findings provide a basis for examining how the feasibility, viability and desirability of Industry 4.0 technologies vary between sub-sectors and work contexts, rather than treating the B&C industry as a homogeneous whole.

At the feasibility and finance end of the lifecycle, research could examine the technical, organisational and economic conditions required for emerging technologies to be adopted, particularly by SMEs. This includes cost–benefit analysis, procurement models, interoperability, data requirements and the distribution of costs and benefits between clients, contractors, technology providers and workers. At the design and planning stages, future work could investigate how AI, digital twins, collaborative tools and other technologies affect professional judgement, interdisciplinary coordination and the relationship between automation and design expertise.

At the production and fabrication stage, research could explore how automation, robotics and digital manufacturing interact with skilled craft, worker autonomy and opportunities for learning. For site-based work, there is scope to investigate technologies such as AR/VR, computer vision, wearable systems and mobile or AI-enabled tools, with particular attention to safety, coordination, embodied learning and the realities of dynamic construction environments. At the occupation and workforce level, longitudinal research is needed to examine how technological change affects skills, career pathways, job quality, productivity and participation across different trades and professional roles.

A further priority is to move from speculative insights towards empirical evaluation. Future studies could pilot specific training interventions, technologies or organisational practices and assess their impacts on productivity, safety, learning, worker experience and equity. Comparative research across Australian states and territories, and potentially internationally, would also test which findings are context-specific and which are transferable. Finally, the design framework itself should be systematically compared with alternative participatory, systemic and speculative approaches to establish where and when it provides distinctive value for industry transformation.

5. PAPER 1 – SYSTEMIC FUTURES: INTEGRATING CRITICAL SPECULATION AND SYSTEMIC DESIGN PRAGMATISM

Systemic Futures: Integrating Critical Speculation and Systemic Design Pragmatism

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Abstract

Speculative and systemic design are both used by HCI researchers to engage in complex sociotechnical change. However, they are rarely integrated in ways that make their complementary strengths explicit. This paper introduces **Systemic Futures Dialogue**, a design approach that interleaves speculative and systemic design methods across micro-macro and present-future dimensions. We report on an 18-month case study with the Architecture, Engineering, and Construction (AEC) industry, that applied a mixture of methods used in both design disciplines. These included semi-structured interviews, systems mapping, future-based scenarios, speculative probes, and participatory reflection. The resulting design approach generates grounded futures by connecting macro-level system dynamics with micro-level speculative critique, identifying tensions between present-day solutions and desired futures. The final Systemic Futures Dialogue contributes methodological guidance for

conducting critical, participatory design work within a sociotechnical system.

CCS Concepts

• **Human-centered computing** → **Interaction design process and methods; Interaction design theory, concepts and paradigms; Collaborative and social computing design and evaluation methods.**

Keywords

Speculative Design; Systemic Design; Mixed Methods; Micro-Macro analysis; Present-Future analysis

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1 Introduction

The deliberate movement away from solutionism in speculative design, toward designer-led critique [21], stands in contrast with

the participatory and pragmatic orientation of systemic design [32]. These different purposes make it challenging to apply both approaches in parallel; while speculative design opts for critique and reflection, systemic design instead aims to find opportunities for change. In this paper we demonstrate how the orchestration of these approaches can be useful to structure a movement between micro and macro perspectives of a sociotechnical system, whilst identifying design tensions between systemic change and long-term desirable futures.

Although speculative design and systemic design have important differences, their methods and foci could be applied in complementary ways, such that the strengths of one address the weaknesses of the other. Speculative design, while powerful for critiquing dominant assumptions and envisioning alternative futures, has been criticised for its designer-led orientation, which privileges expert voices and limits broader participation in imagining futures [43, 51]. While recent efforts aim to democratise this process [24], speculative design can meet opposition from the pragmatics of corporate objectives, and participants may find it difficult to engage in futures thinking without specialised training [24, 51]. Instead, we believe it is possible to embed designer-led speculation in systemic design activities that engage sociotechnical systems in participatory ways [31]. Meanwhile, speculative design can also address critiques that systemic design tends to remain at the level of policy or organisational design, overlooking the role of technology plays in systemic change [10].

However, to our knowledge no HCI research has examined how systemic and speculative design can be intentionally brought together. We therefore aim to articulate the challenges and opportunities that arise from combining methods from both disciplines. We examine the integration of these different methods by presenting a case study in which we designed technology interventions aimed at improving Architecture, Engineering, and Construction (AEC) sociotechnical systems. By sociotechnical system, we mean social systems (e.g. a group of people from different organisations collaboratively designing and constructing a building) that use technologies to assist in the organisation of activities (e.g. using cloud computing to share architectural files between organisations) [6].

From this case study, we extract and present the **Systemic Futures Dialogue** (Figure 1), developed in collaboration with AEC industry representatives. This structured orchestration acts as a guide for designers to balance the different epistemic purposes of speculative and systemic design, helping them to 1) ground speculative design in identified trends within a sociotechnical system, 2) structure participatory speculation, and 3) identify design tensions between planned systemic solutions and desirable technological futures. Overall, this paper makes the following contributions:

- **The Systemic Futures Dialogue**, a structured orchestration that integrates the strengths of speculative design and systemic design, showing how this integration can be reliably used by designers.
- An empirical study with participants from the Architecture, Engineering and Construction industry that provides a **clear illustration** of the Systemic Futures Dialogue in a **real-world context**.

- **Systemic Futures Tensions**, a novel epistemic contribution that results from combining systemic and speculative design using the Systemic Futures Dialogue. This conceptualisation of systemic change tensions generates opportunities to critically reflect on whether sociotechnical change might reinforce existing behaviours or realise a collectively desirable future.

Through these contributions, we offer a reproducible approach for researchers to collaboratively examine how technological interventions may impact a social system. In the long term, we hope this work enables more reflexive design practices that question whether technological interventions support or hinder collectively desired futures.

2 Related Work

2.1 Systemic Design and its Application in HCI

Systemic design is an emerging practice that aims to address complex social challenges by identifying opportunities for change [32]. As outlined in the Systemic Design Toolkit [31], systemic design is informed by both systems thinking and design thinking practices.

The systems-thinking [32, 44] aspect of systemic design encourages designers to see problems as part of interconnected systems rather than isolated issues. Donella Meadows, a pioneer of systems-thinking, defines a system as “an interconnected set of elements that is coherently organised in a way that achieves something... a system must consist of three things: elements, interconnections, and a function or purpose” [44, p.11]. For example, elements within an Architecture, Engineering, and Construction (AEC) sociotechnical system might include architects, engineers, builders, regulators, and consumers, which are interconnected through flows of information, materials, and finances to fulfil its purpose of delivering safe and functional built environments.

The design thinking components of systemic design situate knowledge about a system within an iterative and participatory design process. Design thinking provides tools for exploring how interventions at particular leverage points might influence a system. **Leverage points**, as defined by Meadows, describe aspects of a system that can be used to influence its behaviour, where a small change in one area can produce a major enduring change in another part of the system [32, 44]. For example, a leverage point in AEC sociotechnical systems could increase the number of available skilled workers to meet the demand for building new homes (see Table 1 for other examples of leverage points in AEC sociotechnical systems). Using design thinking methods, the systemic designer might ideate interventions to bring these leverage points into play, such as incentivising high school recruits to join the AEC industry with education discounts or by investing in robotics that help ageing workers continue to contribute their skills in less physically demanding ways. In systemic design, designers iteratively explore and prototype such interventions, aiming to understand how these decisions impact the health and behaviour of the wider system [31, 32, 53].

Systemic design has gained traction in global design communities; most notably, the Design Council recently adapted their Double

Table 1: Categories of leverage points and illustrative examples, inspired by [10], that seek to address a shortage of skilled workers in the Architecture, Engineering and Construction (AEC) industry.

Category	Examples of leverage points in AEC
Acting on the constants and parameters of the system.	Incentivising senior school recruits to join the AEC industry.
Acting on feedback loops and delays .	Creating a support program for women entering the AEC industry, who then encourage other women to join the industry. Alternatively a time delay for workers leaving the industry by creating opportunities for ageing workers to apply their skills in less physically demanding roles.
Changing information flows or system rules .	Outreach programs that inform senior school graduates and female recruits about the opportunities of working in the AEC industry, or using government incentives to ensure businesses train people to meet the demand for skilled workers.
Changing the systems' goals or its underlying worldview .	In a more drastic example, instead of protecting jobs the government might prioritise automating as many jobs as possible, thereby reducing demand for skilled workers and in conjunction the price of building homes.

Diamond framework to accommodate Systemic Design methods¹. However, to our knowledge, there are only a handful of papers that apply Systemic Design in HCI, with these usually relating to sustainable design [9, 27] or methodological research with HCI specialists [2, 10, 35].

Similarly, Transition Design [29, 33] has been proposed as a design paradigm that advocates for long-term, systemic societal transitions toward more sustainable futures. It emphasises the role of future-oriented visioning, theories of change, and multi-level interventions across sociotechnical systems. However, while Transition Design outlines the need to connect short and long-term interventions, there is limited guidance in HCI literature that shows how HCI-specific design methods should be sequenced or orchestrated in practice. Our work builds on the Transition Design agenda by introducing a structured approach to interleaving systemic and speculative design, and by contributing a novel epistemic output, systemic futures tensions, that help make such transitions possible in HCI.

As articulated by Bornes et al. [10], the characterisation of systemic design, as organisational and social, ignores how the design of specific artefacts, products, and services can impact a broader system. Indeed, Lin and Villari [36] suggest that systemic design, service design, and speculative approaches can “help service designers to deal with more systemic and future-related problems” [36, p.1]. For example, how the introduction of construction robotics might change the type of trade skills required for building

structures in the AEC industry. However, there are no HCI-specific papers that focus on the overlap of systemic and speculative design at the level of human interactions with digital technologies.

2.2 Elements of Speculative Design

Informed by critical practices from art, the humanities, and social sciences [50, 61], speculative design aims to “challenge narrow assumptions, preconceptions, and givens about the role products play in everyday life” [21, p. 33]. To do so, the method creatively extrapolates present-day trends and technological innovations to question societal values [1]. For example, Auger’s [1] fictional *Audio Tooth Implant* imagines a reality where society’s progressively shrinking computer chips can be implanted in a tooth. Their designed acrylic tooth that encases an electronic chip and the accompanying journalistic articles invite people to consider the relationship between technology and the human body. While some of the viewing public welcomed the imagined product’s convenience, others refuted a world where humans are synonymous with machines. This speculative approach is not concerned with measuring the usability or efficiency [3] of a real ‘audio tooth implant’. Instead, it aims to generate knowledge by provoking conversations about what people value or desire for the future, as well as how technologies reinforce or obscure these aspirations [21, 26].

Although speculative design has become a prominent approach in HCI, a common criticism of the method is its lack of clarity about what constitutes “good” or “bad” speculative design [50]. In HCI, there are a number of related approaches (e.g. design fiction [8, 18, 56], critical design [3], speculative enactments [22], fabulation [55], or material speculation [58]) and frameworks (e.g. the futures cone [11, 21, 25] or alternative presents [1, 17]) that designers might apply to structure their speculative design process. These might include written forms like future-based scenarios (e.g. [47]) or other narrative-based works (e.g. [41]), fictional products or services (e.g. [12]), performative outputs or materials that are empirically evaluated (e.g. [22]), and even fictional research papers (e.g. [39]). Understandably, these diverse possibilities have attracted criticism that there is little standardisation and clarity about what speculative design *is* and *is not* [4, 20, 28, 38, 42, 50, 62], making it difficult to review the quality of the research contribution [5, 40].

Acknowledging these challenges, Ringfort-Felner et al.’s [50] recent review of speculative design research in HCI and resulting descriptive taxonomy highlights the common qualities associated with “good” speculative design. Importantly, the authors caution readers against using the taxonomy as a checklist. Instead, it offers a shared vocabulary for designers to decide what kind of knowledge they aim to generate, based on the specific design context and cultural norms they seek to interrogate. Their taxonomy outlines nine qualities categorised into three types (speculative, discursive and process) that make “good” speculative design:

- (1) **speculative** - includes fictional, critical, and socio-political qualities of the speculative design that distinguish it from forms of affirmative design, which focus on problem-solving or increasing consumption,
- (2) **discursive** - includes experienceable and thought-provoking qualities, and

¹<https://www.designcouncil.org.uk/our-resources/systemic-design-framework/>

- (3) **process** - includes grounded, participative, reflected or well thought-out design processes, and playful or creative qualities that strike a balance between creativity and methodological rigour.

In this paper we use the qualities within this descriptive taxonomy to structure how speculative design can complement systemic design and vice versa.

First, to address historic challenges for grounding speculative design, we explain how systemic design can be used to link this speculation to empirical data about how the sociotechnical system operates (Section 2.3). We then describe how the fictional and critical aspects of speculative design can be used to critically reflect on the leverage points, in an otherwise pragmatic approach to futuring in systemic design (Section 2.4). Finally, we argue that the *participative* quality of speculative design can be achieved with a combination of designer-led *and* collaborative activities (Section 2.5). When carefully orchestrated alongside systemic design practices, it is possible to strengthen a collaborative approach to speculation, an area that has historically been difficult to achieve in a corporate setting [51, 61].

2.3 Grounding Speculative Design with Systemic Design

Several scholars argue that speculative design must do more than imagine distant futures. It needs to be *grounded in the present*, extrapolating existing social and technological trends to expose their possible trajectories. As Auger [1] argues, envisioning the *distant* future holds conjectural baggage, “playing to spectacle and technocentric dreams rather than being based on logical trajectories or contained by the rules of real life” [1, p.12]. Instead, he advocates for alternative presents where design proposals “utilise contemporary technology but apply different ideologies or configurations to those currently directing product development” [1, p.12], acting as “a form of cultural litmus paper” [1, p.13].

The identification of behaviours in a system can help to ground socio-political qualities of speculation. As several scholars argue [1, 37, 62], *grounding* speculative artefacts in existing empirical findings and theoretical ideas is important. Ringfort-Felner et al. [50] stress the importance of grounding in speculative design to create artefacts that have relevance, reliability and credibility in academic and societal debates. However, it is not entirely clear *how* to do this in a robust and systemic way.

The application of **feedback loops** in systemic design can provide a useful mechanism for grounding speculative design in real-world sociotechnical system dynamics. Feedback loops are used in systemic design to understand trends and behaviours of macro phenomena. In systems thinking, feedback loops describe recurring chains of cause and effect in which actions produce outcomes that, in turn, reinforce or counteract the original behaviour [44]. *Reinforcing feedback loops* amplify existing dynamics [44], such as a continued influx of construction projects putting further pressure on the demand for skilled workers. In contrast, *balancing feedback loops* stabilise systems by constraining change, for example, training and/or attracting skilled workers from other countries, balancing their demand. Feedback loops offer a mechanism for grounding speculative design in present-day dynamics by making explicit how

current trends operate and helping the designer to imagine the political or social consequences that might occur as these feedback loops intensify or break down.

Importantly, design researchers [1, 50] stress that successful speculative design demands a careful balance of analysis of the present and imaginings of the future. If the speculative designs stray too far into the future, they will be alienating, and if they are too obviously plausible, they will lack the ability to challenge existing beliefs and inspire discourse. While systemic design could help to ground speculation, its pragmatism could risk designs taking on a more normative short-term appeal; a balance that is difficult to strike. This paper attempts to provide a structured approach that helps researchers navigate critical imaginings of the future and the pragmatics of systemic change.

2.4 Fictional and Critical Qualities of Speculative Design Enhance Systemic Design

Imaginings of the future are a vital aspect of speculative design. However, contrary to common assumptions, speculative design does not aim to predict the future. Instead, it uses the future as a mechanism to suspend disbelief [21]. By designing for a reality yet to occur, researchers can move beyond expectations since the future is ultimately unknown and holds multiple possibilities [11]. Dunne and Raby, who helped to popularise speculative design, were interested in what makes a preferable future “preferred” for different groups of people and how “working with experts, including ethicists, political scientists, economists, and so on, generate futures that act as catalysts for public debate and discussion about the kinds of futures people really want” [21, p.6]. Importantly, the tradition of speculative design aims to move beyond future-proofing or solution-finding for the fickle future, and instead uses these futuring frameworks to understand what society values and **critique** why this might be.

While Systemic Design engages with futuring practices, by itself, it lacks critical orientation. Systemic design excels at mapping complexity, identifying feedback loops, and revealing leverage points within existing structures [31, 36]. However, it risks reinforcing prevailing assumptions by optimising existing practices or realising unchallenged desired futures [36]. Speculative design complements this by introducing critique as a mode of inquiry. As Lin and Villari [36] argue, speculative approaches can surface tensions, uncertainties, and conflicts that systemic analyses alone may render invisible, enabling collective reflection on long-term implications beyond immediate feasibility. Similarly, Borne [9] demonstrates how systemic models, such as causal loop diagrams, can act as conversational artefacts that support debate and scenario comparison, a role that speculative artefacts further extend by making potential consequences legible as real objects. In doing so, speculative critique helps researchers move from system-level insights to a critical examination of how system interventions with technologies may reinforce or disrupt existing patterns in a sociotechnical system.

Table 2: Comparison of systemic design and speculative design across key dimensions, informed by [1, 10, 21, 32, 50].

Dimension of Primary Focus	Systemic Design	Speculative Design
Time-horizon	Present	Future
Analytical scale	Macro	Micro
Mode-of-inquiry	Collaborative & Empirical	Design-led & Conceptual
Purpose	Pragmatic outcomes	Critical reflections

2.5 Interleaving Speculative Design Leadership with Participatory Systemic Design

A common criticism of speculative design is its designer-led orientation, which risks foregrounding a singular, and often privileged, vision of how society should function [43]. Prior work shows that speculative practices are frequently conducted by a small group of experts whose perspectives, values, and assumptions shape both the framing of futures and the technologies imagined [14, 19, 43]. In particular, Arturo Escobar’s [23] critique of development as a discourse that “made the Third World” (and can be “un-made”) stresses the need to interrogate how design practices construct particular futures and marginalise others. This tendency to design for rather than with(in) sociotechnical systems can obscure how systems operate in practice and risk reproducing existing inequalities [36]. Such top-down approaches sit uneasily with systemic design, which depends on participation from system representatives to understand macro-level dynamics.

HCI research has increasingly explored participatory speculative design to broaden the perspectives that inform future imaginaries [14, 19, 51]. However, prior studies show that greater collaboration alone does not resolve key challenges. Participants may remain constrained by their own experiences [19], struggle with the ambiguity of speculation, or revert to normative thinking [13], particularly in corporate or novice settings [51]. These findings suggest a tension between democratising speculation and the expertise required to meaningfully challenge dominant assumptions when speculative design is carried out by itself, albeit in collaborative ways. Our work explores what might happen when speculative design is retained as a designer-led activity, and instead informed by collaborative activities *inherent* to systemic design carefully sequenced and interleaved with speculative designer-led practices.

2.6 Summary of Comparison between Systemic Design and Speculative Design

In summary, Speculative design and systemic design offer distinct, yet complementary, ways of engaging with complex sociotechnical challenges. Table 2 summarises their primary foci on dimensions of **Time-horizon** and **Scale-of-analysis**, **Mode-of-inquiry** and **Purpose**.

Both approaches incorporate the present and the future time horizons to varying degrees. Speculative design typically pushes beyond the immediate present to explore futures which are distant

[21], alternative [1], or even preposterous [30], using fiction and imagination to suspend disbelief and provoke critical reflection. In contrast, systemic design is more firmly anchored in the present [36], focusing on existing structures, behaviours, and feedback loops in order to understand how systems currently operate and where intervention may be possible [10]. While systemic design may incorporate future scenarios [32], these are usually constrained by plausibility and grounded in observed dynamics rather than deliberately exaggerated or provocative futures [36].

The two approaches also differ in their analytical scale. Systemic design explicitly adopts a macro-level perspective, examining relationships between multiple entities and resources within a complex system [44]. Speculative design in HCI, by contrast, often operates at a micro-level, examining human interactions with particular technologies and the experiential, ethical, or normative implications of those interactions [61]. Although some speculative projects extrapolate these interactions to broader societal concerns [26], this systemic perspective is not always made explicit or analytically structured.

Differences are also evident in their mode-of-inquiry and how participants are engaged. Participation is foundational to systemic design, which relies on the involvement of system stakeholders to surface diverse perspectives and to build shared understanding of complex dynamics [32]. Speculative design, historically, has been more designer-led, with designers crafting artefacts or scenarios that invite interpretation and debate [21, 43]. While recent work has increasingly explored participatory speculative approaches [14, 19, 24], tensions remain between the expertise required to challenge dominant assumptions and the desire to democratise future-making.

Finally, the two approaches diverge in their primary purpose and outputs. Speculative design is oriented toward critical discourse, so its artefacts are intended to question values, expose assumptions, and provoke debate rather than propose immediately actionable solutions. Systemic design, by contrast, is more explicitly pragmatic, aiming to identify leverage points and inform interventions that can be implemented within existing systems

The complementary differences between systemic design and speculative design suggest an opportunity to combine these methodologies. The result is the Systemic Futures Dialogue, which carefully orchestrates systemic and speculative design activities and generates a novel output, **systemic future tensions**. Generated through the careful sequencing of the dialogue activities, designers structure their inquisition so that they follow the “golden thread” [7] of information; from micro insights in the present, to building macro-level system dynamics, extrapolating this out to imagine macro futures, then realising these as micro-level technologies. As a result, the tensions capture contradictions exposed by considering both the macro-level pragmatism and collaborative orientation of systemic design, with micro-level and critical designer-led speculation.

3 Introducing the Systemic Futures Dialogue

We introduce the Systemic Futures Dialogue (Figure 1), which integrates HCI traditions in speculative design with systemic design

practices. It provides a framework for designers and industry stakeholders to navigate the differences between systemic and speculative design in complementary rather than conflicting ways. In doing so, it offers a structured way for community representatives and HCI researchers to collaboratively examine how specific technologies may either disrupt or reinforce entrenched patterns of behaviour within sociotechnical systems. Finally, it responds to long-standing challenges in applying speculative design in industrial contexts [61] by providing a practical means for organisations to engage in critical reflection.

The framework was inductively generated from a reflection on the design work we performed with the AEC industry, drawing inspiration from research through design traditions [28, 62], and from existing literature that indicates an opportunity to combine macro-level methods from systemic design with HCI traditions in speculative design [10, 36]. Reflecting on our design process, artefacts, and existing literature helped us articulate what it means, in practice, to carry out systemic and speculative design in conjunction *with* industry participants. The Systemic Futures Dialogue captures these reflections.

We used the dimensions in Table 2 to motivate the Systemic Futures Dialogue. The framework is structured as a 2x2 matrix, which positions the different design foci along two axes: **present-future** on the *x* axis and **micro-macro** on the *y* axis. In each quadrant, particular design activities are carried out, sometimes in parallel or independently. Some quadrants adopt a more collaborative approach, inspired by systemic design, while others are more designer-led according to speculative design traditions. Researchers move in a 360-degree motion from the [present, micro] quadrant to [present, macro], across to [future, macro], which is then disrupted by critical debate in the [micro, future], feeding back into the [micro, present]. These steps can also be described as *Observe*, *Model*, *Extrapolate* and *Critique*.

The dialogue culminates in the final stage, *Reflect*, where designers compare outputs from the *Critique* phase to the pragmatic solutions developed in the *Model* phase. The result is a set of **systemic futures tensions**, which interrogate the consequences of the proposed systemic changes by identifying how their projected outcomes may be at odds with collectively desired futures. Once *reflect* is reached, researchers might start once again at *observe* to probe for a deeper understanding of the sociotechnical system if significant tensions are found between desirable futures and proposed systemic change.

3.1 Observe [Micro, Present]

The Systemic Futures Dialogue begins in the bottom-left quadrant of the framework, which represents a micro-level focus on the present. As is common in many design research traditions [37], the methods employed in this starting quadrant are oriented toward discovery and sense-making, with the aim of understanding the existing design space. These methods may include user interviews, ethnographic observation, contextual inquiry, diary studies, and desktop research, all of which seek to understand individuals' lived experiences with current technologies. Gathering these insights from a range of different actors in the system (e.g. in our AEC case

study, industry representatives from the regulatory bodies, commercial companies, unions, as well as educators) helps researchers develop an empirically grounded understanding of dynamics across the broader system. It is possible that different starting points in the dial exist, and we leave this open to the research team to decide according to the unique challenges they face.

3.2 Model [Macro, Present]

Moving to the second quadrant, **model [macro, present]**, the focus shifts from individual experiences to a system-level view of current conditions. Insights generated in the *observe* quadrant are synthesised to model how resources (e.g. knowledge, money, materials, or other forms of capital) flow through the system, and to identify *feedback loops* that reinforce or counterbalance existing behaviours. At this stage, a representation of the system is collaboratively created and validated with industry participants, and potential *leverage points* for positively influencing the system are identified.

A range of system-modelling techniques may be employed, including causal loop diagrams [57], systems mapping [31], stock-and-flow diagrams [44], leverage analysis [46], and gigamaps [53]. In practice, systemic designers often rely on the systems mapping process articulated in the systemic design toolkit [32]. This involves a collaborative approach to mapping out the variables and causal loops in a system, then identifying. By doing so, researchers can zoom out to see how challenges that appear discrete at the micro level are interconnected. Working in the [macro, present] quadrant makes visible how interventions in one part of the system may generate unintended consequences (both positive and negative) elsewhere, supporting more informed and responsible design decisions.

3.3 Extrapolate [Macro, Future]

In the third quadrant, **extrapolate [macro, future]**, insights from the preceding quadrants are used to collaboratively imagine alternative futures at the level of the whole system. Here, the present-day system is placed into hypothetical conditions to explore how its structures, relationships, and feedback loops might evolve, intensify, or break down over time. Rather than predicting outcomes, this quadrant focuses on extrapolating existing dynamics to examine their potential consequences under different future conditions.

Futuring frameworks such as the Futures Cone [25], which distinguishes between probable, plausible, possible, and preposterous futures, or Candy's Future Arcs [11], which consider trajectories of growth, collapse, discipline, or transformation, might be used to structure this exploration. These frameworks help designers systematically extend present-day trends into alternative system-level futures. The resulting scenarios may take the form of narratives, storyboards, or other high-level representations that describe how work, practices, or processes unfold in the extrapolated future.

Crucially, these future-based scenarios are grounded in the system dynamics articulated in the **Model [macro, present]** quadrant. They are generated by asking "what if" questions about how the identified feedback loops might respond to changes introduced at different leverage points. For example, how a reinforcing feedback loop might shift if a leverage point identifying new government

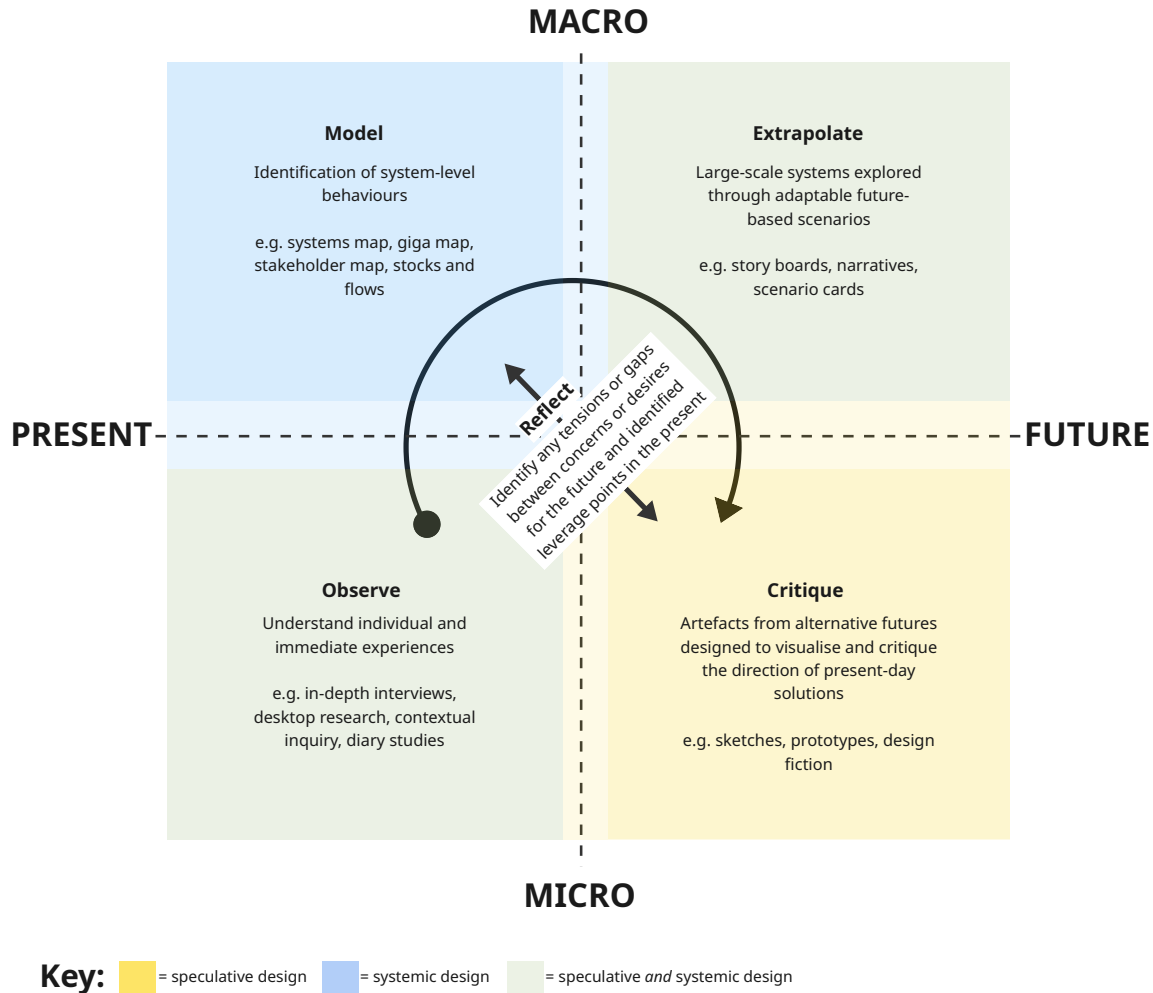


Figure 1: Using the Systemic Futures Dialogue, design practitioners move between observe > model > extrapolate > critique > reflect. The output of each quadrant informs the next, building a multi-layered approach that considers both macro systemic trends and micro opportunities to actively shape the future through the present.

policies is pulled to accelerate technology adoption. As a result, the scenarios remain deliberately macro in scope, focusing on systemic patterns rather than individual interactions.

This quadrant draws on both systemic and speculative design traditions. From systemic design, it inherits a concern for coherence and continuity with present-day dynamics; from speculative design, it adopts an orientation toward imagining futures that may extend beyond strict plausibility in order to surface values, desires, and points of critique. In doing so, the *extrapolate* quadrant enables designers to reflect critically on present-day actions by examining their long-term systemic implications.

3.4 Critique [Micro, Future]

In the final quadrant, **Critique [micro, future]**, the system-level futures developed in the previous **Extrapolate [macro, future]** quadrant are translated into micro-level interactions with specific,

imagined technologies. Here, speculative artefacts are created to depict how individuals might interact with these technologies within the future worlds articulated by the scenarios. This quadrant draws most strongly on speculative design traditions, and the artefacts may take a variety of forms, including sketches, low- or high-fidelity prototypes, and design fictions such as artefacts from the future (e.g. newspaper clippings, policy documents, or product advertisements).

We propose that the creation of these speculative artefacts is primarily led by the design researcher, drawing on their design experience to craft artefacts that are conceptually provocative. However, crucially, these artefacts are not developed in isolation and are informed by the participatory insights generated in earlier quadrants. One of the aims of the Systemic Futures Dialogue is to ground designer-led speculative design in participatory insights of the system, developed through systemic design activities.

Once created, the speculative artefacts can function as probes that are reintroduced to participants to elicit reflection and discourse. Participants are invited to discuss whether these imagined technologies align with or challenge their desired futures and why this is so. To be effective, the artefacts must “strike a balance between creativity and methodology rigour” and encourage discourse that surfaces underlying values rather than prompt affirmative design qualities that focus on problem solving or increasing consumption [50]. These discussions enable critical reflection about how future technologies inform everyday practices and societal norms.

3.5 Reflect [tensions between Micro-Future and Macro-Present]

Finally, by looking diagonally across the **Critique [micro, future]** and **Model [macro, present]** quadrants, researchers can instigate *reflection* between future-oriented critiques and present-day system dynamics. This reflection focuses on interpreting what the critical discourses elicited by speculative artefacts imply for the leverage point solutions identified in the current system.

This reflection phase generates **systemic futures tensions** that articulate the trade-offs between participants’ desires for the future and the actions or interventions that appear most feasible or influential in the present. Importantly the tensions do not emerge simply undertaking systemic design and speculative design as separate activities. The systemic futures tensions are informed by both the forces at play within the system and speculative critique, through careful sequencing that helps the designer *move between micro and macro perspectives*, as well as *pragmatic and critical perspectives*. This makes it possible to identify the contradictions between macro-level systemic change and the micro-level materialisation of this change, as technologies sent from the future. The practical reality of examining the proposed solutions, helps to surface aspirations that may be at odds with the more abstracted [macro, present] propositions for systemic change, exposing where solutions require deeper investigation.

For example, industry leaders may identify leverage points that *prioritise productivity* in the present system, while simultaneously expressing a desire for futures that *avoid burn out*, from constantly churning out products at an increased pace. Rather than treating such tensions as problems to be solved, we invite researchers to examine whether present goals and future desires are genuinely incompatible, to explore why they might conflict, and to consider how present-day actions need to change to create a future that balances the values and needs of diverse actors within the system.

4 Case Study and Design Approach

In this section, we illustrate our approach through a project that used the Systemic Futures Dialogue to investigate future work practices in the Architecture, Engineering and Construction (AEC) industry.

4.1 Challenges in the Architecture Engineering and Construction Industry

Globally, the AEC industry is essential for creating and maintaining infrastructure that supports basic human needs. However, the

industry has come under increased scrutiny due to a lack of sustainability, safety and productivity improvement. The perceived stagnation of the AEC industry across different work facets has attracted interest in how “Industry 4.0” innovations can improve the way work is done. Although Industry 4.0 has varying interpretations [34, 45, 48], we broadly define it as a technological and organisational transformation resulting from advancements in digitally powered inventions [34].

Digital innovation has also supported the development of new work methods and processes. One prominent area, generally referred to as Modern Methods of Construction (MMC), encompasses a broad range of innovations, most of which aim to move construction work from onsite to offsite factories [49]. MMC is a system that involves product innovation (e.g. panellised walls), innovation to processes (e.g. lean logistics), digital tools (e.g. BIM), changes involving integrating design with manufacture, and an integrated supply chain. It includes approaches like modular building and prefabrication [49], where standardised sections, such as entire bathrooms or individually fabricated parts, are built in a factory before being transported and installed on the construction site. These approaches are attractive as they “offer potential for reductions in cost, time, defects, health and safety risks and environmental impact and a consequent increase in predictability, whole life performance and profits” [59, p. 1]. While concepts like prefabrication date back to London’s Crystal Palace in the 1850s, Industry 4.0 technologies, particularly robotics, have made it more feasible to scale these approaches and heralds the beginnings of industrialised construction that adopts a factory driven process of production with a revised set of skills and capabilities for its workforce.

Although Industry 4.0 has been regarded as an opportunity for innovation in the AEC industry, there are several challenges to its adoption. The most critical issues include access to training programs that includes relevant technologies and new production methods, mental health and wellbeing, shortages of skilled labour, cost of technology investment, devaluation of traditional skills, fragmented services and project processes, as well as legal and regulatory barriers [15, 54]. These challenges are **systemic**, meaning they have multiple factors across different entities and groups of people across the industry that influence them. For example, access to training is impacted by various social factors, including government funding, paid time-off for workers, cost of educational resources, awareness of programs and availability of qualified instructors. Since systemic issues are often ambiguous and slow to evolve, progress toward meaningful change has not been as rapid as some expected [48, 54]. With looming societal pressures, like a global housing crisis, the AEC industry is under pressure to address these challenges and see improvements as a collective.

4.2 Case Study Research Objectives

This 18-month case study examined how emerging technologies may shape future work practices in the building and construction industry, with a particular focus on what makes technological interventions desirable for both workers and organisations. Working with industry partners across commercial construction, building services, prefabrication, regulation, education, and labour unions,

the study aimed to surface the systemic forces that enable or constrain innovation and to identify future opportunities for improving working conditions and productivity.

Specifically, the case study sought to: (1) explore how emerging technologies may impact future work practices and working conditions across diverse roles and skill levels; (2) inform strategies for managing transitions in work practices associated with technological change; (3) examine implications for skills, training, and workforce development, including risks of deskilling and challenges of attracting, retaining, and transitioning skilled workers; and (4) identify how technological adoption might be leveraged to enhance productivity while supporting fair and sustainable industrial relations.

4.3 Participants

The project involved 17 representatives from different areas of the architecture, engineering, and construction (AEC) industry. In Appendix A.1, we provide an overview of the participants' backgrounds and their involvement across the various phases and steps of the project. These participants represent a diverse cross-section of specialisations, which helped us gather information about the AEC industry and test our ideas from a variety of different angles. Before the research phase, participants were asked to review a plain language statement and sign a consent form. Participants were not reimbursed for their participation, since the research was sponsored by their organisation and carried out during their regular working hours.

4.4 Method

We developed the Systemic Futures Dialogue as an approach to identify the system-level influences across the AEC industry and to critically engage with future possibilities of work practices. A summary of the method's phases and steps is shown in Figure 2.

4.4.1 Observe [Micro, Present] - Interviews and Desktop Research.

We began with semi-structured interviews with industry representatives (n=9) from regulatory, commercial, and education sectors within the AEC industry. The interviews were informed by desktop research of the issues facing the AEC industry and addressed three broad areas: (1) The primary concerns regarding the impacts of Industry 4.0; (2) How they are responding to the concerns; and (3) What new technologies are likely to be introduced and any expected challenges from their use. Each interview lasted approximately 90 minutes.

Interviews were transcribed and analysed using Dovetail² followed by Reflexive Thematic Analysis (RTA) [16]. Analysis was conducted inductively by the first author, who drew on both the desktop literature and prior experience working in organisational contexts. The process involved familiarisation with the data, line-by-line coding, and iterative clustering of codes into themes. To support reflexivity and grounding, these themes were reviewed and discussed with industry stakeholders (n=6), who contributed their own interpretations of the findings. This phase generated foundational insights into subjective present-day concerns and priorities, which informed subsequent design activities.

²<https://dovetail.com/>

4.4.2 Model [Macro, Present] - Systems Map.

To develop a macro-level understanding of the AEC industry, we constructed a systems map representing the industry as a sociotechnical system. We adopted a systemic design approach that emphasises practical sense-making and visual synthesis. In particular, we followed the Systems Mapping Academy's toolkit³ to create a representation of the system as it exists today.

The systems map was initially developed by the first author and validated by industry stakeholders (n=6). The process began by defining the system boundaries, focal challenges, and guiding research questions, drawing on findings from the *Observe [micro, present]* phase. We then identified key variables, which are nodes within the system representing tangible or intangible resources (e.g. levels of skill, capital, wellbeing, or regulation), and mapped causal relationships between them. These relationships indicate influence rather than sequence, distinguishing the map from a process or flow diagram.

Variables and relationships were refined through multiple iterations until the research team agreed the map captured the system's key dynamics. Reinforcing and balancing feedback loops were then identified and analysed. Finally, the research team collaboratively identified thematic regions within the map and developed narrative descriptions to communicate how different parts of the system interact. The map was validated and refined based on feedback from industry participants.

4.4.3 Extrapolate [Macro, Future] - Scenario-Based Design.

Building on insights from *Observe [micro, present]* and *Model [macro, present]*, we developed a set of future-based scenarios to explore how the system might evolve under different conditions. Scenario development was structured using Candy's Future Arcs [11], which articulate four possible trajectories: continuation of current trends, discipline through regulation or incentives, transformation through new technologies, and systemic collapse requiring radical change.

Each scenario examined how different regions of the systems map might shift under these conditions, with particular attention to the implications for workers' pains and gains. These scenarios were co-developed with industry stakeholders in a participatory workshop (n=8) and iterated based on their feedback. These scenarios focussed on systemic patterns rather than specific technological interactions.

4.4.4 Critique [Micro, Future] - Speculative Probes.

Drawing on the scenarios generated in *Extrapolate [macro, future]*, the research team developed a set of speculative probes depicting micro-level interactions with imagined future technologies. These artefacts were intentionally designer-led, and developed within the HCI research team to leverage design expertise to create artefacts that balance provocation and plausibility. In later sections, we reflect on this choice and its implications for integrating systemic and speculative approaches.

The speculative probes were generated through a 1.5-hour ideation workshop, in which the research team used the scenarios as prompts to imagine technologies and practices associated with each future

³<https://www.system-mapping.com/>

Key: = speculative design = systemic design = speculative and systemic design

RESEARCH PHASE	1) OBSERVE [MICRO, PRESENT]		2) MODEL [MACRO, PRESENT]	3) EXTRAPOLATE [MACRO, FUTURE]	4) CRITIQUE [MICRO, FUTURE]	5) REFLECT [MICRO FUTURE] + [MACRO PRESENT]		
APPROACH	Systemic Design and Speculative Design		Systemic Design	Systemic Design and Speculative Design	Speculative Design	Systemic Design and Speculative Design		
STEPS	1.1	1.2	2	3	4	5.1	5.2	5.3
RESEARCH METHOD	One-on-one semi-structured interviews and desktop research	Research insights validation	Systems mapping	Future based scenarios generated in a participatory workshop	Speculative design	Leverage points identification + desirable/undesirable futures identification [actual timing] • Leverage points • Desirable + undesirable futures	Affinity mapping (comparing leverage points and desirable + undesirable futures) Draft Design Tensions	Design tensions validation Validated Design Tensions
OUTPUT	Draft research insights	Validated research insights	Systems map	4 x Future-based scenarios	8 x Speculative probes (2 per future-based scenario)			
PARTICIPANTS	P2, P5, P6, P11, P13, P14, P15, P16, P17 (n=9)	P1, P2, P5, P6, P11, P12 (n=6)	P1, P2, P5, P6, P11, P12 (n=6)	P1, P2, P3, P5, P6, P11, P12, P13 (n=8)	N/A	P1, P2, P3, P5, P6, P7, P8, P9, P10, P11, P13 (n=11)	N/A	P1, P2, P3, P4, P5, P6, P11, P13 (n=8)
PARTICIPATION APPROACH	Designer-led	Participatory workshop	Designer-led / participant validated	Participatory workshop	Designer-led	Participatory workshop	Designer-led	Participatory workshop
REFLECTIONS FOR FUTURE APPLICATIONS	The semi-structured interviews and desktop research insights informed the dynamics captured by the systems map in the model phase.		The systems map was created by the research team and validated by participants. Future research might examine creating the systems map with more participatory methods as suggested in [29].	The feedback loops identified in the systems map from step 3 helped to inform the future-based scenarios. It was possible to ask participants to imagine what might happen to these feedback loops if the system was placed under different pressures or constraints.	The design experience of the research team made navigating the balance between plausible futures and challenging critique approachable. However, these designs were still informed by input from earlier participation with industry representatives. On reflection, we believe this can help to strike a balance between design expertise and providing opportunities for input.	Due to time constraints, the leverage points and desirable/undesirable futures were identified in step 5.1. Ideally the leverage points would be identified after step 3 and desirable/undesirable futures after step 4, which we discuss in the limitations.	Looking across the Systemic Futures Dialogue it is possible to see tensions between the ideal future, proposed leverage points, and how technologies at the micro level instantiate these ideas. These tensions help to identify opportunities for future empirical research, helping sociotechnical systems actively build a desired future in the present.	Although the affinity mapping was carried out by the design team, it might be that future work does this in participation with industry representatives. Ultimately it is important for industry representatives to review and validate the final tensions that set the stage for future research.

Figure 2: Summary of methods and participants involved in each design stage of the case study.

trajectory. Using a diverge-converge process, researchers first generated ideas individually before collectively discussing and refining them. Selected concepts were then further developed by the lead researcher into speculative sketches. The speculative probes were introduced to AEC industry stakeholders (n=11) in a participatory workshop. Participants discussed what they found desirable or undesirable about the probes and reflected on the values and assumptions embedded within them.

4.4.5 Reflect - Affinity Mapping.

In the final collaborative workshop, industry participants (n=11) reviewed the systems map, future-based scenarios, and speculative probes. Participants first identified leverage points within the present-day system and proposed potential interventions. The workshop participants then worked in groups to discuss the scenarios and speculative probes, documenting what they perceived as desirable or undesirable in each future. The four-hour workshop was conducted in a hybrid format, with contributions captured through a combination of physical and digital sticky notes. Using affinity mapping, the leverage points and desirable or undesirable futures were summarised by the lead researcher post workshop.

Written data from the workshop was analysed using affinity mapping. Notes related to present-day system interventions and future-oriented reactions were clustered separately and thematically analysed. The research team then compared themes across the macro-present and micro-future perspectives, resulting in the identification of three core **systemic futures tensions**. These tensions articulate points where present-day opportunities for change conflict with participants' desired futures. These tensions are a

important generative output of the Systemic Futures Dialogue, capable of structuring future research agendas focused on navigating and reconciling systemic trade-offs. These design tensions were then validated in meeting with industry representatives (n=6).

4.5 Positionality Statement

This research was conducted as part of a collaboration between The University of Melbourne and the Building 4.0 Cooperative Research Centre (CRC), an industry-led initiative focused on advancing technological capability and working conditions in the Architecture, Engineering, and Construction (AEC) industry. The interdisciplinary research team comprised of scholars from human-computer interaction (HCI), labour relations, and AEC domains, informing both the framing of the research problem and its interpretation.

The first author identifies as a woman with a background in co-design, HCI, and management consulting in both IT and AEC-adjacent contexts. While she had prior experience working with AEC clients, she had not worked directly within the industry, positioning her as a partial outsider. This influenced the study in several ways: it required participants to articulate domain-specific practices and assumptions, while also enabling critical distance in questioning norms. Her professional experience informed the design of participatory activities and speculative artefacts, as well as the interpretation of participants' responses. Additionally, her personal experiences being in a cultural and gender minority within male-dominated workplaces sensitised her to issues of inclusion and belonging, though it may have limited her ability to fully interpret gendered experiences outside her own.

The second and third authors identify as men with extensive experience in the AEC industry, contributing insider perspectives on industry practices, constraints, and values. Their involvement supported the contextual grounding and validation of interpretations. The fourth male author, also identifying as a man, and brought expertise in industrial relations, shaping our analysis of labour dynamics, regulation, and power structures. The remaining authors (two identifying as men and one as a woman) have backgrounds in HCI and human–robot interaction, contributing expertise in technological design and interactional analysis.

The combination of insider and outsider perspectives shaped the formulation of research questions, the design of artefacts, and the interpretation of findings. In line with Reflexive Thematic Analysis (RTA) [16], the findings are understood as co-constructed through the interaction between participants' accounts and the first author's professional and experiential perspective, since they carried out any initial coding of verbal or written data. The other co-authors also brought their own positions to bare on the data, helping to refine the final artefacts and design outputs, from different insider and outsider perspectives.

Power dynamics were present in multiple forms. Participants, as industry professionals, held domain expertise, while researchers shaped the structure of engagement and interpretation. Additionally, the project was funded through an industry–academic partnership. While academic researchers retained autonomy over research design and artefact development, industry researchers made valuable contributions to defining research directions and priorities. This collaboration informed and constrained the speculative outputs. Whilst the research aimed to investigate the intersection of critical provocation with practical relevance (in line with prior work on speculative design [1, 51]), it is possible that the industry–academic collaboration led to more plausible speculative scenarios.

5 Results

In this section, we report on the findings in each stage of the case study. We present the artefacts and the knowledge they generated, reflecting on how this knowledge iteratively informed each subsequent stage of the research process.

5.1 Observe [micro, present]

The reflexive thematic analysis of the academic expert and stakeholder interviews surfaced several key themes that address to the major concerns and priorities in today's AEC industry:

- (1) **SKILLS: There is demand for skilled workers and a push for greater workforce diversity.** A shortage of skilled labour is driving up project costs, while ongoing diversity and inclusion challenges limit recruitment from a broader talent pool of diverse abilities, experiences, and identities.
- (2) **TOOLS & PROCESSES: There is inconsistent adoption and interoperability between tools and processes.** Although various digital tools and processes are being used across the industry, a lack of integration leads to fragmented data, inefficient information sharing, and record inconsistencies.
- (3) **POLICY & CULTURE: The AEC industry has many different actors with competing interests, levels of digital**

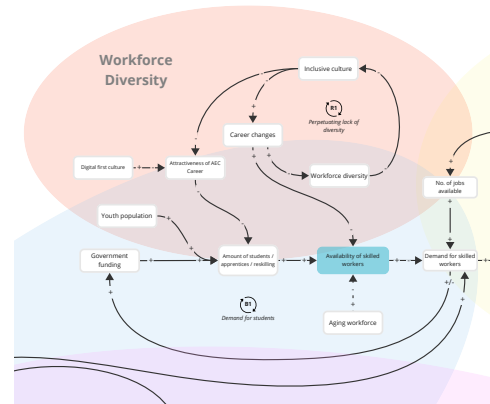


Figure 3: Section of AEC Systems Map showing selection of variables, reinforcing loops (R1) and balancing loops (B1)

maturity, and appetite for change. While these differences make it challenging for people to collaborate, the right policy and culture development can emphasise and support their common goals.

- (4) **VALUES: Sustainability, safety, and quality are core shared values in the AEC industry.** In an environment with competing agendas, reducing carbon emissions, improving worker safety and maintaining output quality are shared goals across the AEC industry.

5.2 Model [macro, present]

The output of this stage was a systems map and a set of region stories, which provide a macro representation of the present-day AEC sociotechnical system. The complete systems map is very large, and shown in a compressed format in the supplementary material (Appendix A.2). A section of the systems map (which is more legible) is shown in Figure 3. The figure illustrates key components of the system map, including variables, feedback loops, regions, region stories and leverage points, which come together to create a rich understanding of AEC sociotechnical systems.

The variables are individual nodes in the systems map and capture the movement of resources or value in the system. For example, “amount of money to build a home”, “available skilled workers” or “amount of building contracts” are all relevant variables. Insights from observations, interviews and relevant prior literature are used to connect the variables, with arrows showing how the different variables positively or negatively influence each other.

Once the variables are mapped, feedback loops are identified. Feedback loops exist where actions in one area, such as a new technological breakthrough or a policy change, can have cascading effects on others [44]. Two types of feedback loops were identified. **Reinforcing loops [R]** connect variables that amplifies a pattern same direction (e.g. in Figure 3 R1: a lack of diversity in the industry creating a culture where recruits from different backgrounds feel unsupported, leading to a reduced pool of potential employees and continued pressure on the current workforce) and **Balancing loops [B]** show flow of variables that create equilibrium (e.g. in Figure 3 B1: as the demand for workers increases, government

funding encourages more students to join, this is balanced by an ageing population who retire from the industry or those who leave the industry).

Once all the feedback loops were named, the research team then identified regions on the systems map that tell a story about the dynamics in the AEC industry. These regions include: *workforce diversity*, *cost of building homes*, *education and reskilling*, *external forces for change*, *awareness and access to new knowledge and tools*, and *interoperability and information sharing* (shown as coloured regions in Appendix A.2)

In the participatory workshop, industry stakeholders identify opportunities for change for each region, also known as “leverage points” in systemic design practice [31]. A summary of these leverage points can be found in Figure 4. Using affinity mapping these leverage points were placed on the systems (Appendix A.2).

Leverage Points	
System Map Regions	Workforce diversity • Offer jobs and tools that support a diverse workforce • Offer additional support with mentorship networks • Keep going with government mandates and reward diverse recruiting
	Cost of building homes • Standardise building approaches and promote modern methods of construction (MMC) to increase productivity • Influence metrics to drive innovation and productivity • Government and industry leadership for standardising building approaches
	Interoperability and information • Encourage early contractor involvement • Measure success of digital tools and share knowledge • Everyone knows a bit of construction management • Encourage a competitive market that plays an infinite game
	Education and reskilling • Upskilling made easier through opportunities like micro-credentials • Mentorship and purpose-designed education • Standardisation and assessment of new skills
	Awareness and access to new knowledge and tools • Innovation cost cuts for small to medium businesses to increase access (ability to wear the costs and increase the margins) • Build awareness of new tools through the education system • Encourage adoption with show not tell and gamified approach
	External forces for change • Share knowledge and demonstrate value of innovation • Mandates for innovation • Reward innovation • Government backed modern methods of construction

Figure 4: Leverage points, showing aspects of the AEC systems that could be modified to significantly influence another part of the system.

The systems map visualises the interconnected challenges at the macro level. It highlights how efforts to “solve” one challenge can unintentionally create negative impacts elsewhere. This awareness of consequences allowed us to think critically about how the system might respond under different conditions, laying the groundwork for future-based scenarios in [macro, future]. For example, without adequate support for education and awareness, introducing new technology to address a shortage of skilled workers could actually reinforce this scarcity, as current trends show that small and medium-sized businesses may struggle to keep up with the cost of upskilling and acquiring new technologies and processes. By visualising these interconnected macro issues, the systems map enabled us to tell a more complete story about how the system might respond to change and to imagine alternative futures in our scenarios.

5.3 Extrapolate [macro, future]

We created four future-based scenarios, informed by the insights generated from the first two quadrants of the Systemic Futures Dialogue (*Observe [micro, present]* and *Model [macro, present]*). The scenarios were informed by micro-level insights from industry participants on the use of technologies in work practices, as well as a macro-level understanding of how industry challenges interact. A copy of each scenario can be found in the supplementary materials.

5.3.1 Scenario 1 (probable) - Artificial intelligence (AI) pushes innovation, for some.

This scenario (Figure 5) simulates a probable future, where we continue on as-is [11], and AI is one of the few changes that impact the system. In this future, it is assumed that present reinforcing loops such as, “a lack of funds and resources to upskill workers” (R2), “perpetuating knowledge gap” (R3), “low adoption reinforces a lack of experience and infrastructure for change” (R6) and “low evidence for tech adoption success” (R7) are strong enough to delay the movement toward modern methods of construction. In this world, onsite manual processes are unlikely to change.

However, in this scenario, large investments in AI can’t help but impact the AEC industry in other ways. Upstream ‘knowledge work’ is accelerated (B3) by the introduction of AI design tools like building information modelling (BIM). Repetitive design tasks are automated, but new challenges are created. For example, upskilling staff in critical thinking skills and evaluative processes to reduce the risk of AI hallucination errors. Unfortunately, the acceleration of upstream services is not enough to reduce the cost of building homes. Unaddressed reinforcing loops like a “self-perpetuating lack of diversity” (R1) means the availability of skilled workers remains low, negatively impacting the ability to deliver projects on time and under budget (R8). In response, there are attempts to disrupt the industry (R5). However, the introduction of new digital applications only fragments the suite of tools further, leading to information inconsistencies (R8), increased administrative tasks and licencing fees.

5.3.2 Scenario 2 (plausible) - Government backs pre-fab.

This scenario (Figure 6) uses the idea of a system under government ‘discipline’ [11] to imagine a future where pre-fab becomes the norm, aided by government policy. In this future, the government takes extreme measures to support the growth of prefabrication work in off-site warehouses. Doing so circumvents existing issues that heighten the perceived risk of technology and process adoption (R4, R5, R7). Government-backed investment in specific technologies and education also aims to ensure the streamlined technology adoption by circuit-breaking the “perpetuating knowledge gap” (R3), “lack of funds and resources to upskill” and “siloes tech and work processes”.

In this future world, there are more job opportunities for people with different abilities and skill levels, which takes the pressure off demand for skilled workers (R8). A steady flow of contracts and available workers offsets the cost of technology investment required for prefabrication work (R8). The controlled warehouse environment supports incremental improvements, minimising waste, over-ordering, and improving project efficiency. However, a drastic shift toward prefabrication is not without its challenges. Although

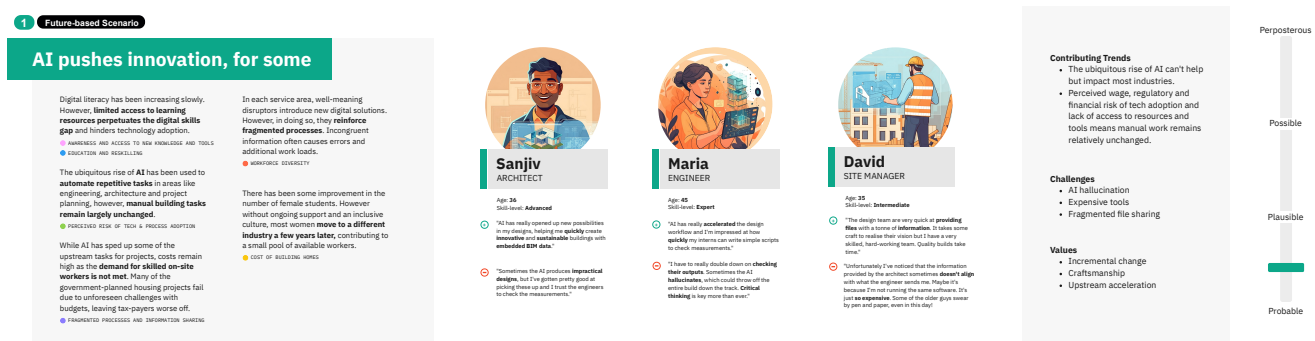


Figure 5: Scenario 1: Describes a probable future where AI impacts the AEC industry, albeit for upstream services like architecture and engineering only. This scenario speaks to the importance of awareness and education, critical thinking skills and a cohesive approach to technology implementation, one that considers adjacent issues like the need for information interoperability, workforce diversity and a desire for physical, outdoor trades.

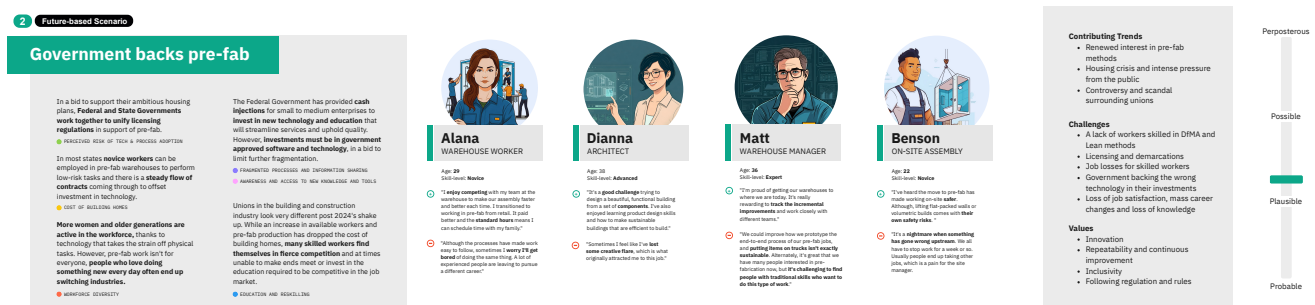


Figure 6: Scenario 2: Describes a plausible future the government brings in policies to back prefabrication methods of construction. This scenario captures the blockers for prefabrication, such as perceived risk of technology investment and access to education, as well as the benefits and risks involved.

the government provides opportunities for reskilling and education, off-site manufacturing is not for everyone. Those who love the outdoors, highly tactile or creative work may consider switching industries, further reducing the number of workers with traditional skills (R8). This could negatively impact the ability to pass on tacit learning experiences in traditional skill areas, leading to issues in end product quality and safety. In addition, on-site assembly presents its own challenges, such as transporting larger materials, particularly in volumetric prefabrication.

5.3.3 Scenario 3 (plausible-possible) - Everyone a subcontractor.

In this scenario (Figure 7), the system is 'transformed' [11] and everyone in the AEC industry becomes a subcontractor in this plausible-possible future. Pulling this lever highlights some of the subcontracting challenges in the system. One of the obvious challenges of subcontracting is the uncertainty around who will pay workers' superannuation, sick leave and other fair work benefits (RS5). Scenario 3 suspends this challenge, moving beyond it to explore the benefits and risks in a world where worker benefits are guaranteed by the subcontracting platforms.

Whilst there may be some deleterious effects, there are some clear positives in this scenario. Subcontractors are more likely to stay in the industry, as they feel supported to live a balanced life and

do their best work. They have the flexibility to manage their work schedule around their home life and can know ahead of time if a job is ready for their services or what the availability of workers is for their project (R8). The movement to digital also attracts a younger audience accustomed to managing their lives through digital platforms (RS2). However, this transformed world also comes with its risks and limitations. In particular, the reinforcing loop "siloeled tech and work processes" (R8) in theme 6 "interoperability and information sharing" is heightened (RS6). The variety of platforms, along with ever-changing teams and workers, makes it even more challenging to maintain information continuity during projects. To improve accountability, the platforms introduce rating systems, which create new power imbalances between workers seeking good ratings and their contractors. While the decentralisation of home building gives customers greater cost-effective flexibility, it also leaves them more exposed to risks without appropriate specialised knowledge in building codes and processes.

5.3.4 Scenario 4 (possible) - Climate crisis and global conflicts force change.

Scenario 4 (Figure 8) imagines the AEC industry under 'collapse' [11], where climate change and global conflict completely disrupt the ability to create and maintain the built environment. In this

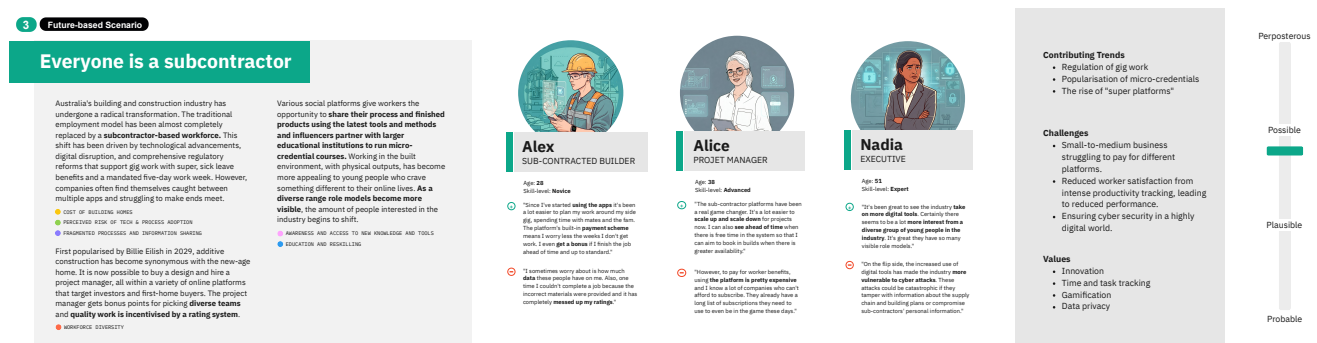


Figure 7: Scenario 3: Describes a plausible-possible future where the industry is transformed and everyone is a subcontractor. This scenario suspends present day challenges for worker benefits and helps the reader to imagine alternate pros and cons of a world where subcontracting is the norm.



Figure 8: Scenario 4: Describes a possible future where climate change and global conflict have reached an apex, completely disrupting the ability for workers to create and maintain the built environment. This scenario situates the reader in a environment where actors have adapted to a system in collapse and extremes as the new normal.

world, climate change and global conflict make it nearly impossible for the system to function in its current form.

In this state of emergency, many of the current reinforcing loops are circumvented. For example, feedback loops (R4, R5, R7, B2, B3) in external forces for change (RS5) would likely shift since the adoption of new processes and technology becomes imperative for maintaining and building homes to keep people safe and healthy. The cost of building structures (RS1) would likely become so inflated that the system has no choice but to find innovative ways to upskill people and find new ways to build and maintain homes more cheaply. Challenges with workforce diversity (R1) become almost irrelevant since anyone who can help in this disaster situation will.

Using scenarios to place key aspects of the system into alternative futures allowed us to interrogate how feedback loops might be reinforced or altered. This provided macro-level insights into the system, which we used to create speculative probes that critique various approaches to change. For instance, Scenario 1 explores the challenges the AEC industry could face if it continues along its current path while becoming increasingly influenced by AI. It demonstrates how, without educational support, the introduction of more digital tools could diminish quality and exacerbate the skills gap, further damaging the system. By projecting how the system operates today into the future, we can identify potential areas for critique in the [micro, future] phase.

These future-based scenarios were developed collaboratively with stakeholders, a key element of the project. While the speculative probes in [micro, future] were created by designers, they were largely informed by the scenarios developed through industry collaboration. This approach helped balance the top-down nature of speculative design with the recognition that designers bring valuable tacit knowledge and skills essential to carrying it out.

5.4 Instantiate [micro, future]

The future-based scenarios informed a series of speculative probes, developed by the academic team. Each scenario had two probes. These probes served as micro-level instances of the scenarios, incorporating speculative characteristics that provoke critical reflection.

5.4.1 Speculative Probes for Scenario 1 (Artificial Intelligence (AI) Pushes Innovation, For Some).

The first probe NextCraft (Figure 9 left), is an augmented reality (AR) device that can be attached to a pencil. It captures the juxtaposition of valuing the tangible aspects of a trade's craft and the pressure from outside forces to automate and digitise work. The pencil can be used to draw, measure and visualise building plans on handcrafted materials, while the AI attachment uses computer vision and voice activation to make work processes faster and document how materials have been installed.

The second probe GEN4BUILD (Figure 9 right), is a prompt engineering resource for architects and engineers. It speaks to current views that upstream knowledge work is an obvious area where AI will probably automate tasks and compensate for more challenging areas to automate, such as on-site work. However, mistakes in how the building is visualised capture the potential for AI to hallucinate and get things wrong. The artefact asks how the desire for speed will impact architecture and engineering, and what checks and balances may be needed.

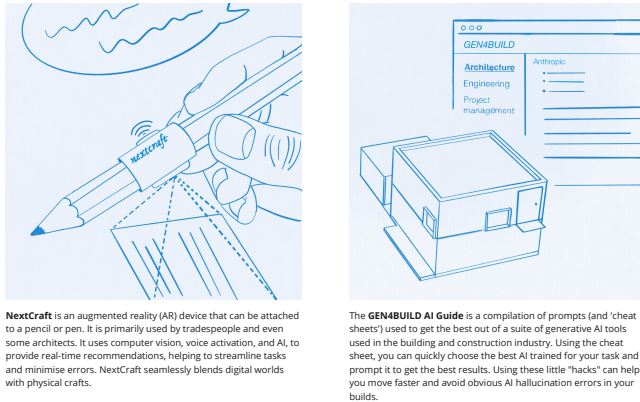


Figure 9: Scenario 1 Probes - NextCraft (left) is an AR and AI device that can be attached to a pencil and used by trade workers onsite. GEN4BUILD (right) is an AI Guide, a prompt engineering cheat sheet for architects and engineers.

Participants in the participatory workshop (n=3 of 11) felt the probes made them consider values such as safety (P2), efficiency (P1, P3), quality and error minimisation (P1, P2), maximising the potential of technology (P2) and interoperability (P3). Interestingly, interoperability was not a value we intentionally sought to reflect in the probes. The stakeholders viewed the probes as both desirable and undesirable. P3 highlighted concern that AI would erode traditional skills and creativity.

P3: “Undesired: general deskilling in traditional [techniques] [...] and [it will] theoretically stymie creativity and innovation.”

They noted the changes depicted are “underway” and “inevitable”, which validates the probable world in scenario 1 if the system were to continue on as-is and relatively unchanged.

P2 raised concerns that AI would increase distrust in technology and said the probes would be undesirable “[...] if the speed of solutions doesn’t keep up with change [in the industry]”. By this, they mean a mismatch between the AI solutions available and the way industry fundamentally operates, which has been a sticking point for the implementation of digital technology in the past. Conversely, P1 noted many desirable aspects of the probes.

P1: “Desirable! better design, improved efficiency, improved outcomes (energy, carbon, circular economy)”

P2 also noted that the probes were desirable since they had the potential to “attract younger generations into the industry”, which

speaks to the current challenges faced with a shortage of skilled workers.

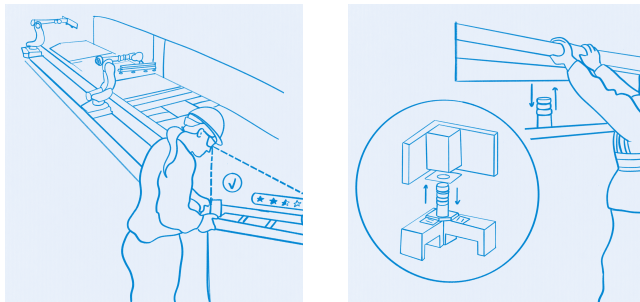
When tracing how the world would change in response to the probes, participants mostly responded to AI as a collaboration partner. P2 noted that education would need to cover “error checking” and “critical thinking”. Similarly, P3 believed that there would need to be a stronger focus on “design management”.

5.4.2 Speculative Probes for Scenario 2 (Government Backs Pre-fab).

The first probe *Lean On* (Figure 10 left) is a projection game that aims to stimulate workers in a prefab environment. The probe shows a female worker and robots, seeding a dialogue about who will staff these off-site warehouses. It also comments on an existing sentiment that a move to off-site manufacturing-style construction will remove the kind of craftsmanship and problem-solving involved in traditional on-site jobs. In other words, people fear this work will be boring. However, *Lean On* brings to light a different type of problem-solving encouraged by Lean production, where workers aim to improve their approach over time and find better ways to complete a task. The projection game asks what might happen if this approach to problem-solving is brought front and centre. Of course, this attempt at positivity could be cast in a dystopic light if workers are encouraged to be efficient at all costs.

The second probe *Click-in Parts* (Figure 10 right), shows what the assembly of a building might look like onsite in a fully pre-fab world. It conjures past experiences viewers will likely have of building Ikea furniture. On Reddit, there are those who view the modular approach as a fun activity or “Lego for adults”⁴, which tellingly is also published on the r\ “unpopular opinion” page. This assembly approach intends to raise questions about what processes and policies will look like. Of course, there are building companies that already do this kind of assembly work, but how will their knowledge and best practices be utilised if we were to mandate production tomorrow?

⁴https://www.reddit.com/r/unpopularopinion/comments/v2oh5a/building_ikea_furniture_is_fun/



Lean On is a projection game that aims to stimulate motivation in pre-fab construction work. It has two settings that you can choose from, *personal best* and *explore*. In *personal best* mode, you can compete with yourself or others to get the best possible time and quality rating for your construction task. Alternately, in the *explore* mode you can follow a new challenge every day and enjoy a variety of different problems to solve. **Lean On** has opportunities to level up no matter how you prefer to work.

Click-in parts makes pre-fab assembly easy. Inspired by Ikea, you can use these parts in your pre-fab construction to streamline and simplify the materials needed for assembly. With a specific set of standardised parts, it is easy to find replacements, disassemble and recycle buildings.

Figure 10: Scenario 2 Probes - Lean On (left) is a projection game built to motivate workers for offsite work. Click-in parts (right) illustrates the modularity of onsite assembly work in a prefab world.

Participants in the participatory workshop (n=3 of 11) felt the probes helped them consider the following values: personal development (P4, P5, P6), ease of assembly (P4, P5), creativity and problem solving (P6).

Desirable aspects of the probes included ease of assembly and replacement of parts (P6), as well as improved mental health, job satisfaction and career development (P5). However, undesirable aspects included a push back on the ‘creativity’ that **Lean On** aimed to provide. Stakeholders felt that there would be alienation of highly skilled workers who might feel “sidelined” by the production process (P4, P6). There was generally a concern that this alienation would reduce the pool of available workers and those with highly specialised skills.

P4: “3 of 4 workers [will] find these processes beneficial”

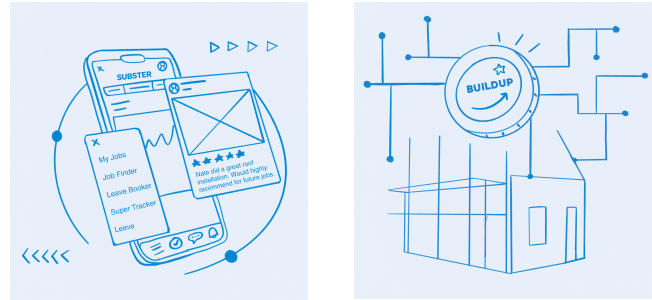
This reflection corresponds to current concerns about a shortage of skilled workers. If people do not find the work engaging then it may be difficult to retain and attract talent in the future.

5.4.3 Speculative Probes for Scenario 3 (Everyone is a Subcontractor).

The first probe **Subster** (Figure 11 left) is a subcontracting platform that allows workers to find work and streamline their jobs. People can gather ratings on the platform as a form of self-marketing and trust-building. Although this kind of platform is not particularly new, its underlying questions about how work processes and policies in the AEC industry might change if these types of platforms are adopted at scale are interesting. In an industry with even more intense fragmentation, how do people pass on information about a project? Does this move to ultra-lean businesses really mean more time spent trying to share information about a project with even more parties?

The second probe **BuildUp** (Figure 11 right), is a blockchain protocol that allows workers to invest in their project. Workers earn tokens that are tied to a small percentage of the building’s value. These tokens contribute to their retirement benefits. Although they are a small percentage of the building, these add up over time.

Quality work increases the value of the house and therefore the value of the tokens, incentivising a level of care, as though it were their own home. It calls for a reflection on what encourages people to produce quality work.



In a world where everyone is a subcontractor, “getting on the apps” is essential. Being on a subcontracting platform, like **Subster**, means you have the security of being paid, taking leave and managing your jobs. Walking on site and knowing what needs to be done is easy, no more wasted time arriving when the site isn’t ready for your work yet. Project managers and customers can give you a rating for different skills, which helps you stand out (or not).

It is now possible for expert tradespeople to collect **BuildUp CryptoTokens** as they work on different projects. These tokens offer a small percentage of ownership over the final building and continue to accumulate wealth throughout the life of the construction. It’s an opt in scheme and a promising way to diversify your superannuation. You can watch your tokens build up through the app and cash them in when you retire. It’s rewarding to know that what you’re building is an investment in your future.

Figure 11: Scenario 3 Probes - Subster (left) is a phone application that is a must-have for people working in building and construction. BuildUp CryptoTokens (right) allows workers to earn income for their retirement.

Participants in the participatory workshop (n=5 of 11) felt the probes captured several values, including: self-motivation (P7, P8), pride (P2, P7, P8), individuality (P2), and traceability (P3, P2, P7, P8, P9).

Desirable aspects of the probes included the ability for people across the AEC industry to monitor the progression of a project so that they can predict when there will be delays, this includes managers and onsite workers (P2, P7). This emphasises the need for better tracking systems to ensure jobs are completed on time. Conversely, undesirable aspects included disjointed applications that make work more challenging (P8) and inefficiencies for coordination if everyone is a subcontractor (P7).

5.4.4 Speculative Probes for Scenario 4 (Climate Crisis and Global Conflict Build).

The first probe **Equilibrium** (Figure 12 left), is a government-backed program for monitoring the energy performance and overall health of retrofitted homes. It brings into question the role of Government in housing and maintenance, being positioned to ask who has access to data about homes and who the obligation to maintain these structures sits with. It also poses questions about home retrofitting and what quality looks like in this space.

The second probe **SafeGear** (Figure 12 right), describes workwear that helps people carry out tasks in extreme conditions. It aims to pose questions about the future of work as climate conditions worsen.

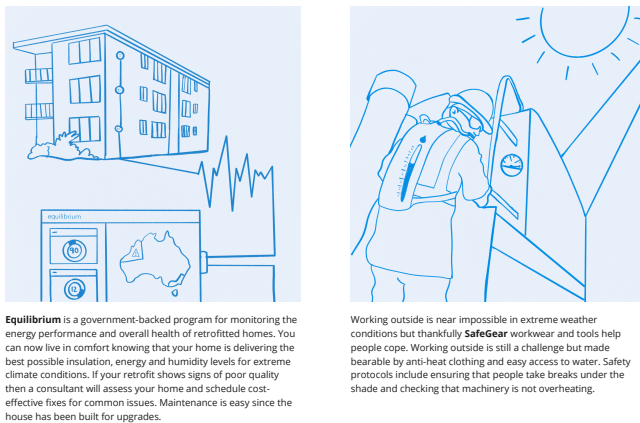


Figure 12: Scenario 4 Probes - Equilibrium (left) is a government program for monitoring retrofitted homes. SafeGear (right) is a wearable for extreme working conditions.

Stakeholders in the participatory workshop (n=5 of 11) felt the probes captured several values, including: healthier homes (P5, P11, P13), health and safety of workers (P3, P11, P13), and, of course, sustainability (P5, P13).

Desirable aspects of the probes included a need to address climate change issues and new innovations in technology to support this. Additionally, participants talked about a desire for healthier homes and a focus on safety for workers. Conversely, undesirable aspects included a drop in quality due to a need for rapid innovation (P3, P5, P13) and the potential that education might struggle to keep up with this pace in the current schema (P13).

5.5 Reflect [micro, present]

By clustering desires and concerns in relation to the speculative probes and comparing them with clustered themes relating to the leverage points in the systems map, we identified three core **systemic futures tensions**. These tensions are a novel output of the Systemic Future Dialogue, generated from the orchestration of systemic and speculative design across micro–macro and present–future dimensions. By moving between these levels, the process identifies contradictions and trade-offs between systemic change solutions and desired futures. This enabled participants to critically visualise and assess how seemingly appropriate changes may reinforce undesirable system dynamics over time.

- (1) **Productivity and Job Satisfaction:** The AEC industry faces pressure to improve productivity due to a shortage of skilled labour and high costs, as one participant explained "[...] saving usually must be in speed/labour reduction (variable costs)[...]". However, the push for greater efficiency may conflict with the industry's desire to create fulfilling jobs that keep workers engaged. It was specifically called out that an undesirable aspect of the probes was a lack of creativity, innovation or uniqueness in the tasks being carried out. This tension raises an important question: **what would it take to improve productivity while also creating satisfying jobs that people feel are fulfilling to carry out in the long term?**

- (2) **Modern Methods of Construction and Preserving or Augmenting Traditional Skills:** Modern methods of construction (MMC) create new opportunities to recruit a diverse workforce. For example, robotics that make heavy lifting easier for women, the older adults, or people with physical disabilities. However, there is tension between embracing innovation and preserving traditional skills, often driven by concerns about the cost of adapting to change. As one participant pointed out, they did not want to "[contribute to a] further accentuated skill gaps as well as "deskilling". This calls into question how the AEC industry will bridge the gap between innovation and preserving or augmenting traditional skills: **which skills must be safeguarded to maintain quality, and what might happen if we design with the human cost of technological change front of mind?**

- (3) **Pace of Innovation and Safety and Quality:** There is a strong push to encourage innovation, but this creates tension with the time required to uphold quality and safety; both are essential for a healthy and desirable future. Alternatively, as one participant pointed out, "*rapid innovation may render existing training programs obsolete, creating a disconnect between education and industry demands*". This poses the question: **how might quality and safety keep up with innovation, and how can education help lead the way?**

These systemic futures tensions are useful in focusing design efforts and structuring a research and innovation agenda. They are grounded in real-world trade-offs and challenges articulated by industry stakeholders. In addition, the tensions offer an accessible way to reflect and critically evaluate possible futures that might otherwise be too alien or too technocentric.

6 Limitations and Future Work

While this work contributes novel insights through the design artefacts we co-created with industry, our approach, generating knowledge by *doing* design, has its limitations. First, we did not directly compare or evaluate our approach against alternative methods. This was not feasible within the scope of a project shaped by predefined goals, timelines, and available resources. Further, it is inherently challenging to identify a process or framework with similar scope. Now that we have articulated this framework, future research is well positioned to systematically compare and contrast it with other approaches.

Second, there are aspects of our process that we would approach differently if given the chance to revisit the design work. While it remains difficult to determine whether these changes would have yielded different outcomes, this is not the central aim of our contribution. For instance, we identified leverage points and desirable/undesirable futures in the same workshop. With the benefit of hind-sight, we would have identified leverage points during the *model* phase (stage 2 in Figure 2) and the desirable/undesirable futures during the critique phase *critique* (stage 4 in Figure 2). These improvements could have only been realised once we were able to critically reflect on our experiences. We were also restricted by timing, typical of industry-based research, where busy participants are asked to contribute to the research with in-kind hours. For

this reason, we combined the identification of leverage points and desirable futures critique in the same workshop. However, we do not believe this had a significant impact on the results, since we validated the systemic design tensions with industry representatives, providing an opportunity to check the workshop outputs.

Finally, while we made a concerted effort to include diverse voices from across the architectural, engineering, and construction (AEC) sectors, we acknowledge that it was not possible to capture every perspective. Broader industry representation was constrained by factors such as time, scale, and resource limitations beyond the control of project team.

7 Discussion

The Systemic Futures Dialogue offers a new structured orchestration and epistemological contribution to futuring work [52], exploring imaginings of technological futures that “takes the messiness of everyday life as a central theme” [7, p.133]. It bridges present-day insights with speculative futures, tracing the golden thread that connects immediate challenges to long-term possibilities. The dialogue’s participatory, systems-oriented approach enables stakeholders to move between detailed problem areas and broader systemic perspectives, creating speculative artefacts grounded in real-world concerns. We conceptualise **systemic futures tensions**, a novel output that allows researchers to identify conflicting values in near and distant futuring. By unpacking key moments in the process, we demonstrate how this approach navigates the balance between designing *with* and designing *for* participants, and how it acts as a catalyst for critical reflection within complex industry contexts.

7.1 Grounding speculative work in participatory and present-day insights

The **Systemic Futures Dialogue** provides a structured pathway between what we know about the world today and desires for the future. It grounds speculative futures in real, observable trends, ensuring that imagined scenarios remain connected to current realities. For example, by tracing the process across the dialogue, we see how early discovery insights, such as the shortage of skilled workers, informed the development of a systems map that illustrated how a fragmented technology landscape could exacerbate these shortages. Viewing these interconnected challenges at a macro level allows us to extrapolate and imagine how the future might unfold under different conditions. For instance, if climate change and global conflict forced widespread reskilling, we could imagine how education systems might adapt or explore new methods of skill development through speculative probes. Looking back from probes like *LeanOn*, we see how tangible problems, such as the skilled labour shortage, directly shaped this design artefact. This approach responds to earlier criticisms that speculative design processes can feel vague or disconnected, providing industry stakeholders with a clearer, more traceable link between present-day issues and imagined futures.

7.2 When to *design for* and when to *design with*

Design futuring methods have the potential to help organisations critically reflect on their strategic plans [61]. However, using critical design futuring in participatory settings presents challenges. These methods rely on experience and tacit knowledge that can

be difficult for novices to acquire, and they may feel disconnected from the predictive, goal-oriented approaches to future planning that industry experts are familiar with. Conversely, taking a purely top-down approach risks imposing a narrow perspective that overlooks stakeholders’ experiences and valuable insights. In this work, we demonstrate an alternative path, showing how participatory activities can generate the data that informs design futuring artefacts. While the final speculative probes were not created directly by the industry stakeholders, participants could see their input reflected in the themes and narratives that emerged throughout the engagement. This approach invites reflection on when we choose to *design with* rather than *design for* and how these can be used in complementary ways.

7.3 Systemic futures tensions as circuit breakers for feedback loops

An important feature of the Systemic Futures Dialogue is its ability to guide researchers and participants between micro and macro perspectives, creating a dynamic process of zooming in and out. As discussed earlier, this movement not only helped to progressively build alternative futures grounded in present-day observations but also revealed how unintended consequences can emerge when focusing too narrowly on a single problem area. For example, while incentivising (or even mandating) the use of certain tools might be intended to drive their adoption, stepping back to view the system through future-based scenarios shows how, without equitable access to resources, such interventions could ultimately do more harm than good.

The final systemic futures tensions act as circuit breakers for reinforcing feedback loops. They prompt industry participants to question the underlying tensions between pragmatic solutions in the present and their aspirations for the future. This process helps participants critically reflect on current priorities while keeping one eye on the kind of future they want to create. For example, while the AEC industry faces mounting pressure to build more homes and increase productivity, speculative probes surfaced another priority: job satisfaction. Most participants agreed that meaningful, satisfying work remains vital. In this way, the dialogue re-centres the research agenda around the apparent paradox of productivity and supporting long-term human satisfaction and wellbeing. These were conversations led by industry participants and offered as the focus of the next phase of research [60].

These tensions offer a novel output from our approach, generated specifically from the orchestration of systemic and speculative design activities across micro–macro and present–future dimensions. This enables participants to examine how, at times, abstract interventions at the macro level materialise as concrete technologies and interactions at the micro level. Rather than producing only solution-oriented outputs, the approach makes visible how seemingly appropriate changes in the present may reinforce undesirable system dynamics over time. This provides a distinct advantage over existing methods or systemic and speculative design as individual activities, by enabling participants to critically evaluate the long-term material implications of change within a sociotechnical system.

8 Conclusion

In this paper, we introduced the **Systemic Futures Dialogue**, a structured orchestration of speculative and systemic design methods. Developed through close collaboration with the AEC industry, this dialogue asks design practitioners to observe, model, extrapolate, critique, and reflect across micro and macro perspectives, using each step to inform and deepen the next. By doing design *with* and *for* stakeholders, we were able to preserve the critical and imaginative strengths of speculative design while making its outputs accessible and actionable for an industry audience. The output of this orchestration is a set of **systemic futures tensions**, which we conceptualise as an novel output that captures the trade-offs between short and long-term desires. These tensions show how organisations can critically reflect on whether their present-day innovations align with their aspirations for the future, and invite them to reconsider how they design and implement technology within complex systems.

Looking forward, we see the **Systemic Futures Dialogue** as a foundation for future research that deepens empirical inquiry into **systemic futures tensions**, expands participatory engagement across more diverse stakeholders, and explores how this approach can be applied in other industry contexts. By offering a pathway to navigate the ontological and epistemic differences between speculative and systemic design, we hope this work inspires others to experiment with, adapt, and extend the dialogue and conceptual outputs to support more reflective and collaborative innovation.

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A Appendix

A.1 Industry Participants

ID	Gender	Years of Industry Experience	Role	Experience	Involvement in Research Steps [Yes (Y), No (N), not applicable (N/A)]								
					1	1.1	2	3	4	5.1	5.2	5.3	
P1	Man	25	Director for Applied Research and Innovation	Dean faculty of Building Construction and Engineering (15 years), research including building and construction (10 years).	N	Y	Y	Y	N/A	Y	N/A	Y	
P2	Man	21	Digital Strategic Partnerships Exec	Structural Engineer on multiple building types, moving to a supplier of mass timber products as design lead. Spent 10 years in a developer building mass timber buildings, and more recently in design automation software.	Y	Y	Y	Y	N/A	Y	N/A	Y	
P3	Man	25	Research Development and Education Manager and Architect	Specialises in the manufacture and design of buildings made offsite using advanced methods of manufacturing. This came after spending the first 15 years finding construction generally inefficient and cumbersome.	N	N	N	Y	N/A	Y	N/A	Y	
P4	Woman	10	Manager, Research and Evaluation	Working in a regulatory agency, managing licensing and registration functions, and managing the research program.	N	N	N	N	N/A	N	N/A	Y	
P5	Man	25	Senior Technical Advisor - Sustainable and Future Built Environments	Sustainable Building Advisor for a Peak Body for the past 20 years and worked on building and construction related projects and research for the last 24 years. Extensive experience in education and training has informed the development of nationally recognised sustainable construction training programs. Extensive experience working with regulator organisations.	Y	Y	Y	Y	N/A	Y	N/A	Y	
P6	Prefer not to say	9+	Chief Analyst	Worked 9+ years for a regulator as their chief analyst.	Y	Y	Y	Y	N/A	Y	N/A	Y	
P7	Man	11	Prefabrication Leader	7 years as an engineering then remaining time in current role.	N	N	N	N	N/A	Y	N/A	N	
P8	Man	11	Business Analyst	Prefab Manufacturing for mostly residential Construction.	N	N	N	N	N/A	Y	N/A	N	
P9	Man	14	National Engineering Manager	Previously worked as a consulting structural engineer in the buildings space. Now have moved into a engineering lead role at BlueScope steel in manufacturing of composite metal decking.	N	N	N	N	N/A	Y	N/A	N	
P10	Man	35	Consultant	Engineering and construction, experience working for large construction companies.	N	N	N	N	N/A	Y	N/A	N	
P11	Man	40	Director of Innovation	Director at a large building services company with a background in mechanical engineering	Y	Y	Y	Y	N/A	Y	N/A	Y	
P12	Man	35	Geral Manager (surveying)	General manager for a consulting firm, specialised in building surveying.	N	N	N	Y	N/A	N	N/A	N	
P13	Man	7	Senior Research Advisor	Leads research at a regulatory body, with an extensive history in regulatory agencies.	Y	Y	Y	Y	N/A	Y	N/A	Y	
P14	Man	12	General Manager (prefabrication specialist)	General Manager of a large international wood products company. Has a background in car manufacturing (an additional 17 years of experience).	Y	N	N	N	N/A	N	N/A	N	
P15	Man	26	Research Director	Research director of a large cross-disciplinary research centre specialised in building and construction. Was trained and practiced as an architect before moving into academia.	Y	N	N	N	N/A	N	N/A	N	
P16	Woman	17	Policy and Industry Collaboration Advisor	Policy advisor for sustainability in the building and construction industry. Trained and practiced as an architect.	Y	N	N	N	N/A	N	N/A	N	
P17	Man	38	Emeritus Professor of Construction Management	Experience across trade and senior management positions in design, construction, estimating, project management and professional consultancies.	Y	N	N	N	N/A	N	N/A	N	

Figure:13 Participants and their involvement in each step of the case study (see Figure 2)

A.2 Systems map of the AEC Industry

A model of the availability of skilled workers and appetite for change in the Architecture, Engineering and Construction industry

The Architecture, Engineering and Construction (AEC) industry is caught in a challenging cycle. The high cost of building projects has been driven by the demand for skilled workers. However, small profit margins discourage organisations from investing in new technologies and processes, compounded by a fear of deskilling and job losses. This reluctance to innovate means the industry appears to lag behind others.

Disruptors see opportunities to improve productivity, but their solutions often add to an already fragmented market. As innovation continues to hum in the background, the perennial risk of "tacking the wrong horse" looms large. As a result, the digital skills gap both exacerbates, with new innovations being invented but not widely adopted.

To address the skilled workforce shortage and close the digital skills gap, the government and educational institutions encourage upskilling and workforce entry. However, this effort faces challenges from a shrinking pool of applicants, lack of workforce diversity, an aging population, and limited appeal to digital-for-youth.

The industry is stuck between a diminishing skilled workforce and a lack of tech adoption. Consequently, building costs remain high and ultimately burden end customers or taxpayers, as the government funds new housing projects.

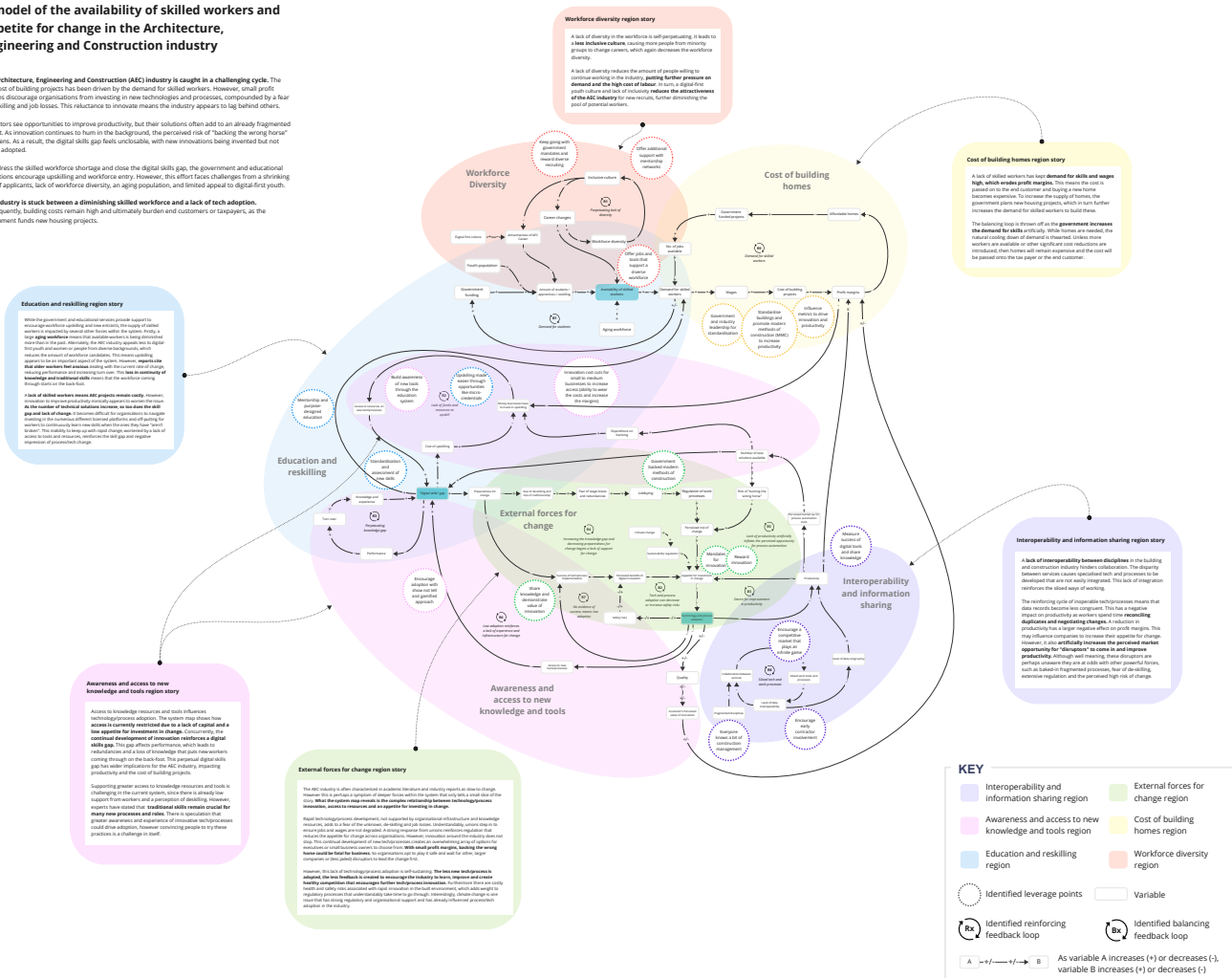


Figure:14 Systems map of the AEC Industry. A full PDF can be found in the supplementary material

6. PAPER 2 – RECLAIMING PRODUCTIVITY: CRITICAL PERSPECTIVES ON SPECULATIVE FUTURES

Reclaiming Productivity: Critical Perspectives on Speculative Futures

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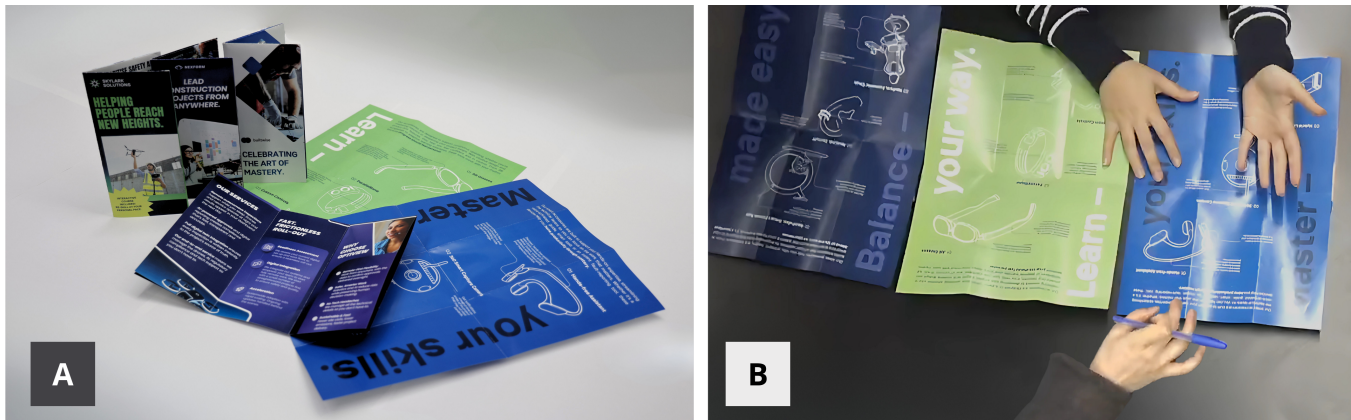


Figure 1: Drawing on speculative design practices [24, 79] and in close collaboration with stakeholders from the Architecture, Engineering and Construction (AEC) industry, we designed three sets of speculative brochures (A). These brochures depict alternative technological futures, used to spark critical reflection with AEC industry representatives across various factions and expertise (B), on what they value most about work.

Abstract

New technologies are often introduced into organisations with promises of increased productivity. Yet productivity is often narrowly defined, and the impacts of technologies on future work practices are poorly understood. This paper reports on workers' concerns and reflections on future work practices in the Architecture, Engineering and Construction industry. In a series of semi-structured interviews, we engaged 17 industry participants, who responded to a set of speculative design brochures that imagine alternative technological futures. The findings show workers experience erosion of job satisfaction, shared purpose, and embodied craft. Drawing on participants' reflections, we propose that emerging

technologies should (1) reclaim productivity as a pathway to job satisfaction and slowing down to innovate, and (2) bridge knowledge work and embodied craft, making knowledge creation more inclusive and streamlined across services. We discuss how technology can both mediate and reinforce power dynamics between executives and employees, and explore the impacts of design choices shaping the future of work.

CCS Concepts

• **Human-centered computing** → **Interaction design process and methods; Interaction design theory, concepts and paradigms; Empirical studies in HCI.**

Keywords

Productivity; Speculative Design; Future of Work, Work Satisfaction, Critical Design, Architecture, Engineering, and Construction Industry



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1 Introduction

The pursuit of productivity is an enduring ambition of workplace technologies. Human-Computer Interaction (HCI) research has aimed to increase productivity of workplace technologies by improving task completion times, increasing throughput or reducing error [81]. Whilst these initiatives have had success, a focus on speed and throughput inadvertently proliferates “busy work” [100] and not taking sufficient account of employee’s “personal productivity” [46], such as job satisfaction and long-term career benefits. There is growing concern that by limiting the framing of productivity only to organisational-level concerns (e.g. device usage duration, task completion, time spent on task), we may be neglecting broader notions of productivity, such as self-reflection, [15, 42, 50, 102], wellbeing [17, 29, 44, 57, 88], and collaboration [25, 27]; all of which are needed to create valuable work and realise the social benefits of productivity [65, 91].

There are two key HCI research challenges which need to be addressed to help workers reclaim productivity as an indicator of better working conditions and to help innovators improve their design of productivity technologies.

The first challenge concerns how productivity is designed for and framed. HCI research frequently relies on self-reported perceptions of productivity (e.g. [44, 64, 88]), influenced by subjective experiences and attitudes [33, 46, 48]. While these self-reports acknowledge the importance of workers’ wellbeing and satisfaction, they typically frame productivity in organisational terms, such as quantity of outputs (e.g. meeting monthly targets [44]) or efficient use of time (e.g. [33]). We argue that HCI researchers should also consider how productivity could be broadened to consider how employees might achieve their own goals, such as greater job satisfaction or self-efficacy [46].

The second challenge concerns the scope of productivity research. Current workplace research tends to investigate specific occupational categories such as knowledge work (e.g. [13, 83, 96]), gig work (e.g. [38, 58, 105]), factory work (e.g. [7, 16, 72]), or trades and crafts (e.g. [53, 59, 103]). This falls short of acknowledging how workplace technologies are influenced by an industry’s systemic norms and economic pressures [91], where people in different roles often rely on each other to complete shared tasks or produce tangible products. These interdependencies suggest that industry-wide investigations into work practices are important, yet remain largely under-explored in HCI.

We explore these two challenges — framing productivity to include personal perspectives and system-wide interdependencies — by working with people in the Architecture, Engineering and Construction (AEC) industry. We engaged industry practitioners from different career stages and areas of expertise, asking them to consider *speculative futures* and to reflect on how productivity intersects with job satisfaction, skill acquisition, safety, and output

quality by interrogating alternative technological futures. In doing so, we asked the research questions:

RQ1: What are the issues and opportunities for work practices in the AEC industry posed by emerging technologies?

RQ2: What are the implications for a critical analysis of technologies being developed today?

To investigate these questions, we apply speculative design [24, 79] as a method for envisioning and critically examining futures of work. Working with industry representatives and informed by prior research on emerging technologies in the AEC sector, we created a set of *speculative brochures* (**Figure 1**). We recruited 17 participants across diverse roles in the AEC industry, for a series of semi-structured interviews to interrogate the speculative brochures. The speculative brochures were designed to provoke reflections on how technologies might reshape future work practices and to raise questions about their consequences for the wider industry.

The findings are presented as two major themes, each of which are critically examined using Virilio’s *en negatif* [99], which assumes well-meaning technological solutions often give rise to new challenges of their own.

The first theme concerned productivity, showing how participants across different roles (executives, employees, trade-workers, knowledge-workers) challenged efficiency-centric views of productivity, emphasising that productive work can also be satisfying, less frustrating, and more sustainable. They described how improving productivity sometimes requires slowing down to learn new technologies, resolve coordination issues, or support downstream collaborators, thereby highlighting a tension between short-term and long-term gains.

The second theme concerned embodied work, showing how participants stressed the importance of embodied, hands-on knowledge in an industry whose outputs are physical and tangible. In the AEC industry, cognitive and embodied forms of expertise are often inseparable — knowledge work requires understanding how building materials are used and trade work requires an understanding of project scheduling to meet building requirements. While emerging tools such as AI, robotics, and AR were seen as offering support for training and safety, and may address the intersection of cognitive and embodied work, participants worried that automation may create a “shortcut culture” or sidelines tacit expertise. These insights led to respective design provocations, which in-turn form the basis of the paper’s key contributions:

- **Reconciling Productivity and Job-Satisfaction:** The use of technology to achieve productive goals should not be limited to efficiency considerations alone. Technologies can employ efficiency as a means of achieving greater job satisfaction by, paradoxically, encouraging slowing-down and reflexivity. Drawing on AEC workers’ reflections on speculative futures, we raise how HCI as a field needs to further investigate the link between productivity and factors like job satisfaction and self-efficacy.
- **Coordinating embodied work and knowledge work:** We highlight the limitations of technologies that assume a divide between knowledge work and embodied work. We suggest emerging technologies, such as extended reality and generative AI, can more actively value tacit knowledge, which

is essential for many workers who produce tangible products. This use of technology to coordinate embodied work and knowledge work, particularly in the AEC industry, contributes to job satisfaction and more human-centred perspectives to productivity.

2 Related Work

2.1 Architectural, Engineering and Construction (AEC) Industry

The AEC industry is vital for building and maintaining physical infrastructure, yet it faces growing scrutiny for its lack of sustainability, safety, and productivity gains. McKinsey reports that between 1994 and 2013, improvement in productivity for the AEC industry is 1.7 times less than productivity improvement in the manufacturing industry¹.

The AEC industry now faces systemic challenges and pressure to improve productivity, particularly in the wake of a global housing crisis. Barriers include skills shortages, limited training access, high costs, devaluation of traditional expertise, fragmented project structures, and regulatory hurdles [18, 89]. These socio-political challenges are complex; affected by government funding, workplace policies, education systems, and cultural perceptions of construction work.

Various technologies have been used in an attempt to address the above challenges. These include: additive manufacturing (3D printing) to create complex structures with less waste [71]; extended reality to support training, as well as the assembly and maintenance of physical assets [2, 34]; robotics that automate repetitive or hazardous tasks [9]; 3D building replicas, such as digital twins or Building Information Modelling (BIM) tools, used to facilitate real-time collaboration [2]; Internet of Things (IoT) and cloud platforms that further enhance efficiency through data integration and monitoring [11]; and predictive insights through AI and other forms of human-AI collaboration [78].

Given this increasing use of new and emerging technologies to address complex industry-wide challenges across the AEC sector, it is important to understand their implications for peoples' working conditions.

2.2 What Does Productivity Mean and Who Does it Serve?

In economic terms, productivity is defined as the ratio of outputs (e.g. goods, services, tasks) to inputs (e.g. time, money, labour, energy) [63]. In a broad sense, productivity refers to "how efficiently an economic activity converts the various inputs and resources it uses, into the final product or service which it produces"[91, p.11]. The outputs are normally a quantity (i.e. how much is produced), but can also be a quality (i.e. how well it was produced) [95]. HCI research typically mirrors this economic framing, focusing on how computing systems streamline task execution, reduce cognitive load and increase speed or accuracy [81].

However, the term productivity is both "widely used and often misunderstood" [95, p.35]. This is complicated further by the

considerable difficulties in measuring productivity [73], which is particularly difficult for knowledge work, where productivity becomes complex to calculate, due to the intangible nature of outputs and the complexity of non-standard work [23, 46].

In HCI, productivity is often invoked to justify the benefits of new technologies or to highlight their challenges. Reflecting the difficulty of assessing productivity of knowledge work, studies naturally rely on qualitative accounts [50, 88, 92, 102] or self-report questionnaires [12, 13, 44, 46, 64], often through open-ended questions such as "How efficient do you feel you were today in performing your work?" [60] or rating agreement to a statement such as "I regularly reach a high level of productivity" [64].

Other researchers have criticised technologies that stress efficiency and (intentionally or inadvertently) reinforce "busy work" [50, 68]. Instead of enjoying the benefits of productivity which should in theory offer workers additional non-work time and improved social outcomes, "[people] tend to fill that freed-up time with more tasks and activities in an attempt to accomplish more" [49, p.60]. Critics increasingly argue that contemporary technologies tend to privilege speed at the expense of other societal values and needs [6, 65]. For example, personal data-tracking devices framed as productivity tools can backfire, fuelling stress and an obsessive drive for constant improvement [56].

Ironically, some productivity tools have even added to the burden of what is perceived to be unproductive work, leading to the introduction of additional technologies to monitor screen-time [46], or mediate increased task switching between devices [44]. Recent Generative AI (GenAI) research shows how these innovations can add to the burden of work, redirecting effort away from the actual purpose of the work toward editing the generated output [77, 102, 106] or thinking through how to prompt the tool [22, 96]. As Bainbridge observed decades earlier [5], automation does not simply reduce workload, but instead creates new work to monitor and maintain the system. We now see similar patterns for GenAI [87], where advanced technologies pushes work to new areas that employees are largely unprepared for, changing the nature of the work and thereby undermining the promises of productivity.

As the prominent economist Jim Stanford [91] argues, productivity can serve the interests of both employers and employees, enhancing competitiveness while also enabling workers to enjoy improved wages, conditions, and job satisfaction in general when its benefits are equitably shared. In support, a growing body of research in HCI shows that workers often connect productivity more generally to job satisfaction or feelings of fulfilment [44, 64, 88]. Guillou et al. [33] go further, arguing for a shift toward Time Well Spent, where people evaluate productivity in terms of meaningfulness and satisfaction rather than throughput.

2.3 Deskilling Risks and Supporting Self-Efficacy through Embodied Work

In times of technological change, productivity and job satisfaction are often tied to the acquisition of new skills. Skill development may enhance individual capability, team collaboration and knowledge-sharing, and can be critical to collective productivity [3, 66]. Governments have therefore placed increasing emphasis on digital skills

¹<https://www.mckinsey.com/capabilities/operations/our-insights/the-construction-productivity-imperative>

training, particularly in areas such as artificial intelligence, where shortages threaten national competitiveness [39].

The benefits of training are, however, unevenly distributed across the workforce. Training in emerging technologies often yields greater productivity gains for less skilled workers than for seasoned professionals [10]. Younger workers are generally more receptive to acquiring new skills, though this is not universal [43]. Older workers, in contrast, tend to perform better in training that builds on their existing expertise rather than training aimed at generating entirely new skills [76]. This points to a need for differentiated approaches to skill development that account for diverse career stages and learning preferences. Without such tailoring, training risks producing dissatisfaction by overwhelming workers or by leading to stagnation or deskilling.

HCI literature shows similar tensions. Studies have shown how various AI and extended reality tools can support novice learning and improve learning processes [31, 40]. Other research highlights the risks of deskilling, where AI development pipelines extract domain expertise, leaving workers with reduced authority in shaping outcomes [82] or alternatively encourage over-reliance, undermining confidence in their own judgment [86]. Similarly, Simkute et al. [87] draws parallels between emerging GenAI technologies and Bainbridge [5] original critique of automation, pointing out how these technologies push skilled workers into performing new roles that they are often ill-prepared for. Furthermore, persistent barriers, such as cost, time and uneven risks of displacement, further complicate re-skilling efforts [69, 76].

Innovation that is necessary for productivity growth [91], is often supported by both intellectual learning and how peoples engage with tools and materials using their physical bodies. Indeed, HCI has long recognised the role of the human body in shaping interactions. Seminal work on situated action [93], embodied interaction [21], and somaesthetics [37] emphasise the inextricable link between mind, body, and environment, grounding meaning-making in practical activity. Even so-called “knowledge work” is never disembodied; it is grounded in physical artefacts, environments and routines [47].

HCI research in both trade and industrial domains supports the significance of embodied work. Barker and Jewitt’s [7] ethnography of “filtering touch” illustrates how robots in dirty and dangerous work reconfigure sensory and affective relations, but still require embodied learning. Liu et al. [54] similarly argue that the transmission of traditional craft skills is inseparable from their embodied practice, highlighting how innovation and tradition are codependent in the physical enactment of making. Kernan Freire et al. [45] demonstrate how tacit knowledge is often invisible to its holders, requiring reflection and social exchange to become externalised. Mitterberger et al. [62] show how interactive robotic plastering systems can retain the aesthetic and technical potential of human-in-the-loop design, in contrast to trends toward full automation that risk excluding embodied craft potential. These accounts align with longer-standing critiques that neglecting embodied dimensions risks overlooking an important aspect of human work.

Importantly, embodied work also contributes to job satisfaction. The infamous IKEA effect [67] explains how people value outputs more highly when they have physically contributed to their creation. In HCI, this aligns with findings that mastery, tangible progress and physical involvement in tasks can enhance workers’

sense of ownership and accomplishment [48]. Likewise, Sheehan and Le Dantec [85] caution that automation that strips away touch, physical contribution or self-sufficiency risks displacing the satisfaction workers derive from their labour. Meaningful work involves more than just the outcomes, but rather the embodied processes of achieving them.

Despite this, HCI has often treated knowledge work and physical work separately. Research about knowledge work tends to foreground reflection, cognitive coordination and information management [50, 64], while trade-focused research tends to address safety, tacit expertise, and craft learning [75, 103]. Yet work in the Architecture, Engineering, and Construction (AEC) industry tends to blur this division: productivity is jointly constituted by knowledge workers (e.g. architects, engineers, project managers) and tradespeople (e.g. carpenters, surveyors, roofers). In the AEC industry, knowledge and embodied work are intertwined; design decisions need to be cognisant of material processes, while trades need an understanding of modern scheduling strategies in order to self-manage productivity.

3 Artefact Design Process

This paper reports on part of larger project within a research centre investigating the design and use of emerging technologies in the AEC industry. The project’s primary objective was to identify the issues and opportunities that emerging technologies create for working conditions in the AEC sector, with a particular focus on industrial relations and workforce training. A strength of this project is the involvement of a variety of stakeholders from regulatory bodies, commercial enterprises, educational institutions, and labour unions

We represent imaginings of new and emerging technologies through speculative design techniques. Taking inspiration from prior speculative design research, carried out by HCI researchers in collaboration with industry participants [52, 58, 80, 90], we undertook a three-stage design process to develop our set of speculative brochures. This consisted of: (1) mapping the socio-political system, (2) identifying real-world design tensions, and (3) establishing speculative artefacts. Twelve industry representatives (see Appendix A Figure 7) were engaged across all stages. These representatives come from diverse areas of the AEC industry, including regulatory authorities, training institutions, peak bodies, construction services, surveying consultancies, architecture, and prefabrication factories. The brochures were then shown to AEC participants in a series of semi-structured interviews, producing qualitative data that underpins this paper’s contributions.

3.1 Stage 1: Understanding the Socio-political System

The AEC industry is a complex socio-technical system where the practices of employees and employers ultimately shape the buildings inhabited by end users. To explore this system, we conducted a desktop analysis of challenges in the AEC industry, producing the systems map, which can be found in the supplementary material. The map was validated and refined through feedback from industry representatives (Figure 7 in A).



Figure 2: Sliders derived from the design tensions in Stage 2 were used to structure three sets of speculative brochures. These brochures were intended to present provocative and unexpected alternative futures, prompting deep reflection from participants.

Our process was guided by systems thinking [61], systemic design [41], and the Systems Mapping Academy toolkit². Systems thinking sees issues within a socio-technical system as interconnected rather than isolated [61]. It highlights how feedback loops, whether reinforcing or balancing, influence system behaviour. In addition, interventions in one part of the system can create ripple effects, often producing unintended consequences elsewhere in the system [61].

This framing was critical for identifying how present challenges and technological interventions ripple out across the AEC system, and informed the design tensions presented in the next stage.

3.2 Stage 2: Identifying Real-world Design Tensions

In collaboration with our industry representatives (Figure 7, in A), we generated design tensions between interventions for present-day system challenges and aspirations for the future. Inputs for this stage included our systems map, future-based scenarios, and speculative sketches of emerging technologies. While these are not the primary focus of our analysis, they served as stepping stones toward the final speculative artefacts, and are therefore provided in the supplementary material for transparency.

The participants ideated preferred interventions to address challenges in the systems map and then reflected on scenarios and sketches as alternative futures. Using Affinity Mapping [55], we cross-examined the written outputs, comparing proposed interventions with desired futures. This design process revealed key tensions between addressing immediate system needs and envisioning long-term aspirations. These tensions included:

- (1) **Productivity vs. Job Satisfaction:** The AEC industry faces pressure to improve productivity due to a shortage of skilled labour and high building costs. However, the push for greater efficiency may conflict with the industry's goal of creating fulfilling jobs that keep workers engaged.
- (2) **Teaching New Skills vs. Upholding Traditional Skills:** Modern methods of construction (MMC) create new opportunities for a diverse workforce. However, there is a tension between embracing innovation and preserving traditional skills, often driven by concerns about the cost of adapting to change.
- (3) **Speed of Technology Implementation vs. Safe Work and Quality Outputs:** There is a strong push to encourage innovation. However, this creates tension with the time required to uphold quality outputs and safe work practices, which are both essential for a healthy and desirable future.

These design tensions were used to structure the sliders (Figure 2) which in turn guided the creation of the speculative brochures in Stage 3.

3.3 Stage 3: Establishing the Speculative Artefacts

We created speculative brochures that illustrated three alternative futures, each highlighting the design tensions to different degrees, instantiated by the sliders depicted in Figure 2. Inspired by Oulasvirta and Hornbæk's counterfactual reasoning [70], this approach used tensions to theorise how design choices might shape real-world responses. Grounding the artefacts in the design tensions created in collaboration with industry stakeholders allowed us to probe how participants reacted to different weightings of competing values and critique how current technologies support,

²www.system-mapping.com

or undermine, desirable futures. The speculative artefacts also enabled a suspension of disbelief [4], helping us to probe the limits of participants' attitudes and beliefs.

The sliders (**Figure 2**), based on the design tensions identified in Stage 2, were used to generate provocative ideas for the three sets of brochures, or *speculative probes*. For example, increased productivity, skill development, and speed of innovation logically go hand-in-hand. To instantiate more thought-provoking ideas, we paired unlikely sliders together. For instance, a strong emphasis on both productivity and traditional skills. We presented deliberately utopic rather than dystopic scenarios, with sliders trending toward more strongly prioritising the different values [20, 80]. By trending toward utopic futures we aimed to avoid overly obvious conversations about dystopias [79], instead prompting participants to think critically about the risks of technologies built with good intentions.

Using the sliders as a guide, we developed three alternative worlds, each represented by a brochure marketing a fictional service and describing three future workplace technologies. To ensure relevance, we created two versions per world (one for project managers and one for building inspectors) and refined them through feedback from five industry representatives (**Figure 3**). We created these different versions so that participants with different backgrounds (e.g. regulatory or commercial) could adequately respond to the speculative probes. We provide a concise overview of each brochure below. For additional detail, the full brochures have been included in the supplementary material.

The speculative brochures follow Ringfort-Felner et al.'s [79] descriptive taxonomy for the quality of speculation. They are *fictional* artefacts that critically explore alternative realities for the architecture, engineering and construction industry. The tensions, instantiated by the brochures, encourage participants to think *critically* about prioritising certain values over others and how this challenges their assumptions about the way technology should be developed, taught, adopted, and regulated. They raise awareness of the *socio-political* dimensions of emerging technologies, bringing to mind how they might impact the feasibility of business, livelihood of workers, and access to educational opportunities. The brochures are written such that the reader can plausibly *experience* the vision these services from alternate futures are trying to sell in simple and specific ways. Configuring the sliders so they felt challenging and not overly obvious helped us to create *thought-provoking* futures. Design stages 1 and 2 ensured the brochures' ideas were *grounded* in empirical data gathered from desktop research and in *participation* with AEC industry representatives.

3.3.1 Speculative Brochure Set 1: Job Satisfaction and Continuous Learning. These brochures (**Figure 4**) depict a future where work is deeply satisfying but less focused on output. Advocates emphasise freedom from pressure to learn or work faster, with personalised products that tailor learning to biometrics and lifestyle. In this world, “machines do the heavy lifting”, inspections are transformed, and “learning happens on-site, exactly when you need it”. The brochures state: “we prioritise safety and quality, never rushing transformation for the sake of speed”.

The brochures promote three technologies: (1) AR sunglasses with a glare visor and safety-certified lenses, delivering “bite-sized

learning modules” and real-time compliance tips; (2) the ParallelBand, which tracks biometrics and circadian rhythm to tailor learning while assuring data “never leaves the wrist”; and (3) a custom controller with long-range signal and high-resolution display, offering accessible AI and robotics management for all experience levels.

3.3.2 Speculative Brochure Set 2: Productivity and Mastering a Craft. These brochures (**Figure 5**) imagine a future where productivity eclipses job satisfaction. Services promise to “create more productive and resilient workplaces” by “removing barriers that slow teams down” and automating complex data collection. Workers are encouraged to “master [a] craft” like bricklaying or painting while AI manages project stress. The service emphasises rapid rollout, with little attention to safety or output quality.

The brochures promise to “support hands-on expertise” and “hone productivity through mastery” with three tools: (1) a hands-free bone conduction device for voice-activated guidance and building standards; (2) a 360° camera that records a project's lifespan, comparing plans to outcomes; and (3) a hybrid leveller that adds approvals and measurements directly to the digital twin.

3.3.3 Speculative Brochure Set 3: Everything Remote. These brochures (**Figure 6**) envision a future where productivity and job satisfaction are jointly prioritised. Services promise remote site management from home offices, freeing workers to focus on “complicated cases where [their] knowledge actually matters” and creating “rewarding leadership opportunities”. Skill development is de-emphasised, with technical details handled automatically. Traditional trades are sidelined as workers manage projects through data-driven decision-making rather than on-site practice. Despite this shift, the service pledges rapid innovation “without sacrificing safety or quality”.

The brochures promise a “seamless blend of life and work” with: (1) a smart fitness app that syncs with equipment to track wellness and reduce stress; (2) a stylish ear cuff for multitasking with audio updates, alerts, and reminders; and (3) an ergonomic chair with medical back support and controls for navigating high-resolution 3D site captures.

4 Study Design

To facilitate critical discussion and reflection, semi-structured in-person interviews were carried out with participants working in the AEC industry. The interviews each lasted 90 minutes.

4.1 Procedure

4.1.1 Part 1: Introduction and Consent. Participants were welcomed, given an information pack and consent form, and invited to ask questions before providing written consent.

4.1.2 Part 2: Design Fiction Reflection and Discussion. Participants described their background, role, and prior experience with emerging technologies in the AEC industry. They were then shown the fictional brochures one at a time, reflecting on each before comparing them as a set. The researcher probed for elaboration relevant to the research questions, for additional details and full transparency the interview guide has been shared in the supplementary materials. Participants also rated each brochure on a 7-point Likert

Key					
Outline = Executive		Fill = Employee		Orange = Trade background	Purple = Knowledge work background
ID	Age bracket	Gender	Years of Industry Experience	Role	Experience
P1	45-54	Man	25	Business Executive, former Surveyor	Executive at a large building services company, as well as a construction data management and digital information initiative. He has a background in the regulatory space, having worked as surveyor issuing building permits.
P2	55-59	Man	40+	Business Executive, former Builder	Business leader of a large commercial construction company, with construction management experience across various large construction companies. Studied a building degree and grew up on construction sites while working for his Dad. Worked his way up from labouring onsite, to managing a large business.
P3	65-69	Man	40	Business Executive, former Mechanical Engineer	Director at a large building services company. He has a background in mechanical engineering, and a keen interest in technology innovation.
P4	35-39	Man	17	Project Manager, former Builder	Project manager for a commercial building company. He has prior trade experience in residential construction with a volumetric builder, went into administration then switched to commercial construction.
P5	25-29	Woman	3.5	Graduate Civil Engineer	Graduate project coordinator, specialising in 'structures'. She is a civil engineering graduate and worked as an undergrad in infrastructure, before moving into the building sector.
P6	55-59	Man	35	Surveyor and Business Leader	General manager for a consulting firm, where he specialises in building surveying. He has a background as a structural engineer then did a post graduate degree in building surveying. He also has experience in the regulatory space.
P7	50-54	Man	30	Property Development Director	Property development director and digital transformation advisor for private and public sectors. He has a background in construction and a keen interest in emerging technologies, particularly data management.
P8	18-24	Man	4	Construction Cadet, former Welder	Cadet at a construction company, currently studying a bachelor of construction management. He started working in construction as a welder, then decided to study building design. His Dad and Uncle work in bricklaying and plastering.
P9	40-44	Man	24	Plumbing Inspection Advisor, former Plumber	Plumbing inspection advisor for a regulatory body. Originally a plumber by trade, working on residential and industrial projects.
P10	60-64	Man	37	Union Representative	Union representative, working in their OH&S unit. He started labouring at 25, then did a Diploma of Occupational Health and Safety (OH&S), Graduate Diploma in Occupational Hazard Management and a PhD in OH&S.
P11	55-59	Man	40	Inspection Manager	Inspection team manager for a regulatory body. He trained as a plumber then started his own business with his Dad who was a gas fitter.
P12	60-64	Woman	40	Educator and Commercial Architect	Commercial architect and educator at a technical institute, interested in emerging technologies. She trained as an architect and went into commercial construction.
P13	25-29	Man	12	Educator and Carpenter	Carpentry educator at a technical institute. He trained as a carpenter and worked on residential buildings before moving into education after a workplace accident.
P14	55-59	Man	35	Surveyor and Business Leader	Registered building surveyor and building regulations expert at an industry peak body. Trained as an engineer and then worked as a building inspector and surveyor.
P15	35-39	Woman	13	Project Manager and Mechanical Engineer	Senior engineer at a large building services company where she also plays a role in their business development. She trained as a mechanical engineer and worked her way up from being a graduate to senior leader at her current company.
P16	18-24	Woman	6	Trainee Draftsperson	Draftsperson at a large building services company. Started as a trainee draftsperson at her current company, after finishing high school.
P17	40-44	Man	21	Work, Health and Safety Exec	Work, health and safety manager at a large building services company. Started with a project support role, working with project managers and site managers in his current company, then moved into working in safety and industrial relations.

Figure 3: We recruited 17 participants (4 women, 13 men) for our study. Although men were more represented, this reflects both our effort to balance roles and perspectives, as well as the broader gender imbalance in the AEC industry [26]. Participants brought diverse experiences spanning business, trades, regulation, design, engineering, project management, health and safety, and digital innovation, which we captured from their interviews and provide in the table. They represented a range of career stages and expertise. Their industry experience averaged 25 years, ranging from 3.5 to 40 years.

scale to indicate how strongly it prioritised the different tensions (1, weakly prioritises to 7, strongly prioritises). These ratings were not analysed quantitatively but used to contextualise participants' qualitative reflections. The participants were shown the brochures randomly each session to mitigate ordering bias in the conversations.

4.1.3 Part 3: Questionnaire. Sessions concluded with a short demographic and technology experience questionnaire (results in Figure 8 in the appendix).

4.2 Data Analysis

All interviews were conducted by one researcher for consistency, audio-recorded, and transcribed in DoveTail³. Transcripts were analysed using Braun and Clarke's Thematic Analysis [19]. Two researchers led the coding, starting with a deductive framework from the research aims and adding inductive codes for emergent insights. The codes were iteratively refined, reviewed mid-way by the team, and consolidated into themes collaboratively to ensure alignment with the research objectives.

³<https://dovetail.com/>



Figure 4: Brochure Set 1: Job Satisfaction and Continuous Learning: These brochures depict a future where learning new skills and job satisfaction are prioritised over traditional skills and productivity. Safety and quality also take precedence over rapid technology implementation. The supporting technologies depicted include: (1) AR safety glasses deliver on-site training, (2) the ParallelBand for biometric-based learning, and (3) a custom controller for accessible AI and robotics management.



Figure 5: Brochure Set 2: Productivity and Mastering a Craft: These brochures depict a future where traditional skills and productivity is prioritised over learning new skills and job satisfaction. Rapid technology implementation also takes precedence over safety and quality. The supporting technologies depicted include: (1) a bone conduction headset for voice-activated interaction with building standards, (2) a 360° camera for tracking project progress, and (3) a hybrid leveller that integrates measurements and approvals with a digital twin of the building.



Figure 6: Brochure Set 3: Everything Remote: These brochures depict a future where productivity and job satisfaction are prioritised over retaining traditional skills and learning new skills. Rapid technology implementation, safety and quality are equally important. The supporting technologies depicted include: (1) a fitness app for wellness and stress reduction, (2) an AI-powered ear cuff for project updates and reminders, and (3) an ergonomic chair with controls for remote robotics and site navigation.

4.3 Participants

For the critical discussion and reflection on the speculative artefacts (the main data we report on in this paper), we recruited 17 industry participants (13 men and 4 women). **Figure 3** shows the background information on each participant, including their age bracket, gender and years of experience. These 17 participants were involved in the study, where as the co-design industry representatives listed in **Figure 7** (Appendix A) were involved in designing the brochures used as stimuli in the study. Participants' familiarity with technology is shown in **Figure 8** (Appendix A), which lists the emerging technologies they self-reported using in their work and more generally, the emerging technologies used by their organisation. We aimed to recruit a diverse range of voices in different roles and career stages. Participants were recruited through the industry representatives' organisations (see **Figure 7, Appendix A**). All participants were employed full-time and nominated by their respective organisations to take part in the study. We ensured that the interviews were conducted during work hours.

4.4 Position Statement

Our research team combines expertise in HCI and Industrial Relations. In line with reflexive thematic analysis [8], we treat our positions as analytic resources that informed how we interpreted the data. The first author conducted and coded all the interviews. She has experience working in IT and management consulting, where she previously worked on projects within the AEC industry that sought to improve the data sovereignty and sustainability

practices. Identifying as woman, her experience working in male-dominated industries and growing up as an Australian immigrant has heightened her awareness of belonging and inclusion, informing her interpretation of participants' responses. The second and fifth authors have expertise in labour relations, worker rights, and organisational politics. Their perspectives directed our attention to how emerging technologies reconfigure power, including ongoing questioning of who productivity benefits and how it is defined across roles. We collaborated with representatives from five sponsoring organisations, a regulatory authority, industry peak body, real estate developer, building services company, and a training institution (disclosed in Figure 7, Appendix A). Their perspectives helped us to understand sector-specific practices and language. We engaged with these perspectives reflexively, recognising how they introduced particular institutional viewpoints into the research. The project was funded by an industry based Cooperative Research Centre (CRC), of which the sponsors are members. The CRC has independent research committee with formal procedures and structures which governed the research project. Our role as university researchers with HCI expertise brings traditions of academic practices and human-centred perspectives. Together, these positionalities informed the development of the themes and their interpretations.

5 Findings

We identified two key themes that address our first research question (RQ1). Consistent with speculative design as a method for constructing questions rather than proposing solutions [30], each theme is presented as a provocation for future research in HCI. We engage in a critical discussion of these provocations in section 6.

5.1 Theme 1: Different Views on Productivity

The first theme captures perspectives on workplace productivity. Participants expressed a range of views that illustrate their complex relationship with technologies that enhance productivity. These perspectives go beyond participants equating productivity with efficiency. It captures how improved productivity can include a sense that technologies make work more satisfying. However, perhaps counter-intuitively participants expressed that improving productivity sometimes means slowing down to learn new technologies or investing in tasks that take more time. These ideas are captured by following subthemes:

5.1.1 *There was a desire for technologies that make work easier or more efficient to focus on creating satisfying jobs.*

Indeed, P1 valued the satisfaction tied to efficient work, provided they are not "overloaded":

P1 *"I'd be able to be more efficient [...] surely unless you're overloaded, surely that would be better job satisfaction."*

Similarly, participants from both employee and executive roles, as well as trade and knowledge work backgrounds (P9, P10, P15) voiced reluctance to focus on productivity as efficiency alone. In particular, P10 suggested that technologies should create better jobs, with productivity emerging as a by-product.

P10 *"People just want better jobs, because if there're better jobs, they're more productive"*

As P15 further explained, making work "less frustrating" or more "rewarding" could be just as valuable as increasing the speed of completing the task.

P15 *"I think, obviously, if you can get something done quicker, or eliminate something altogether so that you don't have to do it [that's good]. But also, maybe there's like an aspect [where], you may still have to do something, but it's somehow done in a more rewarding way, or it's less frustrating to do it [...] not necessarily quicker, but just easier."*

Technologies that automate or make tedious aspects of work more enjoyable were welcomed. Participants across different roles and skills exemplified mundane administrative tasks that distracted from more meaningful contributions (P1, P2, P5, P8, P16). For example, P5 described how automation could make a project more fun.

P5 *"Getting caught doing all the other admin stuff, a lot of time prevents you from doing enough checks. So doing, having these running all the time and doing those checks for you is gonna, it will prioritise your quality, but it will, it will give you a better output, a fun product."*

Many participants (P1, P2, P4, P5, P6, P9, P10, P11, P12, P13, P15, P16) emphasised the opportunities for futuristic remote technologies to provide a healthier work-life balance. For example, P4 and P16 reflected on how remote work technologies could reduce overwork, support modern family expectations and promote inclusivity.

P4 *"we've got families, we've got other priorities, [...] more about ourselves, our health, our family. You know, dropping kids off at school, that kind of stuff. So I'd be looking for anything that could sort of help me minimise [working overtime]."*

5.1.2 Participants recognised that, perhaps counter-intuitively, improved productivity also meant slowing down to learn new technologies or communicate with others. P6 points out the "chicken and egg" challenge of investing in learning new productivity tools, where they have trouble finding time to upskill or implement new productivity tools, especially when they are comfortable with the current way of doing things.

P6 *"So it's a bit of a chicken and the egg type thing that, we're too busy to actually implement it, but if we implemented it it would make us less busy [...] So if we can actually dedicate some time to start adopting and implementing some of these, that will actually release more time [...] and so I think it will be a snowball effect if you can invest that time and effort [...] But it is hard work because you're busy doing what you're doing, [...] you go to your comfort zone of things and ways you know how to do things and then as soon as you start stepping out of that to these new areas, you're not as confident or, committed quite often."*

While autonomous robotics and technologies that support remote work were seen as offering certain individual benefits:

P2 “[I can probably do] 12 hours worth of work in 6 hours [at home because] I don’t have people coming in and asking me questions [...] or someone arrives at reception and wants to catch up with someone to talk about a job or whatever it is. All those distractions are taken away and it makes life a lot easier.”

However, participants also acknowledged the limits of focusing only on individual efficiency. As **P16** admitted, the desire for uninterrupted solo work can conflict with the collaborative demands of the industry.

P16 “I am guilty sometimes. I just want to have an easy day at work. I just want to model and that’s all I want to do. I just want to work through, you know, that particular task, but it’s not like that every single day — there are days where you have to collaborate.”

This tension between individual efficiency and “slowing down” to communicate with others is especially salient in the AEC industry, where specialised services (e.g. design, engineering, project management, construction) must ultimately coordinate to produce a shared, tangible output: the completed building:

P15 “I suppose sometimes it’s not so much about my part in that, but a downstream part in that as well. Perhaps it’s doing something that doesn’t directly benefit me, but I know is making the process for someone else downstream easier. [...] It’s like a productivity for them, might not be for me, but that tech is still obviously beneficial if it’s helping out down the road.”

Across both subthemes, participants stressed that “productivity” cannot be understood as speed or efficiency alone. They wanted technologies that make work easier, less frustrating and more meaningful. Perhaps by reducing administrative burdens and supporting healthier work-life balance, while also recognising that genuine productivity sometimes requires slowing down to learn new tools or coordinate with others to support downstream collaborators. These insights reframe productivity as something created through satisfying and sustainable ways of working rather than simply doing tasks faster.

Provocation 1: How could productivity be reframed to prioritise experiential aspects, beyond speed, and efficiency?

5.2 Theme 2: Connecting and Applying Different Types of Knowledge

A defining feature of AEC work is creating tangible structures that people can see, inhabit, and experience. In responding to the brochures’ alternative futures, participants emphasised that this connection to making something “real” was what attracted them to the industry. Producing a physical output requires embodied knowledge about materials, developed through hands, tools, and bodies interacting in space. Participants discussed how emerging technologies may mediate this bodily connection with the external world, either enhancing or diminishing the satisfaction of contributing to the built environment and the chance to apply their learnt skills. These ideas are captured in the following subthemes:

5.2.1 Technological automation appears at odds with people’s pride in applying learnt embodied skills. Most participants (**P1**, **P2**, **P3**, **P5**, **P7**, **P8**, **P13**, **P15**) agree that seeing the final physical building is a major source of satisfaction in their work. This is true of people who have experience in a physical trade, like **P13**, a carpenter turned trainer.

P13 “I’ll take my wife every single time I go for a drive around a certain way because I’m like, I built that house down there [...] it’s a satisfaction of going, [...] I built that one, I built that one, I built that one. And I feel like the apprentices [...] they all do the exact same thing. Like they’re quite proud of their work [...] they’ve all got folders on their phone of everything they’ve done in their whole career so far.”

As well as those with knowledge work backgrounds like **P7** and **P15**:

P7 “[The craft] is more romantic [...] I can still smell wood being cut and I don’t know, the smell of fresh concrete [...] symbolises a space and a place for me where this [remote hub with robotics] doesn’t feel like [...] you’re gonna get close to it.”

P15 “So, although I’m not a hands-on person, I still really get a lot of satisfaction from that physical side of [projects].”

This affinity with the physical output is the key reason why many participants joined the AEC industry in the first place. Similarly, Participants like **P8** and **P13**, with trade backgrounds, describe a sense of pride in seeing their embodied contribution to the construction of the building. As a result, the possibility of outsourcing the skills that they have invested in to a robot would not feel satisfying.

P8 “I’ll drive past the job and I’ve got my girlfriend in the car and I go “oh yeah, I remember working here, I did this, I did that,” [...] it’s more rewarding [than] if you say, “oh yeah, a robot did that.”

P13 “[...] I don’t think I would get much job satisfaction with it, [...] [it] feels like I’m setting the machine up to go. I don’t know, it almost feels like if you’re making a cake or something, if you buy a cake mix in a box, it feels like the work’s already done for you. But if you do it from scratch, you have more satisfaction from it.”

This desire to maintain embodied skills juxtaposes the goal of engineering systems to eliminate human variation. **P14** explains how, in modern methods of construction that engage in human-robot interaction, skilled carpenters can introduce errors into the engineered system if they follow their trade-based intuition rather than the programmed-based instructions.

P14 “If there’s a virus in the system [...] call it the carpenter who thinks he knows better than the system, then unless we catch it and stop it, then that’s always going to end up being a problem [...] the computer actually will spit it out and say you need to put stud there, stud there, stud there, there, stud there, stud there [...] if you’ve got somebody who’s adjusting stuff it pushes it out.”

However, P13 highlights how the tacit knowledge gained through training as a carpenter contributes to smoother building projects overall. Specifically, carpenters' attention to detail, such as accounting for the natural bows in timber, ensures that parts arriving on site are easier to assemble for the team.

P13 *"For an example, like when you learn to frame walls on apprentice, you'll have your bows in your stud and your bows if you're doing an external wall and standing up that way, your bows will always [go a certain way] [...] Where if it's a prefab factory, they're not checking for bows or anything like that, they don't care, they just want the product out [...] They're just chucking studs in, so it's go, go, go."*

Notably, many employees across both trade and knowledge work (P5, P8, P10, P12, P13) echoed this desire for their years of training and applied expertise to be valued, suggesting points of commonality across the AEC ecosystem.

P10 *"[businesses] haven't utilised the knowledge and the skill and the experience, which is sitting dormant on the shop floor, [...] They're not getting involved and then people are just feeling, you know, disenfranchised, disheartened, [...] they realise they've got no control over their work life, 'What's the point?'"*

5.2.2 People expressed how their body plays an important role in learning. A common suggestion for supporting physical skills and traditional knowledge is to retrain workers into different roles. However, our results showed some fundamental challenges with this kind of upskilling and transfer of knowledge. For example, P10 explained the socio-political challenges, where some people go into a trade because they were not afforded the opportunity to develop certain literacy and numeric skills.

P10 *"Our training unit, I think they put 10,000 people through a year and I think it's, it's a 60% or 80%, it's a staggering amount of people who need some type of assistance in numeracy and literacy when they're looking at a brochure or a manual, you know, how to read that, [the help required is] quite high."*

The discrepancy between the intended new skills and existing worker proficiencies creates significant challenges. If opportunities for reskilling in robotics or modern methods of construction is reliant on a certain method of teaching or mode of information that does not make learning accessible, then different approaches need to be considered. P13 emphasised a preference for kinaesthetic, hands-on learning, contrasting it with abstract, text-based instruction.

P13 *"Most of the kinaesthetic or the tradie blokes [...] if we watch a video of someone else doing it once, we seem to understand it better than reading a book or something like that. But if you've got the AR glasses showing you as you're doing it, I think it would be great."*

There are some opportunities for technology to support rather than automate embodied work. For example, P17 described a desired future where augmented reality and AI technologies provide a more proactive and physical approach to safety reminders.

P17 *"I don't see [technologies] being a risk for people that use them every single day. There's a lot of our team that do use them every day [...] whereas people that use them rarely need to do them 5 yearly just to confirm [they're compliant]. They're probably the ones who need more training, and ideally you'd use VR to be able to do that training without going to an expensive classroom. You go and actually take it out to the site and they can do it on the site they put that on and then confirm that they know how to do certain checks and how to do certain things."*

Alternatively, the speculative brochures prompted participants to imagine using a combination of GenAI and augmented reality (AR) to aid workers on the building site. For most participants across the system (P4, P5, P6, P7, P8, P9, P10, P11, P13, P15, P17), this was an unsettling idea. In their eyes, this technology could enable anyone (with little or no experience) to follow step-by-step guidance and achieve results previously reserved for skilled trades. P4 worried that relying on AI and robotics could normalise having unskilled workers on-site, undermining traditional apprenticeship models and the trust placed in passing down expertise from experienced professionals.

P4 *"That kind of worries me a little bit in terms of people should know their task before they get there [...] I shouldn't be teaching them how to do their job while they're there. So that does genuinely worry me a little bit [...] the apprentice shouldn't be sitting there learning off AI or a robot, the apprenticeship you learn off someone [who has a] huge amount of skill in the industry."*

Some junior participants questioned the logic of learning certain skills in the first place if "AI can do it".

P8 *"Sometimes I think AI probably removes learning. That's very contradicting. But If AI can do it, what's the point of learning it?"*

Yet other experienced participants, who primarily act as knowledge workers in the system, warn against "shortcut culture". In P15's perspective, relying on AI could lead junior staff to miss important contextual understanding, learnt through directly engaging with the construction standards in full.

P15 *"One of the things we find at the moment is the younger generation coming through are far, far more inclined to [...] just go straight to the answer that they're looking for. [...] which is actually a little bit of a concern for the more senior people, because standards are a [...] weirdly written document, right? And quite often you find that if you take a little piece without reading the context, it maybe doesn't actually give you the same answer or the same outcome. So we're [...] constantly encouraging people, as boring as it is, you need to go and [...] understand the document as a tool before you can start taking pieces out of it."*

Similarly organisational leaders with a trade background such as P1, believe certain skills in the AEC industry require time invested in people going on site and getting close to the context a skill is carried out in.

P1 “A set of experiences over the time with doing all these inspections, going to site and picking up these skills that you inherently don’t get from a textbook. So, the, there’s a difference, in my role as teaching, graduates coming through, you can learn as much as you can learn from a textbook, but learning from on the job and getting out there and seeing it and seeing what it does is quite valuable.”

Throughout these subthemes, participants across all roles and skill backgrounds, consistently emphasised that AEC work relies on embodied, hands-on knowledge and the satisfaction of contributing to something physically real. While emerging technologies offer opportunities to support training and on-site decision-making, participants worried that excessive automation or over reliance on AI could undermine the development of skills across knowledge work and trades that both require embodied training.

Provocation 2: What would systems look like if they were designed for the intersection of cognitive and embodied skills development?

6 Implications and Discussion

“To innovate the vessel was already to innovate the shipwreck [...] each period of technological development, with its instruments and machines, brings its share of specialised accidents, thus revealing ‘en negatif’ the scope of scientific thought.”

— Paul Virilio [99]

Based on the provocations that arise from the themes above, and in response to (RQ2), we propose directions for future research, which include both an optimistic solution and *en negatif* perspective [99]. While it is important to direct our efforts away from possible dystopic futures, an exploitative future under the guise of a utopia is no better. As proposed by Lin and Lindtner [51], we do not shy away from the negative possibilities of technological innovation. Rather, we accept that with any new invention or way of being, there are potential negative outcomes that demand consideration.

6.1 Productivity Research that Values More than Efficiency

Provocation 1: How could productivity be re-framed to prioritise experiential aspects, beyond speed, and efficiency?

Our findings continue to challenge assumptions that productivity primarily serves to encourage busyness, speed, or increased output [35, 49, 50]. Although participants cautioned against rising workloads due to technologies framed as boosting productivity, some talked about experiencing satisfaction when tasks became safer, less frustrating or beneficial to others downstream. These accounts corroborate HCI research with knowledge workers, that links perceived productivity to positive experiential factors, such as job satisfaction [33, 44, 46] and self-efficacy [48].

While HCI research focusing on knowledge work has established a link between productivity and job satisfaction [33, 46, 48], to the best of our knowledge, there are few studies that critically

examine this link. Kim et al. [46] note that the “emotional state” of workers affect productivity, yet do not elaborate on this link. Guillou et al. [33] go further to suggest using the metric “time well spent”, illustrating how “the way people feel” and “satisfaction” is an element of this metric. Kaur et al. [44] measure the emotional state of participants, relying on organisational behaviour studies on the “happy-productive worker hypothesis” that states happier workers are more productive [97]. We call to mind Frøkjær et al.’s [28] influential paper that examines usability measures, arguing that “efficiency, effectiveness, and satisfaction should be considered independent aspects of usability” [28, p.351]. We suggest that, given the link our results emphasises between job satisfaction and productivity across both knowledge work and trade skills, there would be significant value in a similar study being carried out to critically examine these links and measures of productivity in HCI.

Beyond job satisfaction, participants’ reflections highlighted a need to slow down to learn or communicate with others, which supports productivity not only for themselves as individuals but for their workplace as a whole. This supports emerging arguments that, productivity is achieved in the first place by investing in time to learn and innovate [91]. However, as discussed in section 5.1.2, participants found that innovation is often most needed at the very moments when workers are too busy to step back, reflect and imagine doing things differently. Some participants noted that investing time in mastering new skills can feel counter-intuitive if it temporarily slows down output, even though such learning may ultimately have long-term benefits.

While slow technology has traditionally been positioned in opposition to efficiency and productivity [68], our findings suggest workers perceive it as not needing to be the case. Participants across both knowledge and trade roles were generally supportive of productivity, but acknowledged the importance of reflection to improve productivity and job satisfaction. Rather than positioning productivity and reflection as opposites, slow technology could be used to inspire new workplace tools and interactions that deliberately nudge people to pause, reflect and learn as part of their everyday practice. In design traditions more broadly, reflective design aims to bring “unconscious aspects of experience to conscious awareness, thereby making them available for conscious choice” [84, p.50]. For example, Xu et al. [102] recently demonstrated how supporting reflection through AI work tools can encourage critical thinking. Taking this a step further, future technologies might oscillate between slowing down to learn and grow, and providing a “tailwind” that allows people to enjoy a flow-state of applying their hard-won expertise. For example, Tankelevitch and Kewenig et al. [96] suggest that the demands of interacting with GenAI systems can be addressed by (1) providing metacognitive supports that help users reflect on their own processes, or (2) reducing metacognitive load by offering clearer explainability and customisability. We highlight a design opportunity to deliberately pace technologies so that they oscillate between supporting deep metacognitive reflection and reducing mental load. In practice, this could mean systems that, at times, slow people down to encourage critical awareness of their work [102], or to a more frictionless flow state.

In adopting Virilio’s *en negatif* perspective [99], we encourage researchers to think critically about what it means to focus design goals on job satisfaction and embed the idea of reflective design and

slow productivity [65] into workplace technologies. For example, redesigning technologies with productivity as a means to do more satisfying work might be an exploitative pursuit if workers are not given autonomy over this decision. Sara Ahmed [1] recounts in *The Promise of Happiness* the “long histories of scholarship and activism which expose the unhappy effects of happiness, teaching us how happiness is used to redescribe social norms as social goods” [1, p.12]. While the pursuit of ideals like job satisfaction may appear well-intentioned, researchers must ask who is defining satisfaction. In this case, we as designers are stating that this satisfaction is something other than the social pressures of adding value by cramming as many outputs into the day as possible. However, this reframe does not alter the underlying power dynamics between employer and employee. Ultimately, employers, even alongside employees, are still poised to reap rewards of any improved productivity. Here, the ethics of nudge theory [36] become particularly salient. Efforts to ‘nudge’ workers toward reflection or satisfaction may, without safeguards, become coercive strategies that instrumentalise well-being in the service of monetary gain [36]. This has an eerie ring of the ‘happy slave’, a politics that demands others live according to a wish [1], perhaps instigated by employers or even by us as designers.

To reframe productivity around experiential qualities rather than efficiency alone, workers must retain autonomy over how the benefits of technology are realised. Without this autonomy, even well-intentioned efforts to support satisfaction risk becoming coercive. For example, prescribing how wellbeing should be achieved and instrumentalising it toward organisational output. Kaur et al.’s [44] AI-powered break-encouragement system demonstrates this tension in aiming to “keep workers happy so that they stay productive”, whereas participants in their study wanted to “improve productivity so that work becomes safer, easier, and more enjoyable”. Our findings show this dichotomy: P1, speaking from an executive perspective, assumed that increased speed or output in “doing two projects instead of one” would naturally produce satisfaction, whereas P10 imagined a future in which meaningful, satisfying work produces productivity as a by-product.

These opposing orientations have the potential to encourage fundamentally different designs. In Kaur et al.’s system, the break-recommendation feature proposes future tools to “avoid disrupting people’s focused work times” [44, p.9] stressing the need to time an “opportune” moment to take a break, which they frame as making people happier. However, if designed from P10’s perspective, perhaps the authors might have emphasised how their tool could help workers stop “hours turn[ing] to blurs without something to break them up” [44, p.9], perhaps suggesting how workers can design breaks or self-reflections in their day so that they feel more present and autonomously improve their working conditions. Based on our participants’ aspirations for the future, we urge HCI researchers to examine whether technologies optimised for organisational goals genuinely achieve the same ends as those shaped around employees’ desires. Designing for one is not equivalent to designing for the other, and conflating the two risks reproducing the very productivity pressures such technologies seek to address.

6.2 The Intersect of Cognitive and Embodied Work

Provocation 2: What would systems look like if they were designed to focus on the intersection of cognitive and embodied knowledge?

Our findings showed that both participants with a knowledge work and trade background felt a strong connection to the tangible outputs of their work, whether through hands-on trades or more theoretical applications of knowledge. Satisfaction was closely tied to feelings of self-efficacy and ownership over what they produced. In response to the speculative brochures, participants frequently expressed concern that these imagined futures abstracted human bodies away from the physical outputs of work.

Several participants with trade expertise worried about being pushed into administrative or roles where they supervise robots doing the skill they once learnt, distancing them from the tangible outputs of their labour. While such views might be dismissed as “resistance to change” or nostalgia for traditional skills [32], this interpretation overlooks the deep human connection between effort and outcome [67], especially when that outcome is a physical artefact like a house. Beyond earning a wage, participants expressed a fundamental desire to remain connected to the *making* process, and to see the tangible outcome of their skill development. They feared being reduced to supervising robots performing tasks less skilfully than they could themselves, a scenario they described as dissatisfying, disenfranchising, and devaluing of their expertise.

The promise of “new jobs” in an automated future did not inspire enthusiasm. Participants believed that these new jobs were likely to demand extensive retraining (that they had little time to pursue), relied on levels of computer literacy (that made the retraining inaccessible), or represented work that did not align with their interests or expertise in embodied work. According to participants with a trade background (e.g. P8, P10, or p12), training approaches currently applied in the industry often default to text-heavy, abstract formats that privilege knowledge work styles of learning. Instead they emphasised the value of tactile, spatial and kinaesthetic forms of mastery. Furthermore, participants from a knowledge worker background (e.g. P15 or P5) also expressed a desire for knowledge to be situated out of the computer and in the world. Based on these desires, we suggest there is opportunity for HCI research to represent abstract concepts like work scheduling in physical spaces. Similar to Henning and Hornbæk’s system [74], which uses augmented reality to move abstract calculations into the ‘physical world’, future systems might use augmented reality to overlay the next stages of a building project into a physical space, communicating dependencies between different elements on a building site in a more tangible way.

HCI has a strong recognition of how the human body is crucial in both trade [7] and knowledge work [47]. However, the field has perhaps been guilty of either focusing on knowledge or trade work in separation, without a consideration of how these skill sets are symbiotic in many industries. Much of the discourse on GenAI has centred on knowledge work, for example, by optimising remote team meetings [14, 83, 98] or writing text-based materials or other knowledge worker outputs [48, 101, 104]. Our findings highlight a need for greater consideration of the overlap between cognitive

and physical forms of work; where industries like AEC, require knowledge workers (e.g. architects, engineers or project managers) to understand how physical materials are constructed and tradespeople (e.g. plumbers, roofers and electricians) need to understand how modern modes of scheduling works to autonomously negotiate how their work ties into a larger project. A combination of augmented reality (AR) and GenAI may help to bridge these modes of work [94]. However, our participants also voiced concerns that entirely remote solutions could compromise safety and erode the sense of place that anchors embodied skill; like the evocative ‘smell of wood’ that affirms the reality of making. Future technologies should respect both cognitive and tangible practices, with the recognition that productivity should recognise that embodied expertise develops slowly, and that time for learning is itself a crucial part of productive work.

However, from an *en negatif* perspective, further integrating AR and AI into workplaces with the wrong goals can risk sidelining the embodied knowledge that has long underpinned expertise in the AEC industry. On-site training through headsets can create the illusion that complex skills can be acquired by simply following prompts, reducing learning to surface-level interactions rather than the tacit, embodied practices developed through mentorship and repetition. Indeed, participants feared this shift might threaten professional identity and also weaken pathways for transmitting craft knowledge between generations. The push to automate, accelerated by global pressures such as housing crises, compounds this risk: rather than respecting workers’ accumulated expertise, technological change often seeks to remove humans altogether, treating them as obstacles to efficiency. Participants themselves noted this trend, with one comparing the engineering tradition to removing a “virus” from a system. However, such approaches fall prey to the false promise of artificial productivity gains. As Bainbridge’s “irony of automation” [5] reminds us, attempts to remove human effort merely displace it elsewhere, often in less supported, more precarious roles. Participants echoed this, observing that speculative technologies would still demand oversight and coordination, a finding echoed in contemporary analyses of GenAI [87]. What emerges is not greater productivity, but a redistribution of labour that undervalues embodied knowledge and leaves workers unprepared for new roles.

Based on our findings, we invite HCI researchers to consider how productivity might improve if technologies are designed to build on, rather than bypass, the embodied skills workers already possess. P14’s description of embodied intuition being treated as a “system virus” exposes a deeper issue where AI and AR systems implicitly assume that expert deviation is noise to be corrected rather than knowledge to be understood. Our findings suggest that, instead of enforcing behavioural conformity, future systems should be designed to *interpret unexpected actions as potentially meaningful expressions of tacit expertise*, particularly in domains where skilled, embodied labour is important. This could be achieved by designing for *Interpretive Flexibility*, in which systems treat deviations from predicted behaviour as candidate signals of situated knowledge rather than as errors. Unexpected human corrections, can instead be provisionally recognised as *expert cues* to consider and integrate into the broader system, especially when performed by experienced

workers. Such systems will require a careful consideration of expert and novice definitions. In these framings, expert intuition is not a “virus” to be removed, but a source of value that technical systems must learn to recognise and build upon.

7 Limitations and Future Work

Our study focused on the Architecture, Engineering, and Construction (AEC) industry. This context enabled us to investigate an under-examined space where cognitive and embodied work intersect, offering HCI researchers valuable insight into a large and globally significant workforce. However, the specific organisational structures and regulatory pressures of the AEC sector may limit generalisability to other domains. We sought to mitigate this by focusing on transferable aspects of work, such as coordination, craft expertise, and the creation of tangible outputs. Future research should consider how differences in project requirements, skill compositions, and power relations across industries might influence the applicability of these findings.

Our sample of 17 participants aligns with similar qualitative and speculative HCI studies [16, 80]. This approach provides rich qualitative insight into workers’ subjective aspirations and concerns for future technologies. These insights can guide subsequent studies employing more quantitative methods. We acknowledge that the in-depth nature of our interviews and the time required to complete these, meant that not every role in the AEC sector could be represented. However, we provide detailed participant backgrounds to illustrate the diversity and complexity of their cross-disciplinary experiences.

A key strength of the study was engaging a wide range of industry experts over the project’s year-long duration. However, not all participants could be involved at every stage. Instead, we maintained group of industry representatives (Appendix A) who guided the design process and informed the final speculative brochures, while later participants (selected to ensure role diversity across surveying, site trades, engineering, architecture, and management) responded to the probes rather than co-creating them. This discontinuity may have influenced how tensions were framed, although we believe the diversity of perspectives ultimately strengthened the analysis and revealed how different roles and generations respond to the ideas informed through our co-design workshops.

The sliders used to inform our speculative brochures were designed to produce futures that felt uncanny yet grounded, aligned with speculative design best practices [4, 80]. These probes intentionally leaned toward utopian futures to encourage critical reflection. We intentionally positioned the sliders to introduce uncanny futures (e.g. the unlikely pairing of improved productivity and retention of traditional skills). While this approach encouraged critique, the emphasis on optimistic scenarios may have limited exploration of more dystopian perspectives.

Finally, we used the sliders as a design tool to generate artefacts that visualised the tension and co-existence of seemingly opposing values (e.g. productivity and job satisfaction, or productivity and traditional skills). Even though this approach helped challenge assumptions suggesting these values are inherently in conflict, it may also risk implying zero-sum trade-offs between the values. Future research should examine the methodological implications of

using such sliders in speculative design, particularly their capacity to balance clarity and complexity.

8 Conclusion

Productivity cannot be understood merely as a ratio of outputs to inputs. By engaging AEC workers with speculative design artefacts, we share how productivity is lived, negotiated and contested across diverse roles. These reflections remind us that technologies promising to “save time” are never neutral. They redistribute effort, redefine expertise, and recalibrate the value of human contribution.

Through provocations produced by the findings we critically engage with three opportunities for HCI research, providing both *en negatif* reflection and positive direction forward. First, we show how reframing productivity as a pathway to job satisfaction, not simply as output maximisation, can inspire alternative directions for technology design. Second, we demonstrate the importance of foregrounding embodied work, cautioning against technological trajectories that treat physical expertise as inefficiency to be eliminated.

More broadly, this research contributes to a growing body of HCI scholarship that critiques the taken-for-granted logics of productivity, seeking to reclaim it in the service of social as well as economic outcomes. As researchers and designers, we are faced with a choice to continue pursuing ever-greater efficiencies or to cultivate futures where productivity is a means to more fulfilling, sustainable, and dignified work.

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A Appendix

Key: Outline = Executive Fill = Employee Orange = Trade background Purple = Knowledge work background Green = Mixture Knowledge Work and Trades

ID	Age bracket	Gender	Years of Industry Experience	Role	Experience
IR1	65+	Man	25	Director for Applied Research and Innovation	Dean faculty of Building Construction and Engineering (15 years), research including building and construction (10 years).
IR2	40-44	Man	21	Digital Strategic Partnerships Exec	Structural Engineer on multiple building types, moving to a supplier of mass timber products as design lead. Spent 10 years in a developer building mass timber buildings, and more recently in design automation software.
IR3	45-49	Man	25	Research Development and Education Manager and Architect	Specialises in the manufacture and design of buildings made offsite using advanced methods of manufacturing. This came after spending the first 15 years finding construction generally inefficient and cumbersome.
IR4	50-54	Woman	10	Manager, Research and Evaluation	Working in a regulatory agency, managing licensing and registration functions, and managing the research program.
IR5	60-64	Man	25	Senior Technical Advisor - Sustainable and Future Built Environments	Sustainable Building Advisor for a Peak Body for the past 20 years and worked on building and construction related projects and research for the last 24 years. Extensive experience in education and training has informed the development of nationally recognised sustainable construction training programs. Extensive experience working with regulator organisations.
IR6	Prefer not to say	Prefer not to say	9+	Chief Analyst	Worked 9+ years for a regulator as their chief analyst.
IR7	30-34	Man	11	Prefabrication Leader	7 years as an engineering then remaining time in current role.
IR8	30-34	Man	11	Business Analyst	Prefab Manufacturing for mostly residential Construction.
IR9	30-34	Man	14	National Engineering Manager	Previously worked as a consulting structural engineer in the buildings space. Now have moved into a engineering lead role at BlueScope steel in manufacturing of composite metal decking.
IR10	50-54	Man	35	Consultant	Engineering and construction, experience working for large construction companies.
IR11	65-69	Man	40	Director of Innovation	Director at a large building services company with a background in mechanical engineering
IR12	55-59	Man	35	General Manager (surveying)	General manager for a consulting firm, specialised in building surveying.

Figure 7: Co-design Industry Representative Backgrounds

Key: Outline = Executive Fill = Employee Orange = Trade background Purple = Knowledge work background Green = Mixture Knowledge Work and Trades

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Figure 8: Study participants' self-reported personal use of emerging technologies, and more broadly the use of emerging technologies by others in their organisation.

7. PAPER 3 – WORKPLACE TRAINING FOR CONSTRUCTION 4.0

Paper 3 is currently under review. The report will be updated when paper 3 is released.



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