CONSTRUCTION WORK FUTURES

Automation, robotics and work futures in the Australian construction industry

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FUTURES Hub

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Sarah Pink (futures anthropologist) led the AUTOWORK Australian construction industry research, and developed the first stage literature and industry material review, second stage interviews and analysis, second stage workshop analysis. Ben Lyall (sociologist) contributed to the first stage literature and industry material review, second stage interviews and analysis. Hannah Korsmeyer (design researcher) developed the third stage design and facilitation of workshops and workshop recruitment. Bianca Vallentine (project manager) delivered project management support and workshop coordination. Graphic Design is by Hatoun Ibrahim. Updates are supported by Sarah Pink’s Australian Research Council Laureate Fellowship. 2024-2029, Project ID: FL230100131.

CONTENTS

INTRODUCTION

Work Futures

As automated systems, artificial intelligence (AI), and robotics become increasingly part of organisations, workplaces and everyday life, they have become part of visions for the "Future of Work". This is equally the case for the construction industry, even though business researchers, engineers and consultants have characterised it as relatively slow to digitalise in comparison with others such as automotive and manufacturing industries.

A new Work Futures approach

This report introduces a new *Work Futures* approach to understanding work, automation and robotics in the construction industry. We propose understanding work futures as coming about in dialogue with human, technological and environmentally sustainable futures.

The idea of the singular *Future of Work* driven by technological change is flawed; history has shown that assumptions about how automated and robotic technology will change society are consistently incorrect. Our concept of *futures*, moves on from this to denote *possible futures* and *plural futures*, which are subject to change.

By focusing on *Work Futures* we ask what futures could be plausible, and how they will inevitably be reshaped or *complicated* by the contingencies of future situations that have not yet unfolded. These *complications* must inform our thinking; and to account for them we must acknowledge the possible futures of a wide range of people beyond the engineers and business consultants whose voices usually dominate. This includes tradespeople, safety specialists, educators and the industry's new tech workers (including startups from outside the traditional boundaries of the sector).

Moving on from technology-driven "Future of Work" solutions

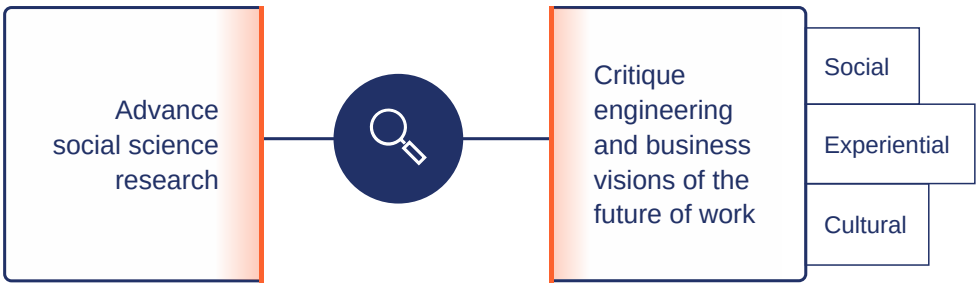
We argue that it is time for a new approach, driven by the need to account for future people and environments. Business, science and engineering visions of the future of work have speculated about how robots will replace or collaborate with human workers, and have suggested large-scale workforce reskilling will be required. Yet in promoting technology driven solutions they do not sufficiently account for the diverse people who work in the industry, they overlook social science perspectives, and they frequently fail to calculate the environmental damage related to technology development and use. Approaches driven by technological solutionism leave many open questions about changing climates, human values, and what training can encourage equitable work futures.

Construction Work Futures

Social science research accounts for the realities experienced by workers and experts with direct experience of working in the construction industry, and of employing evidence-based theories of socio-technical change (e.g. Lingard & Turner 2023, Leiringer & Dainty 2023). However construction industry research and scholarship has rarely analysed futures through the social sciences. Instead, engineering dominated approaches frequently view workers and the structure of the industry as "barriers" to technologically driven futures, which must respectively be trained and restructured to fit technological solutions.

For example, proposals that increased "robotic automation on construction sites could" reduce injury rates, undertake repetitive tasks, and help "to enable construction in settings not currently feasible" (Melenbrink et al 2020: 1) are based on the ideas of only "architects, civil engineers, mechanical engineers, computer scientists and roboticists" (Melenbrink et al 2020: 14-17).

In this report we extend research in two ways: we advance social science research to propose critical, alternative and realistic industry visions, grounded in possible future everyday realities, based on empirical research; we critique engineering and business visions of the future of work by accounting for the social, experiential and cultural dimensions of work futures.



How to read this report

This report delivers new knowledge to and a novel frame through which to contemplate work futures. It has been presented in an accessible format for busy industry, public and other sector readers. Based in rigorous academic research it offers academic researchers an introduction to our research programme.

- **Executive Summary**
  Readers interested in rapidly accessing the findings of our research should turn to Executive Summary, where our key insights, implications, recommendations, and commentary on what we don't yet know are outlined.
- **Methods**
  We have innovated new digital and in-person methods for investigating work futures, which are transferable and scalable across other industries and research fields. We share these in the methods section.
- **Perpectives on Construction Industry Futures**
  We have reviewed the most relevant academic, industry and other sector literature to reveal the key assumptions and critiques that dominate debates about the future of work in the Construction Industry.
- **Autowork Visions**
  We report on our original research with experts working within the industry to deliver new knowledge about what we can learn from contemporary experiences in the industry (Learning from experience), and the possible futures (Possible Futures) that are considered to be realistic and viable. We offer the views of our participants often in their own words (Quotes), and our own assessments of the current starting points for futures of automation and robotics in the construction industry (Implications).

Learning from experience
What we can learn from contemporary experiences in the industry.

Possible Futures
Possible futures that are considered to be realistic and viable.

Quotes
Views of our participants often in their own words.

Implications
Our own assessments of the current starting points for futures of automation and robotics in the construction industry.

EXECUTIVE SUMMARY

In this executive summary, we share ***22 Key Insights*** from our research into the possible futures of work in the Australian construction industry, offer tentative ***Recommendations*** for anticipating work futures, and reflect on ***The Unknown***, or questions that emerge from our research and motivate further investigation.

From the "Future of Work" to "Work Futures"

1

Key Insight
There has been an enduring focus on the Future of Work, but this singular approach to the future is limited and a shift to a focus on Work Futures is needed.

Recommendation
Work Futures should be understood as plural, human focused, attentive to safety, health and wellbeing and capable of balancing technological innovation with a commitment to environmental sustainability.

The Unknown
How will human values, experiences and expertise shape Work Futures?

Future visions of the Australian construction industry

2

Key Insight
Industry reports we reviewed focus on technology driven solutions for the construction industry's skills shortage and ways to improve productivity and efficiency. They see prefabrication, human-robot coworking and software development as prime solutions, and advocate for the retraining and upskilling of workers to fit the new roles these solutions will create.

Recommendation
We recommend involving worker and industry participation in the design of work and technology futures, and accounting for a more diverse range of possible future modes of working and training possibilities.

The Unknown
How will human values, experiences and expertise shape the ways technology becomes part of construction industry futures?

Construction Industry 4.0, 5.0 & 6.0

3

Key Insight
There have been attempts to align the construction industry with Industry 4.0, 5.0 and 6.0 concepts used in engineering and business fields. They tend to indicate forms of change driven by technological advancement.

Recommendation
We recommend cautious engagement with these concepts for three reasons: uptake of 4.0 and 5.0 technologies has been limited and 6.0 technologies are in development; social scientists have raised concerns about the safety, wellbeing and ethical implications of 4.0, 5.0 and 6.0 technologies; and importantly the linear 4.0, 5.0 and 6.0 stages do not directly map onto the work futures visions of the construction industry indicated by our research.

The Unknown
Will 5.0, 6.0 and further 'versions' of digital transition prove to be useful for the construction industry? To what extent will they align with the realities of the industry's digital transition?

A slow and uneven digital transition

4

Key Insight
Dominant engineering and business narratives depict the digital transition in the Australian construction industry as "slow" and behind other industries. Focus on the speed of transition and externally driven technological innovation misunderstands how digital transition occurs. Existing social research suggests that slow modes of digital innovation are uneven, but are benefiting the industry's complex ecosystems. Our research found many examples of small successful digital transitions, and demonstrated the future possibilities, benefits and value of a slow and careful digital transition.

Recommendation
We recommend that construction projects should be nurtured as sites of digital innovation and supported by long term investment in digital innovation from within the industry, rather than treated as recipients of external technological innovation.

The Unknown
What will be the next digital innovations to emerge from within the industry? And how will these set construction innovations apart from other sectors?

Future Australian innovation

5

Key Insight

Australia is often portrayed as a recipient of technological innovation developed elsewhere. However we found examples of innovations in robotic and automated technologies led by technology startups embedded in the Australian construction industry.

Recommendation

Technology startups are likely to play a key role in the future of the Australian construction industry and are important in bringing home-grown and tailored innovation to both the Australian industry and transferring this overseas. Greater investment in startups could augment this in the future.

The Unknown

Will future investment support technology startups in the Australian construction industry, and could this enable Australia to be a leader in digital innovation in the industry?

Worker engagement in digital transitions

6

Key Insight

Our research emphasised the benefits of fully engaging construction industry workers in digital transitions. We found participants' direct personal experience of the industry had supported the success of digital initiatives and the development and implementation of robotic and automated technologies. Bespoke technologies developed in and for the industry were notably successful.

Recommendation

Our findings question the feasibility of proposals that the construction industry workforce might be retrained to suit envisioned future automated and robotic technologies. We recommend that the design and engineering of new technologies should account for the complexities of work as it is experienced on construction sites.

The Unknown

What models, structures and incentives might be created to ensure that workers are engaged in and participate in digital transitions going forward? How could this be beneficial for both ethical work futures and technology uptake in the industry?

There will not be a complete digital transition to automated and robotic construction

7

Key Insight
Digital transition is not a linear process which can be fully "completed". The Australian construction industry is undergoing an uneven, slow and careful digital transition, composed of many instances of innovation, technology integration and human creativity. The transition is shaped by the structural conditions of a project-based and fragmented industry characterised by subcontracting, high costs and the complexities of on-site work.

Recommendation
A complete transition to automated and robotic technologies is unlikely and in some cases not desirable, and it would be sensible to plan for an uneven, slow and careful transition.

The Unknown
How will the uneven transition continue to evolve? Is it possible to identify large-scale patterns, future modes of innovation, and how these might be related to each other?

Future human workers will be needed on construction sites

8

Key Insight
Our research indicates that human workers will play a significant role in future construction work. In possible futures, the construction industry will still involve work in complex and unpredictable terrains where human knowledge and judgement is needed more than (or alongside) machine learning and automated and robotic technologies. Some traditional skilled work will continue to be desirable, and human work will be valued in some areas of the sector.

Recommendation
Preparation should be made for a future where human workers will undertake some existing roles both solely and in collaboration with machines, and where new human roles will evolve as new technologies become established.

The Unknown
How will future workers experience working on construction sites in possible futures, and what will human-robot and other workplace relations be like? What new human roles will evolve around these relationships?

The future of technology training is complicated and contested

9

Key Insight
Our participants envisaged a range of different future training possibilities and needs, including existing successful training initiatives that were developed within and by technology startups. They suggested that challenges to training were presented by the structure of the industry and its subcontracting model, the limited cost effectiveness of companies investing in digital training, diversity in approaches to training, limited technology standardisation and interoperability, and a lack of technology training for managers.

Recommendation
If large-scale training, retraining or re-skilling of workers to accommodate the rollout of new technologies in the construction industry appears unlikely, new training models should be identified and tested for viability.

The Unknown
How will construction companies, TAFEs, universities, technology startups and other organisations, train future technology workers? How might this be coordinated?

The fear of job losses is not a barrier to automation and robotics

10

Key Insight
We found that many industry insiders and workers in the industry were not concerned about job losses. Our research suggests that the slow digital transition of the industry and the current skills shortage could enable a process whereby traditional skills remain, and with new workers trained in digital workskills suited to emerging roles, a new more diverse workforce will steadily emerge.

Recommendation
Assumptions that a digital transition to an automated and robotic construction industry generates workers' anxiety about job losses should be questioned. Approaches to construction industry automation and robotics should pay attention to the sentiments expressed by workers.

The Unknown
How will workers adapt to and shape a new context where fewer traditional construction roles are required? Will uses of automation and robotics and the evolution of new roles in the industry solve the skills shortage, or will new shortages of tech workers emerge?

The growing participation of diverse genders

11

Key Insight
As new roles are emerging in the industry, women are increasingly taking them up, and our participants saw greater possibilities for this in the future. We found women in senior management positions in construction companies and technology startups, as well as in administrative roles.

Recommendation
Consideration should be given to how to ensure that future construction industry roles, including roles at the intersection between technology and construction are appealing to people of diverse genders.

The Unknown
How will the culture and the workplace and social relations of the construction industry change as a more diverse and technologically skilled workforce emerges? What steps would be required to ensure the future construction industry is a gender inclusive workplace?

Future troubleshooters

12

Key Insight
In possible futures AI and robotic technologies are likely to break and need to be repaired, and this implies that human skills will still be needed, and will be used together with AI for both diagnostics and to sustain productivity while technologies are repaired.

Recommendation
Our research suggests the role for future technology troubleshooting in the construction industry should be recognised as a specialist skill which will require knowledge of both technologies and the industry which they are applied in.

The Unknown
How will the role of the troubleshooter evolve? What training will be provided? Will troubleshooting skills be transferable across a wide range of technologies? When will troubleshooting be remote and when will it be onsite?

The role of the digital creative industries

13

Key Insight
The involvement of digital creative industries in construction is creating and is likely to continue to create a new layer of future professionals with specialist knowledge employed in the sector. This is particularly evident at the intersection between technology startups and the construction industry.

Recommendation
While the construction industry has not traditionally been seen as a workplace for digital creative producers, there would be benefit in recognising the role of creative skills in the industry.

The Unknown
Will the future construction industry become a key place for creative industry professional careers? Will these professionals be employed in large construction companies, in startups, or in creative agencies servicing this and other industries?

Future remote workers

14

Key Insight
Remote work is already undertaken in administrative, design and technology troubleshooting roles. Our research suggested that: remote work is likely to increase in the future; who remote workers will be - in relation to privilege, salary and location - may vary across a range of different roles; and little work would be completely remote while some roles will be hybrid.

Recommendation
Visions of the future of the construction industry could account for the possibility that it will include a remote and hybrid workplace.

The Unknown
How will future remote working be organised in the construction industry in possible futures? Where and when will it take place? To what extent will it involve human-robot collaborations? How will the industry manage increased work across international borders?

Future hours of work

15

Key Insight

In possible futures the hours worked, and time of day or night of work in the construction industry are likely to shift. Our research suggested this could occur in relation to automated and robotic technologies, climate change and extreme weather. It is also possible that construction work might increasingly resemble gig economy work. Research participants raised questions about worker safety, the ethics of surveillance and the inequalities that these possible futures could give rise to.

Recommendation

Consideration and attention should be given to possible future shifts in the hours of construction work, and how this might be shaped by climatic and structural conditions. This may have implications for the need for regulation, and other frameworks to ensure that such working conditions are safe and that vulnerable workers are protected from exploitation.

The Unknown

How will future hours of work be organised in the construction industry in possible futures? What wider impacts might reorganisation have on the built environment?

Safety, health and wellbeing

16

Key Insight

Automation and robotics will not remove health and safety risks in the construction industry, but if implemented carefully could reduce risks. In a digital construction industry, safety involves physical safety and health, an increased focus on mental health, an awareness of emerging cyber safety and digital privacy challenges. Future digital safety measures may also involve the use of augmented and virtual reality, and digital twin technologies. The cost of implementing new technologies in a fragmented project-based industry may be prohibitive.

Recommendation

Safety should underpin the introduction of technology in the construction industry. Careful consideration should be given to new safety risks associated with automated and robotic technologies, as well as the benefits they imply.

The Unknown

What will be the as yet unidentified safety, health and wellbeing issues for future construction workers working with emerging technologies? How will this be reshaped by a new gender-diverse and possibly internationally distributed and hybrid remote/onsite workforce?

Social relationships of work

17

Key Insight
The social relations of work, involving mutual support and trust often depend on in-person collaboration and support worker safety and health, including a current focus on men's mental health. Our research suggested that future automated and robotic technologies, and remote work could make it more difficult to sustain the social and trust relations underpinning such initiatives, and the isolation of remote work in particular could impact on the mental health of workers of all genders.

Recommendation
Attention should always be paid to the impact of digital transition and the implementation of automated and robotic technologies on the social relations that underpin work in the construction industry. Care should be taken to ensure that support networks remain in place and that they are effective.

The Unknown
How will the social relations of work evolve in possible work futures in the construction industry? How will social relations develop between a new gender-diverse and possibly internationally distributed and hybrid remote/onsite workforce? What structures might support beneficial relations?

Future Materials

18

Key Insight
Materials used in the construction industry are impacted by robotic and automated systems, including their assembly, installation and removal. Alongside this, materials are increasingly engineered, sustainable and safe. In the future new materials are likely to continue in this vein. However existing materials - including wood, bricks, and dangerous materials such as asbestos, silica and engineered stone - will remain and will be used or encountered in renovation and retrofit projects. In some cases automated and robotic technologies will make these materials easier and safer to remove or work with, but in others human judgement and manual work will still be needed.

Recommendation
There is likely to be a mixed economy of materials in circulation and use in possible construction industry futures. Provision should be made for the evolution of new and existing materials, and the implications for work tasks in the construction industry, and the training needs this will imply. However the persistence of existing used and banned materials should be acknowledged, and worker safety in relation to these materials should be planned for alongside innovation in new materials.

The Unknown
What new materials will be developed to support a future construction industry and how will this impact on workplace tasks? How will dangerous materials be removed and accommodated in possible futures? Will robotic technologies ever be intelligent, agile and cost-effective enough to safely dispose of dangerous materials? Will human judgement, skill and agility always be required?

Markets, capital and a fragmented workforce structure visions of future tech in the construction industry

19

Key Insight
The ways that markets and capital structure the short termism and project base of the industry make cost a determining factor which discourages technology adoption and innovation.

Recommendation
Our research suggested that new project timescales, investment and innovation models could support technology innovation in the industry. Large companies may benefit from partnering with technology innovators and startups.

The Unknown
Will the subcontracting and fragmented structures of the construction industry ever change? What would be needed to make possible the longer term investment needed to encourage greater innovation and investment in technology augment digital transitions in the future?

The future of subcontracting and service models

20

Key Insight
Participants believed that there are unlikely to be disruptive changes in the future in either the structures of contracting or the kinds of contracts which will be made, or in the risks and responsibilities associated with this. They assumed that the services offered by subcontractors are likely to include automated and robotic services, and that contracts are likely to be digital and potentially automated, and noted a risk of future inoperability.

Recommendation
Putting future-proofed standards in place could avoid a possible future “race” to be first in technology innovation, followed by calls to standardise and regulate.

The Unknown
Will the growing participation of technology startups perpetuate the subcontracting models of the construction industry in possible futures? How will the evolving digital service economy of the construction industry grow in possible futures? What are the implications of this?

Sustainability and the future of construction

21

Key Insight
We found limited sustainability initiatives in the Australian construction industry, particularly related to digital and emerging technologies. 3D printing was highlighted as part of the growing sustainable tech ecosystem and, as retrofitting and the circular economy are increasingly part of the future construction industry, there will be possibilities to use AI in design and documentation processes. However alongside this the use of robotic and automated technologies to undertake retrofitting tasks and work with circular economy, materials may be limited and will require expert human skills, knowledge and judgement.

Recommendation
Environmental sustainability should be emphasised in planning for the Australian construction industry itself, and be a key consideration of future partnerships with technology startups and training providers.

The Unknown
What new roles will a growing focus on environmental sustainability create in the Australian construction industry? How will these intersect with the wider digital transition of other industries?

Automated and robotic technologies in academic research

22

Key Insight
Academic research funding is limited because it is predominantly project-based. Academic computing and engineering research into automation and robotics may struggle to introduce new automated and robotic innovations into the industry if it overlooks social relations and structures of the industry.

Recommendation
Academic research funding for technology development for the construction industry would benefit from engaging social science research, in order to ensure the viability and social relevance and sustainability of future designs developed in engineering research fields.

The Unknown
Will research funding organisations make a commitment to funding interdisciplinary research and to ensuring that social science perspectives are engaged to guide research that is intended to have societal impact?

METHODS

The findings in this report are based on mixed qualitative methods. These include desk based and fieldwork components.

Literature review

164
articles

The literature review had two objectives, to:

- Identify existing STEM and business and economics visions of the future of automation and robotics in the construction industry;
- Preparation for fieldwork with up to date engineering innovations in construction industry technologies.

From 2019-2022 we reviewed 164 articles from 51 journals, using search terms: Robot; Automation; Construction work; Artificial intelligence; Worker construction automation; Workers industry 4.0 (and later 5.0 and 6.0). We also searched specific journals: *Construction Management and Economics; International Journal of Construction Management; Automation in Construction; Safety Science,* and popular databases for related technical disciplines *ASCE; and ICE*. The initial review was conducted in 2020, and from July 1, 2020 we updated our review through a Google scholar alert for 'automation construction', and by searching journals and new social science books related to the industry.

Analysis of reports

16
reports

We identified 16 reports and consultancy articles published between 2016 and 2023, either focused on or with implications for our understanding of work futures in the Australian construction industry. We analysed the reports qualitatively to document their key arguments and coverage relating to the future of technology, work, workers and skills in the construction industry.

Participants

20
interviews

30
participants

5
women

25
men

We engaged with 30 participants, through 20 one-to-one ethnographic interviews, three in-person visits to companies and four design ethnographic futures workshops. Ten participated in both site visits or online interviews and workshops. Nine participated in workshops only.

Participants had significant training (operational licences, university degrees, and additional certifications) and extensive individual and business experience. They included startup founders, a CEO, CTO, CRO, educators, suppliers, builders, entrepreneurs, safety professionals, engineers, safety experts (across a union, private company, advocacy organisation, and startup), a public servant, academic experts and people working in software development, recruitment and administrative roles.

Reflecting the gendered nature of the industry, five participants were women and 25 were men. Most men participating in our research had been construction workers in some capacity themselves in the past. Fieldwork with participants was undertaken between 2021-2023.

Our research ethics involve a layered process of consent and approval: all participants are given the option of having their own names used or being anonymous and of checking and approving all mentions of them.

Interviews and ethnography

Our ethnographic approach involved three activities delivered by Sarah Pink and Ben Lyall:

- *Online research* acknowledged the digital environment the construction industry is evolving with, we analysed online materials from social media and from company websites, podcasts and other publications.
- *Interviews* with 20 participants. Those undertaken during the Covid-19 pandemic were online.
- *Site visits* to three companies. We toured office and workshop space and a construction site. Some interviews were undertaken during site visits.

Design ethnographic futures workshops

Design ethnographic futures workshops were designed in response to our objective to learn with participants about their visions of possible automated and robotic construction industry futures. The ethnographic research findings inspired a series of prompts through which to invite participants to imagine realistic and plausible versions of work futures in the construction industry. One workshop was held online and three in-person. All workshops were video and audio recorded.

Ethnographic findings presentation

1

Participants were first presented with a brief summary of the ethnographic research findings.

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→ **Participants emphasised the future role and value of human expertise in automated and robotic work.**

Participants emphasised the need to account for how people will work with automated and robotic systems and technologies in the future. Many participants felt that manual work undertaken by humans would continue to be central to the industry in the future. Human collaboration with robots may be needed particularly in situations where everyday creativity and exchange of knowledge are essential. Participants noted, for example, the unpredictability of construction sites, and the complexity of accessing and reaching roof spaces and other areas as factors which would need human judgement and agility.

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Knowns	Unknowns
Human workers will need to ensure that robotic and automated technologies and systems run smoothly. Technologies and systems sometimes break or need human creativity to be fixed, this will not change in the future. Robots might find it difficult to work in unpredictable circumstances and uneven terrain.	• How will people be trained in troubleshooting in the future? Who will do the troubleshooting? • Will the future construction sites where people and robots work continue to be unpredictable? • How might people work with robots in situations of uncertainty? • Will machine learning be reliable enough in the future? • What will happen when a robot makes a mistake?

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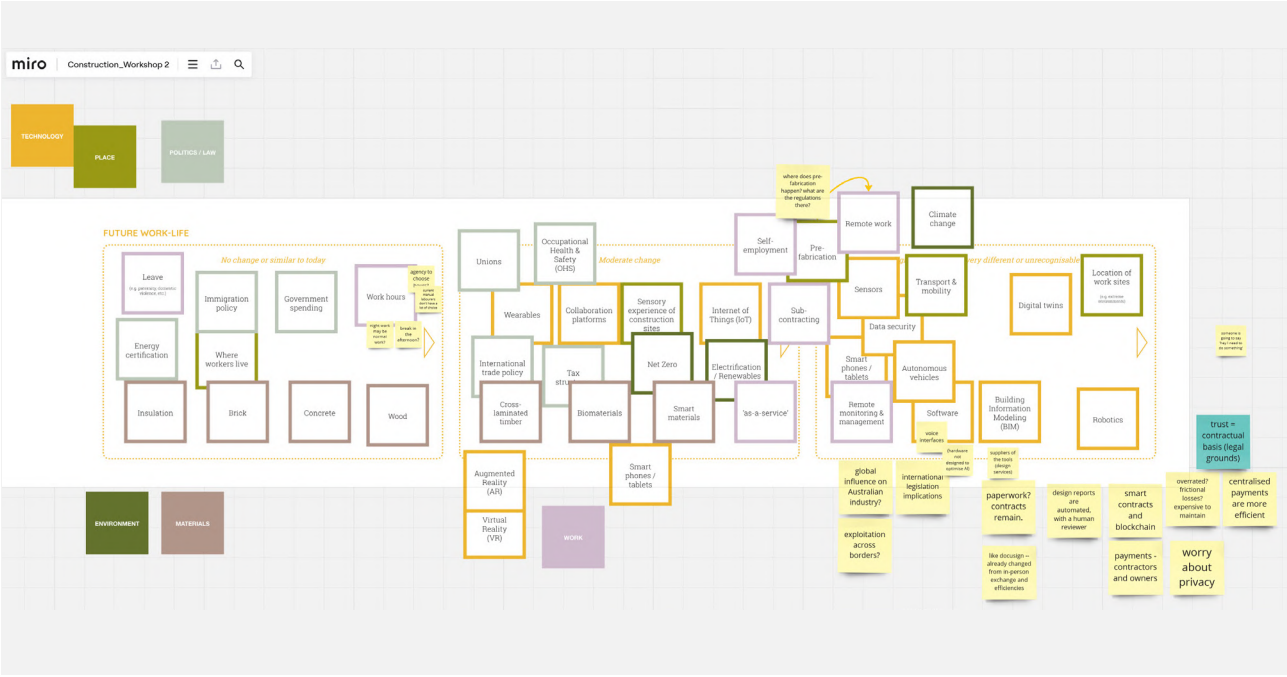
Example of preliminary findings: implications, knowns and unknowns following Stage 1 of the ethnographic research. Slides created by Hannah Korsmeyer.

Design card activity

2

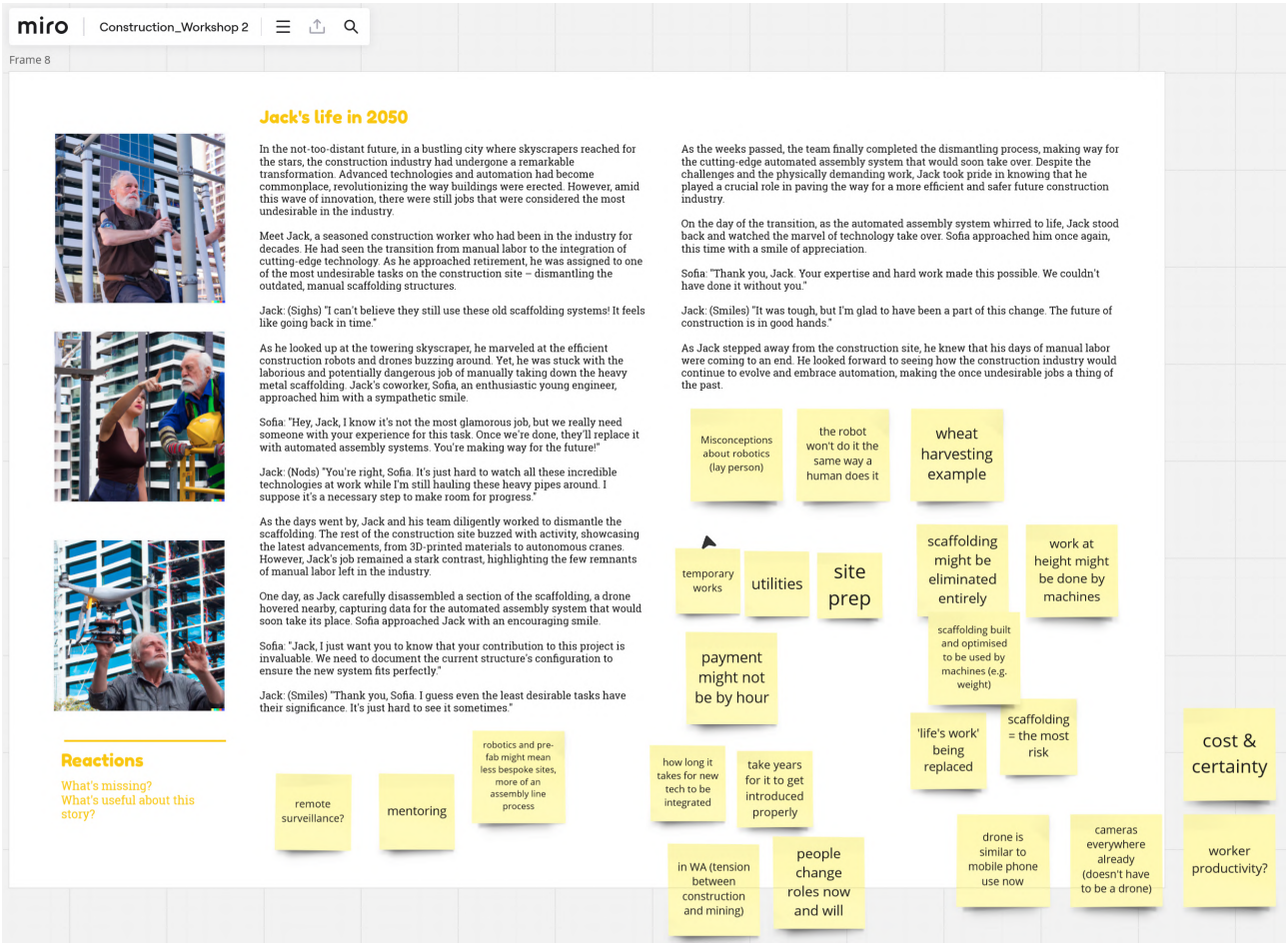
Participants organised a set of design cards, developed by Hannah Korsmeyer to represent the key themes of the research findings - across domains: technology; work, place, politics/law; environment and materials - and to discuss where they thought change would occur. Rather than literally mapping the patterns of change they suggested, our method was to video record and analyse participants' discussions of the possible industry futures the activity prompted.



Generative AI story correction

3

Second, Hannah innovated a technique to invoke possible futures using the generative AI technology (ChatGPT and DALL-E) to create final illustrated stories which participants were asked to read and comment on in the workshops. Their comments were analysed by Sarah to further build our ethnographic understandings of the contingencies, values and practices that would shape viable and realistic industry futures.



Engineering innovations in automated and robotic technologies for the construction industry are both ambitious and characterised by changing trends. Between 2019 to 2024 the changes the industry was undergoing globally, and the predictions associated with it, were continually redefined through the concepts of industry 4.0 to industry 6.0.

PERSPECTIVES ON CONSTRUCTION INDUSTRY FUTURES

Construction industry futures have been conceptualised from business, engineering, government and consultancy perspectives. We outline key approaches to understanding these futures before turning to the specific circumstances of the Australian construction industry.

Construction Industry 4.0, 5.0 & 6.0

Construction 4.0

Construction 4.0 (sometimes referred to as Building 4.0) refers to the proposed transformation of the construction industry through integrating technologies including the Industrial Internet of Things (IIoT), cloud computing, big data, Augmented and Virtual Reality (AR and VR), and autonomous robotics. It was assumed such technologies would solve problems relating to energy efficiency, prefabrication, sustainability, safety and environmental management (Statsenko et al 2023). Business and engineering literatures consistently cite two 2020 systematic reviews (Melenrink et al 2020, Gharbia et al 2020) which echo industry 4.0 perspectives, they suggest that implementing robotics on construction sites will initially be challenging, likely to involve robotic systems for assembly tasks (with lower order assembly undertaken off-site) and will raise safety concerns for human-robot collaboration for on-site robotic construction. They propose future innovation requires design and materials suited to automation and robotics, rather than seeking to automate existing building processes.

However, academic experts raise doubts about how these changes would support future workers (Sherratt et al 2020), since while they may improve aspects of safety they would create new dangers and were unlikely to support inclusivity (Lingard and Turner 2023).

Construction 5.0

By 2022 Construction 5.0 was proposed as an industry future which would improve profit and efficiency, sustainability, competitiveness and adaptability (Najafi 2023). Engineering research echoed this sentiment, seeking to accelerate human-robotic team and co-bot (robots that collaborate with humans) research in construction (Onososen and Musonda 2023). It was suggested that co-bots would assist construction workers in repetitive or physically demanding tasks on construction sites and to improve reliability and efficiency, and an increase in cobots in offsite prefabrication and manufacturing (Burden et al 2022).

Social scientists pointed out that this may contribute to human wellbeing but raises new ethical issues (Lingard and Turner 2023).

Construction 6.0

By 2023-4 Industry 6.0, which could involve quantum computing, neural connections between people and machines, with a sustainability focus, was being discussed (Almusaed et al 2023). In the construction industry it was suggested that "neurological linked hardware" may enable workers to use "brain commands" with cobots in the future, through "haptic feedback and wearable interaction devices" (Burden et al 2022: 215).

Implications

While there have been attempts to align the construction industry with industry 4.0, 5.0 and 6.0 in engineering and business fields, to date uptake of these technologies has been limited. Moreover, social scientists have raised concerns about the safety, wellbeing and ethical implications of 4.0, 5.0 and 6.0 technologies. Furthermore these stages have little synergy with our findings concerning human visions of the industry's future discussed below. We recommend engaging with them with caution.

The Australian context: A "slow" digital transition?

Globally, the construction industry has been characterised as undergoing a "slow" digital transition (e.g. Gharbia et al 2020), as "one of the biggest industries in the world" which historically "has been among the slowest to digitize and innovate" (Mckinsey & Co, 2023), and comparatively "slow" to apply robotics on Australian construction sites (Burden et al 2022: 210). The slowness of the construction industry's digital transition has led to calls for new "tools, methods, and processes" (Pantazis et al 2023: 193).

However, this characterisation of the industry as "slow" in its digital transition requires reinterpretation. Research shows many less obvious and taken-for-granted small scale digital innovations are "taking place continually on construction sites throughout the industry, in all specialisms"

(Gruneberg 2023: 36, Glass et al. 2022). This misconception is driven by the assumption that innovation is always led by engineering achievements and a failure to account for the impact of social and everyday innovation.

While Australia is not a major contributor in academic construction industry robotics research (Onososen & Musonda 2023), local social science construction research leads in fields of worker safety (e.g. Lingard & Turner 2023) and psychosocial safety (e.g. Sun et al 2022) and creativity and innovation for safety (Pink et al 2017). These works show that social innovation is an important element of the digital transition in the Australian construction industry.

Implications

While dominant engineering and business narratives depict the digital transition in the Australian construction industry as "slow" in the sense of being behind other industries, existing social research suggests that slow modes of digital innovation are benefitting the industry. Consequently construction projects should be viewed as the places where innovation occurs, rather than as the recipients of technological innovation.

Future visions of the Australian construction industry

9
reports

We analysed nine key reports which reflect on automation, robotics and the Australian construction industry, produced by the CSIRO (Quezada et al 2016), McKinsey & Co (Chui & Mischke, 2019, Blanco et al 2023), Autodesk & FMI (2022), Build Australia (2021), Oxford Economics (2022), KPMG (Armstrong et al 2023, KPMG 2023), AAB (2021). Collectively the reports depict the future of the Australian construction industry as led by technological change and supported by technological solutions.

Proposed benefits of automation and robotics

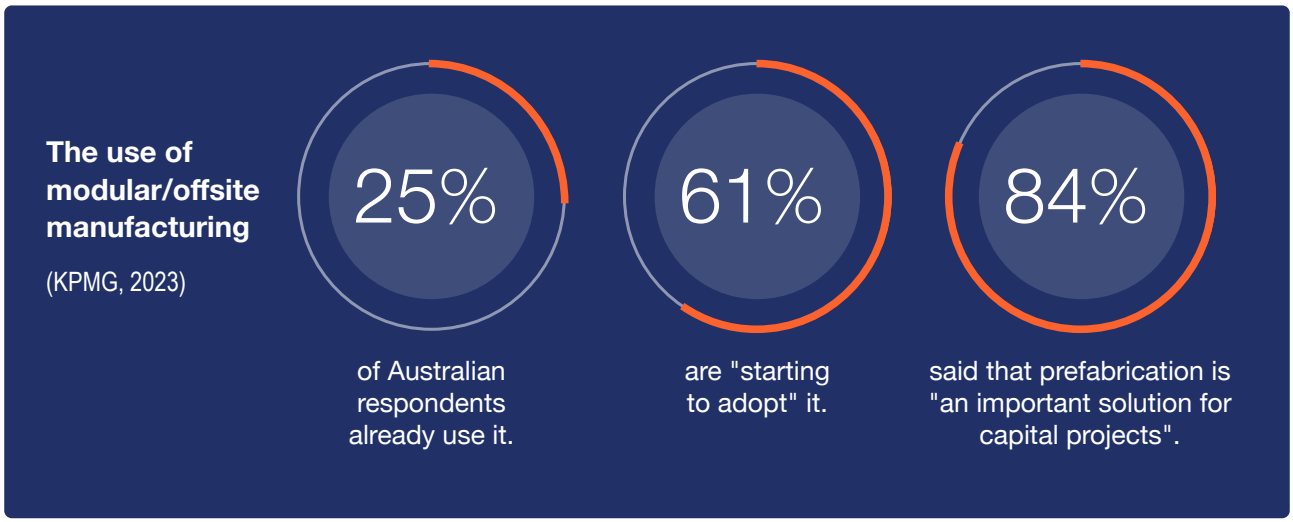
Reports reviewed propose that automated and robotic technologies, used on construction sites (e.g. manual on-site tasks like bricklaying, modular off-site construction, and planning, management and Building Information Modelling (BIM)) and for offsite modular construction, will be taken up slowly. The suggested benefits will be to increase productivity, efficiency safety, and skills, employment and wages for increasingly technologically skilled workers (Chui & Mischke [McKinsey] 2019), support recovery from the Covid-19 pandemic (Build Australia, 2021) and build trust between partner organisations (Autodesk & FMI 2022: 77). A KPMG report (Armstrong et al. 2023) suggests an increasing uptake of "mobile platforms, robotic process automation and artificial intelligence (AI)" will "help improve the industry's performance" and suggests collaboration and investment with "tech giants to bring new and exciting innovations".

Suggested barriers to automation and robotics

Reports reviewed claim that barriers to the benefits to be accrued by the uptake of automated and robotic technologies include the structure of the industry and its contracting system, and worker training and reskilling. An Oxford Economics report (2022) commissioned by the Australian Constructors Association suggests “there is no shortage of technology solutions available to improve the efficiency of the construction industry but there are many barriers to using them”, one of which might be removed by “greater use of contracts that facilitate open and transparent sharing of information and whole of life costing” (2022: 9). The CSIRO suggests that “the challenge is to shape the workforce to fit the future” (Quezada et al 2016: 66), and McKinsey & Co proposed repositioning workers in the industry with companies taking responsibility for training them to take up Construction 4.0 roles (Chui & Mischke, 2019).

Prefabrication and modular construction

Reports reviewed identify robotics and prefabrication as already contributing to the future of construction in Australia. For example, in 2023, KPMG “tracked the use of modular/offsite manufacturing”, and report that 25% of Australian respondents already use it, 61% are “starting to adopt” it and 84% said that prefabrication is “an important solution for capital projects” (KPMG, 2023). A White Paper from ABB which self-describes their company as “one of the world’s leading robotics and machine automation suppliers” and advocates for modular off site prefabrication and 3D printing, as solutions to problems related to those including productivity, worker safety and skills shortages.



Software applications

Software was emphasised in reports reviewed, for example, KPMG notes the high potential of “project management information systems (PMIS), integrated project controls, building information models (BIMs) and

advanced data analytics", and McKinsey & Co identifies the intersection between the construction industry and software start-ups as key in the future of the industry (Blanco et al., 2023).

Implications

Industry reports frequently propose prefabrication, human-robot co-working, the future of software and the retraining and reskilling of workers for tech roles as solutions for worker and skill shortages, and promoting productivity and efficiency. However their data tends to be sourced from "experts" and industry leaders or desk-based reviews and we recommend balancing such views with insight reflecting worker perspectives.

Automated and robotic technologies in academic research

Academic research funding is limited because it is predominantly project based

Academic research funding is predominantly project-based and follows cycles of government funding programmes. When funded on the basis of its technical promise for the construction industry without the contribution of social science expertise, research is at risk of not generating realistic applications for industry or benefits for workers.

Some academic research is undertaken in collaboration with companies, with a thriving applied research field in relation to the construction industry. Participants cited research initiatives in universities that they had heard of which had experimented with automated and robotic technologies, or in the development of smart materials.

In Australia we found little evidence of impact of innovations in automated and robotic construction industry technologies by University-based research teams. Our literature review suggested globally engineering research is focused on discovery research, application can be difficult to implement and lack of attention to the social relations of work futures can lead to failed technological innovation.

Implications

Academic computing and engineering research into automation and robotics seeking to introduce new automated and robotic innovations into the construction industry would benefit from collaboration with the social sciences in order to account for the social relations and structures of the industry.

AUTOWORK VISIONS

People Futures

The slow and
uneven transition

Who are the Future
Construction Workers

Safety, Health
and Wellbeing

Industry Futures

People Futures

Our research addressed how people who work in the construction industry understand automated and robotic work futures. We report on their visions of work futures.

Workers should be fully engaged in the digital transition

Participants emphasised the importance of engaging workers from the outset.

Our research revealed examples of how digital transitions have come about through worker engagement, participation, acknowledgement of workers' expertise and co-design.

A strand of CodeSafe Solutions' work involved producing safety videos featuring workers demonstrating safe work practices, designed in collaboration with workers through a participatory video process and shared via quick reference (QR) codes. The videos effectively support worker participation in safety practices by connecting with workers' existing digital and work knowledge and practices. CodeSafe has generated a digital transition through accessible safety training based on fully engaging workers in the process.

Amanda, an Executive Manager in Health, Safety, Environment, and Quality (herein, HSEQ), described how the company she worked for had invested in a tech startup, inspired by an idea from her team. The startup developed sensors to ensure the safe fixing of a façade to a building. Using sensors to "track when certain flaps are open" helped alleviate a consistent risk related to "working below and around the whole façade area installation". The tech startup had an office on the site and the construction workers continually delivered feedback to the tech company, which in turn was responsive to them, thus facilitating the construction workers participation in digital transition.

Personal industry experience supported successful of digital initiatives

Most men participants, from CEOs to tech workers, brought hands-on industry experience to their approaches to automation and robotics. They believed these experiences were foundational to their ability to innovate while engaging with the reality of worker experience.

Dan (Business Development Construction at FBR), had previous experience of working and running several construction industry businesses. He saw himself as "privileged to be able to work amongst additional trades to understand how they get to the certain level that they do", reflecting that, "looking at the opportunity that I've had previously …has been priceless". Dan believed this level of understanding and "knowledge of how it actually works" was crucial to automating the industry.

David B who had a long trajectory in the construction industry in Australia and internationally was inspired to found tech startup CodeSafe after experiencing a safety incident. David's work is always relational and prioritises workers' knowledge and participation where new technologies are introduced.

In the construction industry bespoke technologies will be the more successful

Participants involved in implementing or evaluating new technologies emphasised that successful technological innovation should be explicitly designed both for the industry and for worker's needs.

"[We have] people coming to us all the time to say, 'David will you collaborate with us on a project'. I say, 'What have you developed?', and some of it is hardware. So what was the intent of developing that? I think when you've been around the game long enough and you understand the psychology of the end user, sometimes I've had to be really gentle with people to say, 'look I think it's really great what you've done but I really can't see that being adopted'". — DAVID B, COFOUNDER AND CRO

David B reflected on an industry event he had recently spoken at, commenting "I reckon there was 50 software providers and technology providers in that room and I would say 90% of them couldn't get their initiative really implemented into the industry because they were technology people building technology for operations people who had very little operational background and experience." — DAVID B, COFOUNDER AND CRO

Amanda (Executive Manager, HSEQ) suggested "it's how technology is pitched [that] can make or break [if it's] accepted by the whole industry". Within a road worker safety project her team had explored the role of robots as traffic controllers, but were put off by the approach of a company who had developed a robotic solution in this field, who presented the concept as "we're this company developing it, how good are we?", rather than, "here's a solution for the whole industry".

David B (Cofounder and CRO at CodeSafe) had worked with a company which had installed an expensive digital system, but found the staff quickly gave up using tablets and smartphones to access it, and reverted to their paper system. David's company had subsequently started to work with them to re-engage workers with technology, emphasising the need to introduce technology in ways that work for people.

Human workers will play a significant role in future construction work

People will always be needed to work on construction sites

Participants drew on diverse knowledge and experience to confidently argue that people will always be needed to work on construction sites.

"The construction industry's always going to be very hands on. … I don't think it will ever ….go to 100%. You, look at other industries, and I think the most ever, any industry ever gone to is 80%". — DAN, BUSINESS DEVELOPMENT CONSTRUCTION AT FBR

Darren (Site Manager) reflected on the site he currently managed, where although robots could do part of the work manual tasks were still required, such as human workers moving the rubble after the robot had "just left the mess and distraction behind", so "somebody's got to clear that as you go". He emphasised how often "you've got live environments [such as building in a working hospital] and complexities of build and so many different things happening". He also suggested that whereas robots are task-specific "about 30 robots" would be needed to do the work of one person, because people can move between tasks, for instance "the chippie will come in, he'll build a shelf there, he'll modify a door".

New roles will evolve as new technologies become established

Some participants saw neural networks as the next stage for technology in the construction industry.

Nayeem (Lead Software Engineer at FBR) suggested that in the future the engineer's role would be "to train the neural network and understand how to filter data and how to clean dataset to be able to produce high quality neural networks that make good decisions on problems". While he didn't think that bricklaying would be replaced by this in "a year's time", he saw a trend whereby "we'll stop trying to solve them [complex problems] using functional programming and we'll move to using neural networks or using techniques where the software identifies and solves its own problems."

Implications

Our findings question the feasibility of simplistic engineering and industry proposals that the construction industry workforce might be retrained to suit envisioned future automated and robotic technologies. While future workers might collaborate with cobots or make decisions within automated systems, our research suggests that creating the technology first and subsequently retraining people to suit often fails. Instead design and engineering should account for the experienced complexities of work on a construction site.

The slow and uneven transition

Academic literature and industry reports reviewed have characterised the "slow" digital transition of the construction industry as inefficient and a barrier to productivity.

A slow transition is not a limitation

We found that "slow" is not a disadvantage; the *slow movement* has for over thirty years redefined slow as generative and productive. Slow refers not to the speed at which something happens but to processes that involve care and attention, respect for local knowledge and environments and engagement with place, and the wellbeing of humans and other species. Whereas engineering and industry literatures tend to portray the slow transition as a "problem" to be solved, we found generative and successful elements of the slow transition were supported by human values and practices.

There are many examples of non-digital slow technology transitions

Technologies are often incrementally and unevenly integrated into building companies.

Gerry (a Union Occupational Health Safety and Environment Manager - herein Union OHSE Manager) discussed the introduction of craneable scaffolding, which is an innovation beyond conventional scaffolding, designed to "be built, maintained, dismantled" and rebuilt in the next place. Gerry noted this was "quite a change and there was a bit of negativity from a lot of our traditional, older members", until they understood the process. He didn't expect all companies to use this new scaffolding technology, but the example demonstrated how slower integrations of new technologies into industry processes can happen.

There is a successful slow digital transition in progress in the construction industry

We found instances of digital transition in large and small companies, training and start-ups.

The robotics startup FBR had driven a partial transition to robotic bricklaying in Western Australia. This transition was not created outside the industry and applied to it, but involved the development and testing of FBRs innovations in robotic technologies on construction sites and in building real homes. Mark P (Executive Director and CTO at FBR) commented that their entry to the building industry had been to engage building companies to build with them, be subcontracted by the builder to undertake robotic builds, and demonstrate the possibilities.

The startup CodeSafe was already embedded in the construction industry and had innovated in uses for QR technologies before the Covid-19 pandemic. David B (Cofounder and CRO) described how during the pandemic "technology went off the charts because people needed the technology platform for all these sign in/sign out contact tracing." However, introducing QR code for contact tracing on construction sites was not simply a technological transition. David B and Gerry (Union OHSE Manager) engaged with workers as QR Code tracing was installed to ensure that they trusted the system and its use.

Implications

A focus on the speed of transition and externally driven technological innovation misunderstands the value of a beneficial slow careful digital transition. This requires long term investment in technology development, and innovation from within the industry.

Emerging technologies for possible futures

Some participants assumed future technologies would lead to greater automation

Participants imagined automated and generative AI technologies would be used in some areas in the future.

Brett (Senior Manager, transport infrastructure projects) suggested future fully automated building design software would save costs by eliminating the need for large teams to work on building design, so “the design services industry I think has a limited life to it”. Shane (Networker) likewise reflected that “by using Generative AI they [architects] can come up with a design in a very short time”, indicating that he saw it as an opportunity to speed up design work.

Startups and other companies anticipate future emerging technologies

Anticipating future technologies was integral to the work of the startups and other companies we encountered. Participants emphasised they needed to be ahead, and anticipate new technologies.

Marcus who worked as an Account Manager, for a company that supplied geospatial surveying technologies to the industry said it was important to stay ahead, and in their case, he stated “obviously we’re doing drones and scanning and all this other sort of stuff, so as a company ourselves we’re keeping ahead of the game with what’s new because in 10 years time all that will just be normal”.

Mike - the Managing Director and CEO at FBR - said the company had a long-term research and innovation programme, and explained “we’re not just reacting to the new technologies that are coming along, we’re anticipating them, and in some instances, we’re actually developing them ourselves”.

Mark (Executive Director and CTO at FBR) kept up to date with technology development, and assessed that “we’ve seen a massive evolution in user interface, the introduction of voice interfaces and the next step is going to be the neural link”. Emphasising the uncertainty related to this he said: “we don’t know where that’s going to go, and consequently what the software is, and how that will interact with humans”.

The digital transition is uneven and generates inequalities

The digital transition is occurring unevenly; in some organisations there is little or no engagement with new digital technologies; for others the cost of new technologies was prohibitive; and some areas were more likely to transition first.

Little engagement

Gerry (Union OHSE Manager) told us that in his experience there had not been "much discussion about robotics being introduced". He saw robotic technologies as being introduced in the future, but was reluctant to put a precise date on this.

> "No one's come to us and said, 'Look, we want to introduce this new robotic system or process'". Instead, "people will come to us when they've got new products, a new type of scaffolding or a new type of crane perhaps or machine … It's more about machines which will take a human to operate it basically". — GERRY, UNION OHSE MANAGER

Cost prohibitive

The cycles of capital invvestment, project-based contracts and power relations that govern the construction industry can make digital transitions inaccessible to both small and large construction companies.

David B (Cofounder and CRO at CodeSafe) pointed out that for small companies the digital transition was "complex" and "the majority of times it's cost prohibitive". CodeSafe's model conversely was based on the "deliberate decision that if a mum and dad operator can't afford our solution it's too expensive". Their tailored solutions and costs ensured their technology services were accessible tor both "a mum and dad operator that's still got a legal duty and still wants to do a good job to keep his house and his kids at school and all the rest of it" and "a large Tier 1 who's got a multibillion dollar infrastructure project to build".

Transition may be evidenced earlier in particular domains

It may be easier for some domains of work to take up technological innovations earlier than others.

Daniel (WHS research, state government) noted that while robots already work on bridges, undertake inspections and detect faults, they were not considered to be able to work in a roof space. He suggested this means they "can't work in a roof space at the moment", but sees innovations trickling down into this kind of work.

> "You tend to find that a lot of the innovations happen first in major infrastructure, like lot of those technologies that were listed, like digital twins, BIM, you know robotics, that sort of stuff, seem to be led out of there because that's where the money and the economy comes from and then it trickles down, you know". — DANIEL, WHS RESEARCH, STATE GOVERNMENT

Automation is not absolute

Companies are delivering automated tasks or elements of tasks

We found a number of companies involved in the delivery of automated tasks or elements of tasks on construction sites, rather than the automation of work processes or of construction sites as a whole. Discussions focused on sensor technologies, digital twins and IoT, contact-tracing, QR code, work systems, robotic bricklaying and robotic arms.

Our fieldwork with FBR demonstrated how human workers worked with and alongside Hadrian, the robotic bricklayer. This included: Hadrian operators and the trades who work on the same buildings in sequence with the robotic bricklayer. Dan (Business Development Construction at FBR) explained, there is a "balancing act" working with a disruptive technology like a robotic bricklayer, since it changes the construction process, but it does not eliminate the work of the trades who come in before and after. He highlighted the importance of good communication and not creating unnecessarily additional work for those trades.

> "There's always going to be that interaction with the other trades that you need to complete a house or any commercial build. So yeah, you've got your plumbers, you've got your electrics, you've got concrete, etc, etc. So I think those jobs will still exist or there might be more hybrid jobs where people can cross skill and do more than one thing" — MARTIN, GENERAL MANAGER OF OPERATIONS AT FBR

Manual work will continue to be central to the industry

Participants believed manual work undertaken by humans would continue to be central to the industry in the future, due to the unpredictability of construction sites, and the need for human judgement and agility. They suggested the skills shortage in the trades limits the work that can be done robotically since it is contingent on the trades being available to supervise and assist. For example, jobs involving electrics in inaccessible spaces would be difficult to automate. It would be undesirable to automate some traditional craft skills and tasks where the human-ness of the work is highly prized.

Nayeem (Head of Engineering at FBR) suggested there may be an increase in the roles of electricians as automation and robotics grew. John K (Head of Electrics at FBR) similarly offered that "you will always need traditional or conventional electricians for installing power, lighting, things like that. I think we're a long way off ever having a robot do that … you would need to have a robot which is capable of climbing a ladder or lifting itself up into a roof space, crawling through a roof space".

Implications

Digital transition is not a linear process which can be fully completed. The Australian construction industry is undergoing an uneven, slow and careful digital transition, composed of many small instances of innovation, technology integration and human creativity. The transition is slow due to structural conditions and the high costs involved. A complete transition to automated and robotic technologies is unlikely and in some cases not desirable.

Who are the Future Construction Workers

The latest Australian Bureau of Statistics data (from the 2021 census), indicated that over 1.06 million Australians (8.9% of the workforce) were directly employed in the construction industry, with related industries areas like manufacturing, transport, and services (electricity, gas and water trades, as well as waste management) accounting for another 1.4 million jobs (ABS, 2022). There are additionally significant overlaps with architectural, engineering, and design occupations. In larger construction firms, employment in human resources, health and wellbeing, workplace safety, transport, logistics, warehousing and security roles, is also not captured in this data. Participants anticipated significant change in the roles workers will play in possible futures.

of the workforce were directly employed in the construction industry. (ABS, 2021 census)

Training

Participants were vocal about the limitations of existing training, highlighting that its delivery is a contested terrain, driven by capital and short timescales.

Existing technology training is complicated

A number of our participants delivered training, or were involved in education provision at vocational and technical institutions. One company had developed its own in-house training programme. Participants were critical of existing training models where on-the-job training was unevenly implemented and difficult to monitor.

Anne (Union Head of Education and Training) noted the instability and precarity of the workforce in a context of subcontracting where it was difficult to conduct “effective training”, while simultaneously regulatory frameworks mandated certification, which subsequently generated significant training requirements.

Participants managing work on construction sites raised concerns about the fluidity of employment in the sector, workers “having to learn on the job” where they see apprentices “as green as the day they came in” after 3 or 4 years of training (Darren, Site Manager).

There is a lack of technology training for managers

While the existing literature we reviewed emphasised the need to reskill and train workers in new technology fields, participants identified the additional need for manager training.

Anne (Union Head of Education and Training) pointed to a lag between the introduction of new technologies and training and the further need to train managers and supervisors.

> "Developing a tech and automation strategy as part of health and safety is not something that health and safety practitioners are trained in, or are very aware of". — AMANDA, EXECUTIVE MANAGER HSEQ

Participants were critical of digital training programmes in education institutions

Participants reported fearing that in the future there would be "more responsibilities put onto the workers" which would not be "conducive to the development of their skills and knowledge" (Anne, Union Head of Education and Training). Anne lamented this would be "a lot more online, a lot more digitised, a lot quicker and dirtier". We saw examples where apprentices and trainees learnt using a forklift and crane simulator, but digital learning had little advantage and they "definitely preferred the real machines when learning" since "it just wasn't quite real enough" (Gerard, Vocational and Technical Educator).

The limited cost effectiveness of companies investing in digital training

Safety managers were vocal about the limitations on engaging new technologies, such as virtual training systems, in an industry with project based investment cycles and a fragmented and fluid workforce.

John (HSEQ Manager) explained that training is a significant commercial investment, and in the context of low "current retention rates" would be too costly to invest in Virtual Reality (VR) training when he can "for example, deliver a [Microsoft] PowerPoint presentation and get a very similar message across, and then go on site and do site competency verifications".

Amanda (Executive Manager HSEQ) emphasised the need for efficient and cost-effective training involving multiple parties: "if there was a financial benefit for companies, they would do some of the training … it would cost a few grand to retrain them. But I also think the manufacturers need to play a part in that as well, because it's in their best interest to have people trained properly".

There is a disconnect between industry visions of future jobs and current training

The 'jobs of the future' rhetoric of industry projections (Quezada et al. 2016; Taylor et al. 2019) are out of sync with the immediate concern for worker shortages that drives incentivised education and training programs (such as government support). Subsidisation programs exist in Victoria where many courses between Certificate II and Certificate IV, as well as Diploma levels, have fee-free elements. These include concreting, waterproofing, surveying, and plant operations (*State Government of Victoria*, 2024). Student places in some courses are jointly subsidised by the Federal Government (*Australian Government*, 2024). There is clearly political will to address labour shortages in priority trades, but it remains to be seen whether this can or will also include a digital skills shift.

Future training

Participants noted that existing training at technical and vocational institutions does not train workers to operate specific new technologies, but to deliver the standards required for construction tasks that technologies are used in. Some participants envisaged that in the future workers would be trained in new work tasks, which new technologies would be embedded in, either as workers move into new roles or as younger people with tech skills enter the workforce. Other participants suggested a need to refigure the relationship between jobs, technology and training, to ensure that technology driven jobs were introduced and trained for. Participants suggested it was difficult to plan for future training for a number of reasons.

Disagreements amongst educators over the future trajectory for the industry impacted the delivery of training. For instance some vocational education teachers believed that sustainable prefabricated housing should be the future, while others argued for a future where building is still done manually "from the ground up" (Daniel B, Apprentice Builder).

A lack of standardisation in construction automation made it difficult to identify how training should happen in the future. A participant suggested that once one technology or system dominates in the industry it would be possible to "work out, well, how does the training or how do we educate, or how do we bring people into, to using that technology?" (Dan, Business Development Construction at FBR).

"Are you introducing jobs with technology, or are we losing jobs?" — DANIEL B, APPRENTICE BUILDER

"We're going into uncharted territory, it's, like, there is not one person that I could think that would have the ability to do everything that we're doing and move forwards, so, it's going to be across the board. I think there's going to be scholars, there's going to be people from the construction industry, there's going to be people working from completely opposite industries, which will come on board and adapt to this". — DAN, BUSINESS DEVELOPMENT CONSTRUCTION AT FBR

Implications

Earlier in this section we documented existing assumptions that large scale training, retraining or re-skilling would be required. Our participants suggested large scale reskilling was unlikely to be viable. They envisaged a range of different future training possibilities and needs. They suggested that challenges to training were presented by the structure of the industry, the cost, diversity in approaches to training, and there being no dominant technology system to train for.

The fear of job losses is not a barrier to automation and robotics

There is a dominant assumption that in the construction industry there is "an uneasy perception of robotics in their workspace—driven by the fear that workers will be replaced by automated machines" (Burden et al 2022: 216). However, we found little evidence to support this amongst participants from within the industry.

Industry insiders do not fear job losses

Participants were confident automation and robotics would not take workers' jobs in the future. Mark P (Executive Director and CTO at FBR) found that people who already work in the industry have more confidence in automated and emerging technologies because they can see the value proposition. He suggested some bricklayers would be pleased to give up the heavy work of bricklaying and others would stay on to deliver bricklaying still needed alongside robotic work. Amanda (Executive Manager HSEQ) suggested that one of the issues relating to fear of job losses resulted from how technology companies external to the industry present technology.

> "Interestingly, a lot of the time, it's people who aren't actually in the trade who post [on social media], saying, 'these robots are terrible. They're going to take all the brickies' jobs'". In contrast, those in the trade commented "I'm a brickie. I'll be glad when these robots turn up". — MARK, EXECUTIVE DIRECTOR AND CTO AT FBR

> "From what I've seen, the tech companies and the providers aren't very good at addressing that issue. So, they just say, 'how good's [sic] this technology?', and straight away people think, 'I'm losing my job'". — AMANDA, EXECUTIVE MANAGER HSEQ

The skills shortage will limit job losses

Participants consistently referenced skills shortages as preventing robots from putting people out of work. They often suggested that as new jobs emerge, younger people don't want to work in the traditional roles that the industry offers.

Participants suggested there was a gradual reduction in demand to join the industry in that every year there are fewer "new young people coming in" and the workforce is "getting older on average" (Mark, Executive Director and CTO at FBR). FBR's HR Director explained that the accusation that robotics is "putting brickies out of work" is not viable, since high school leavers aren't becoming brick layers. In their case "Hadrian's [the FBR robotic bricklayer] doing the part of the build that the brickies don't want to do. A technology like Hadrian is so needed". This was echoed by apprentice builder Daniel B, who cited a high average age for brickies in Australia, and commented that "the young kids these days, the younger generations, don't want to bust their gut that hard".

Automation and robotics will create future jobs

Participants suggested automation and robotics will create new jobs, often intersecting with existing ones. For example, future construction may have more in common with manufacturing, and architecture may overlap with engineering.

A participant envisaged a "natural attrition" as some manual labour would become merged with some manufacturing jobs, evolving in the future into digital system supervision roles (Mark M, Vocational and Technical Educator). These new roles could be appealing to diverse workers at diverse age and career stages, and genders, and offer new forms of worker flexibility.

For Daniel M (Builder) "It's just a different, like, traditional jobs might change, but there's still jobs being created" he emphasised that humans would still be needed to work with robotics in the industry in the future, summing up that "I certainly don't live in fear of the T2000 Terminator models taking over my life, but I know that, yeah, I know that it will speed up some things but it just means other stuff will happen elsewhere."

The relationship between training, skills, and demand

The construction industry's slow digital transition (section on Slow and uneven transition) has ensured that a technology-driven workforce exodus of traditionally skilled workers is unlikely. Participants believed that future training could be targeted to suit future roles as needed, and cited examples of how this is already happening.

Participants working in education and training roles (Mark M; Gerard) noted that vocational and technical courses do not train future workers in redundant forms of work, and that young people are seeking out forms of training based on what skills they can learn in the short term, based on what they know about jobs and their availability in the future.

"We still teach the principles and the theory but the training has had to change and the plant has had to change". — ANNE, UNION HEAD OF EDUCATION AND TRAINING

"One of the biggest things we [are] trying to challenge [is] the barrier around people losing their job. In the plan that we came up with, we made sure that, whatever job was being replaced [...] that person was retrained or whatever into another job on the same project". — AMANDA, EXECUTIVE MANAGER HSEQ

Implications

Dominant narratives assume that the digital transition to an automated and robotic construction industry requires large scale reskilling of workers, and generates workers anxiety about job losses. Our research suggests the slow digital transition of the industry and the current skills shortage could enable a process whereby traditional skills will always be required. New workers will gain digital skills suited to emerging roles, and a new more diverse workforce will emerge.

Gender and the growing participation of women

The gendered nature of work in the construction industry, where women are underrepresented, has long since been acknowledged, is evident in the Australian construction industry particularly in the craft and trade occupations, and has led to calls for more research into women's occupational safety and health in the industry (Lingard & Turner 2023: 115).

of Construction Managers in 2021 included women.

Encouragingly the Australian Government's most recent census data (2022) explicitly highlighted how **"female representation is increasing gradually in the Construction industry"**, which included women accounting for 10% of Construction Managers in 2021, with a quarter of these holding Building Construction Management qualifications (ABS, 2022).

Additionally in 2023 Master Builders Australia (2023) reported that "women make up 14.5 percent of the industry's total workforce and 2.7 percent of building trades" and women's participation is increasing. We found that the growth of automation and robotics in the industry was encouraging women into new roles in the industry. We saw women in senior roles: an Executive Manager HSEQ responsible for worker safety at a large company, the CEO of a tech startup, and a Director of HR at a tech startup.

of the industry's total workforce are made up of women.

New roles and skills needed in the new construction industry startups were integral in opening up possibilities for women to participate in the industry. For example, the HR Director of FBR told us her ambition was to recruit more women into the unconventional roles in the industry that were emerging in the startup space. She had recruited two women architectural technicians and hoped to recruit a woman "trainer operator" [of construction site robots], saying that "there would be no greater feeling than having our first female operator … it would be an amazing opportunity to you know, be the first female, how empowering". Another "success story" she saw as "exciting" would be to see "an executive assistant who wants to throw in the towel in the corporate world and be our next Hadrian operator".

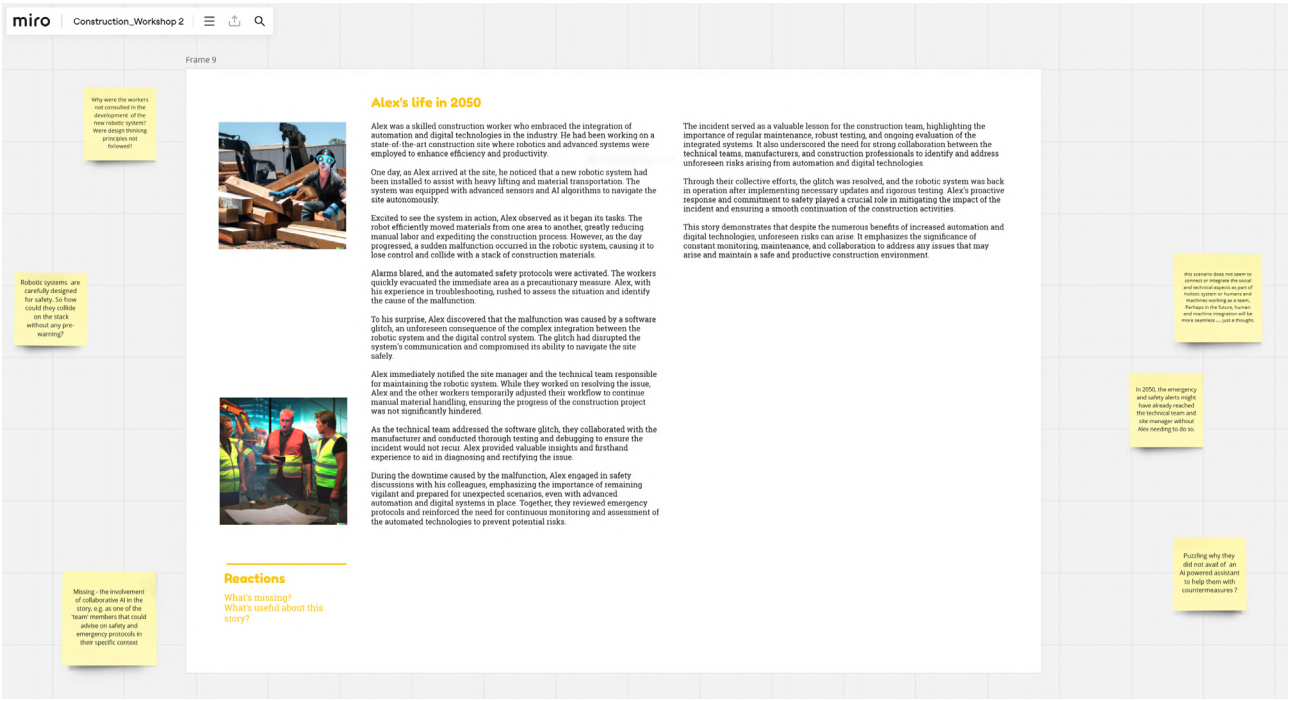
Implications

As new roles are emerging in the industry, women are increasingly taking them up, and our participants saw greater possibilities for this in the future.

Future troubleshooters

Participants suggested that in possible futures people and robots would work alongside each other in systems that were increasingly and at least partially automated. However, automated systems and robotics, like all technologies, can break or have software bugs and need to be fixed. This raised the questions of: who will be responsible for repairing these technologies; what roles will this create; how will people be trained for such roles; and how will enough knowledge of how to perform tasks that are typically done by machines be sustained and maintained once humans stop doing them. Our findings suggest that troubleshooting will be integral to automated and robotic futures.

We presented participants in a workshop with a ChatGPT generated possible future story in which a software glitch in a newly installed robotic system.



Shane (Networker) comes to the industry with an academic perspective. He suggested that by 2050 AI might be “working with humans” and “fixing the machine” (Shane), for instance participating in discussions with the human troubleshooters and that there would be an automated process to detect the malfunction, safety alerts and drones.

Participants who were more used to working on the ground on construction sites emphasised that it was unrealistic that once the machine broke down, people were immediately available on the construction site to take over the work manually. They explained that these manual skills would likely have been lost by 2050. Participants concluded that in the future both human skills and AI would be needed to diagnose malfunctions.

Implications

In possible futures AI and robotic technologies are likely to break and need to be repaired, and this implies that human skills will still be needed, and will be used together with AI for both diagnostics and to sustain productivity while technologies are repaired.

The role of the digital creative industries

As the construction industry evolves there has been growth in the role of the digital creative industries in construction companies. Moreover, robotics and automation bring construction together with a digital startup industry. This has led to growth in social media engagement, dynamic websites, videos, podcasts, blogs, and associated materials and communications.

Notably, we found, digital creative industry professionals were engaged in-house in startups rather than subcontracted through creative agencies.

Aaron, the Senior Marketing Advisor at FBR was “here full time, doing marketing, filmmaking, lots of stuff.” His role included documenting and sharing the development process, telling us “we shoot pretty much every build, every bit of assembly, every bit of testing, commissioning, all the time”. Mike (Managing Director and CEO at FBR) and Mark (Executive Director and CTO at FBR) noted the different categories of audience for these videos, from their many shareholders to the internal audiences to keep their team of (at the time of about 100) employees informed. The videos were also valued as historical documents, with potential uses in documentaries, training videos, and for compliance purposes. FBR also works with animators to create representations of their work for internal communications. The company’s extensive website news, and regular social media posts create powerful momentum for their work and their story.

The work of CodeSafe involves extensive media production. A key pillar of their work, as noted above includes the production of worker safety videos accessed through QR codes. Clients then have a secure channel on the CodeSafe platform to access the information they are looking for.

Implications

The involvement of digital creative industries in construction is creating and is likely to continue to create a new layer of future professionals with specialist knowledge deployed in the sector.

Future remote workers

Participants agreed that in the future, work in the construction industry would become increasingly remote. But they also raised issues relating to safety, governance and gender.

Remote working is already emerging in the industry

A range of existing remote working practices are already emerging in the industry. Remote training options are offered to on-site workers and

troubleshooting of new technologies is delivered remotely, especially in the case of technologies like drones. There are also emerging remote workforces including administrative staff.

Who will future remote workers be?

Participants suggested a range of future remote work will occur, including remote administrative work, the remote operation of machinery, using digital twins, AI undertaking remote work. They also raised questions concerning the inequalities this might represent.

Emily, a younger woman working as a Contract Administrator imagined her future workplace as being “anywhere”, and commented that even now, after the pandemic “it’s easier to work remotely”. She felt that once someone was trained in her kind of role, then they would not need to be on site, and could work remotely anywhere in the world.

Any work that’s done remotely now is a “candidate” for AI doing the work “probably a lot sooner than we think”, starting in five years and becoming mainstream in 10 years (Mark, Executive Director and CTO at FBR).

Being a remote construction worker in the future may be a privilege, whereby remote workers with knowledge and skills may be able to advocate for themselves: “people can - if they know what they’re worth to an industry - they can dictate where they live and how many days they come to work” (David B, Cofounder and CRO at CodeSafe).

Future remote work could be hybrid with onsite work

Where participants saw remote work as becoming the norm in the future they also suggested humans would often be needed on site to work with machines, and that in some cases it would not be viable for robots to work independently on site.

Future workers would only be needed on site for “minor fixing and maintenance, or troubleshooting” (Ewan, Senior Control Systems Engineer at FBR).

> "Its very difficult when there's a human element there, for instance this [the building they are currently retrofitting] is a live environment we've been working in the whole time. How could you just then put a robot to work? You can't programme something to teach how we're going to behave, you can't anticipate that, so there's still a lot to work on that front".
> — DARREN, SITE MANAGER

Implications

Remote work is likely to increase in the construction industry in the future. However, who remote workers will be - in relation to privilege, salary and location - is set to vary across a range of different roles. It is unlikely that future work will be completely remote, but some roles may be hybridised.

Hours of work

Participants saw future working hours being shaped by the gig economy, industry limitations, and climate change. They were also aware that new technologies might enable new future hours of work where turn taking in tasks might be organised in collaboration with automated and robotic technologies. However they raised concerns about potential inequalities.

Climate change and future extreme weather could impact hours of work.

Participants considered extreme weather and temperatures would impact hours worked.

> "It's quite possible that night work might become the normal work and day work might become the night work because you can't work in extreme temperatures, like in the middle east, you don't work in the afternoons … you have a "big break in the afternoon" and work early morning and later in the day "that could happen in the rest of the world as well". — SHANE, NETWORKER

Future construction work could be gig work

Participants proposed that the growth of platform work, the gig worker economy, and new employment models, would impact the hours worked by construction workers. This raised concerns about regulation and safety.

Daniel (WHS research, state government) outlined a possible future where gig workers can work across multiple companies, with no limits on shift lengths and breaks. If taken up in the construction industry, this would have dire implications for worker health and safety. Daniel was also concerned by the possibility that low-paid workers overseas would be able to work long hours to operate robots on construction sites remotely. To pre-empt some of these issues, David B (Cofounder and CRO) discussed a new "digital worker passport" which gives "visibility across every environment that worker works across" and which "helps us manage fatigue, training". For David, "one of the things that was exciting was that we built into the onboarding mechanism both psychosocial risk factors and physical risk factors but also their geographic location [so they can manage commute time]".

Inequalities surrounding future work hours will need to be addressed

Participants suggested workers' power to control their hours of work would vary globally, in relation to role and skills and differences in national legislation. They suggested that while younger generations of digital workers might be able to choose their hours of work, if manual labour roles on construction sites become more scarce, manual workers could become vulnerable to exploitation as they struggle to find work.

> "Unless the world changes its political structure immensely" a lot of people are going to be exploited, while in the "more advanced economies" like in Europe there is a push to more flexible working hours including working from home and automation". — MARK P, EXECUTIVE DIRECTOR AND CTO AT FBR

Implications

In possible futures the hours worked, and time of day or night of work in the construction industry are likely to shift in relation to the roles played by automated and robotic technologies. However it is important to be vigilant of the dangers to workers, the ethics of surveillance and to the inequalities that this could give rise to.

Safety, Health and Wellbeing

As one of the most dangerous industries to work in, questions of training, everyday work practices, the organisation of work and gender in the construction industry are bound up with worker (physical and mental) safety and health. Challenges to "the protection and promotion" of precarious workers' health in the industry, highlight the complexity of the relationships between organisations and the long and complex supply chains involved, where "competitive tendering and commercial arrangements can create structural (cost and time) impediments to the protection and promotion of workers' health" (Lingard and Turner 2023: 17). In this section we discuss safety, health and wellbeing in relation to future automation and robotics.

Automated and robotic tech was often discussed through the prism of safety.

Because safety is such a key issue for the industry, participants often framed the introduction of automated and robotic technologies through the question of safety and health. For example, participants saw work tasks performed by robots (e.g. a robotic bricklayer or an imagined asbestos removal robot), robotic arms (e.g. for electrical work above head) as safer than when performed manually. Safety was also supported through the use of on-site automated systems (e.g. for contact tracing during COVID) and for accessing safety information and training.

Gerry (Union OHSE Manager) was often consulted about the introduction of new technologies in the industry, he told us "the first thing I look at is the safety side of things. So I won't look at productivity, I won't look at the cost, just look at the safety side of things. If it's a safe product, then yeah, let's have a look at what comes after and how it affects people".

Digital privacy as safety

Automated contact tracing systems had been introduced across construction sites during the COVID-19 pandemic. Participants highlighted the work they had done to reassure workers that these systems would both keep them safe and respect their privacy.

> "There was a little bit of initial resistance because, concerns around tracking. As you probably know, in construction, there's a bit of sensitivity around that with the unions and things. So, we sat down with the union secretaries, went through it, and they all were happy. As soon as we agreed to things like their data wouldn't be used to have any negative consequences on employees, like not being there on time or things, they were fine. As soon as we explained to workers that it doesn't track you outside of the site, then they were fine as well. I think it actually gave them a bit of a reassurance that the contact tracing was happening effectively". — GERRY, UNION OHSE MANAGER

Off-site automation and robotics could be safer

Participants generally considered off-site uses of automated and robotic technologies for 3D printing, prefabrication and other tasks as safer than existing on-site work.

Ahmed (Founder and CEO at Luyten) suggested manual work in the construction industry is not sustainable over a lifetime of work: there are too many pressures on worker health and safety, preceding - but also amplified by - Covid-19. Ahmed is confident that in his field of 3D printing, workforce upskilling is possible: software training is tied to the use of systems, and some professions/trades (such as architects, roofers, and glaziers) can integrate their work with new materials and designs.

Automation and robotics can remove some health and safety risks

The focus on assisting with and/or transferring "dull, dirty and dangerous" work (known colloquially as DDD or '3 D's') work to robots is a consistent goal and selling point for robotisation. It appears often in industry analyses, corporate priorities, and academic research. This was already becoming a reality in some companies as well as part of the imagined future for participants.

Mike and Mark (CEO and CTO) at FBR emphasised the hard work delivered by construction workers and that "the dull, dirty dangerous phase is so relevant to construction, because so many of the job roles and the things that they have to do on building sites are exactly that, they're dull, they're dirty, and often dangerous", noting the industry's poor health and safety record, telling us that "one of the opportunities that we've had is to really drive home the need to improve the onsite safety, and take out the risks for people".

> "If you go out to one of our sites and you see the way that we conduct ourselves out there, and the way that the teams, they're tight knit, they look after one another, we really always press that home with everybody, is everyone goes home with the same amount of toes and fingers they came to work wivth. And if there's any risk of that, we stop, no question".
>
> — MIKE, MANAGING DIRECTOR AND CEO AT FBR

> "I'm sure there is a role for artificial intelligence to start shifting loads. I think that it [could] be a good thing. That would save a lot of people [from] getting injuries and that sort of thing without too much of an impact in terms of people's livelihoods and their economics and sustainability". — GERRY, UNION OHSE MANAGER

Automation and robotics will not remove all safety risks

For some participants, the introduction of robotics could improve but not remove all safety risks where they envisaged humans and robots working together.

> "We'll get moderate change in the way we deliver safety on site, but I don't see us revolutionising safety when we've still got a human element". — JOHN, HSEQ MANAGER

Darren (Site Manager) discussed how in their company they have been using a robot to demolish part of the existing space as part of a retrofit project. He identified this as making the work safer for them, since, he said "we would be putting people more at risk by doing it by hand both from the fatigue and from the actual … vibration of the tool itself, whereas now with the remote control you don't have that worry any more … it's literally an operator standing all the way back … it's a step forward but you're not removing the operator … he's just performing that task much safer and he's able to do it for a prolonged period".

Jonathon (Project Manager) gave the example of the forklift which is dangerous since the object being lifted could fall on the human, he said that one way to remove the risk is to remove the human who would be "standing 10 metres away, they're still controlling, observing, seeing the whole area but if there was a collapse they're not at the immediate point of impact". He added that the benefit of having workers actually there on site, is that they can walk around to see different vantage points and move things so that the robots can do their work.

AR & VR and safety

Augmented Reality (AR) and Virtual Reality (VR) technologies have been identified as a generalised Industry 4.0 technology with rapid applicability to construction, and a growing trend of applied research in safety (Statsenko et al. 2023). Participants in our research imagined future benefits of AR and VR but saw barriers in their implementation. Costs especially, where seen as prohibitive in some situations. It was suggested that it would be more likely that sensors and beacons will be used in the future.

John (HSEQ Manager) and Darren (Site Manager) discussed how if "you just had a normal set of glasses and it gave triggers like 'hey guys you shouldn't walk there'" and advised workers on what tools or equipment they'd need as they moved through into different parts of the site, that this would be good for future safety on construction sites. They also suggested advances in BIM models whereby buildings can be experienced in VR at the design stage "will really revolutionise the way we build" (John, HSEQ Manager).

"For me as a safety professional just to walk through a building and for example look at glass structure and see it lighting up in real time and be able to inform the client the best way to build just from a safety perspective is phenomenal. [But] from an application point of view, when I'm doing the build, VR then becomes very challenging, it's talking about connecting every single subcontractor [and] every single worker on site to VR technology. Suddenly the costs rise significantly and it's putting in for example beacons and all the programming beforehand and all of a sudden instead of doing a ten million dollar build we're going to have to charge you fifteen million which then becomes unaffordable". — JOHN, HSEQ MANAGER

Implications

Safety involves digital privacy, as well as mental and physical safety and health. Automation and robotics will not remove health and safety risks in the construction industry, but if implemented carefully could reduce risks to workers. AR and VR could increase safety, but the cost of implementing these technologies in a fragmented project-based industry could be prohibitive.

Social relationships of work and mental health are fundamental

Participants emphasised the relevance of social and gendered relationships of construction work, to mental health, trust and learning in the present and in possible futures.

Men's mental health

There is a particular concern with men's mental health in the industry (Turner and Lingard, 2020) as well as amongst our participants. Men who spend a lot of time working together also depend on each other emotionally. Mental health questions must similarly be at the fore in relation to implementation of and transition to robotic and automated technology,

Remote work and safety

Participants highlighted the risks of a lack of social relationships and mental health support for remote workers.

In a possible future workers are likely to increasingly collaborate with robots rather than other workers, they may work remotely from home or elsewhere, leading to increased worker isolation and the exclusion of workers from peer support. Even where provision is made to support remote workers in Australia, it could be difficult to ensure the safety of remote workers operating robotic and automated technologies from overseas.

"How do you ensure that what you consider to be safe work hours is followed in other countries where they have different understandings of safety". — DANIEL, WHS RESEARCH, STATE GOVERNMENT

Trust

Participants emphasised the importance of trust in their everyday work, and its relation to safety. This also came to the fore when technologies like sensors were being implemented in high-risk sites and situations.

"You have to truwst the process and then you do also have to trust the people". — DAN, BUILDER

Implications

The social relations of work, involving mutual support and trust often depend on in-person collaboration, and are in construction are fundamental to safety. Future automated and robotic technologies, and remote work could make it more difficult to sustain these social and trust relations, and the isolation of remote work in particular could impact on workers' mental health.

Industry Futures

Innovation in the Australian construction industry

Australia is still often seen as a receiver of technological innovation

Consistent with reviews of automation in academic works (Gharbia et al. 2020, p. 11-12), participants often cited seeing or hearing about examples of innovation in Europe and Asia that are yet to be embraced or even arrive in Australia. They noted that Australia relies on the importation of devices from China and Japan, as well as the ongoing influence of the US (California/Silicon Valley) in technology development but commented on the difficulty of implementing digital innovation.

> "There's certainly individuals in the business that are a bit more long-term sighted [...] but I think, at the ground level, they're so focused on the day-to-day delivery and just getting through today, that that more long-term strategic thinking about new ways of working is quite challenging. It's so hard to get involved in new things or think about the future when people are so swamped with just what's on their plate today". — AMANDA, EXECUTIVE MANAGER HSEQ

Technology startups are driving innovation in Australia's construction industry

Technology startups are actively involved in delivering automated and robotic technologies, systems and services in the construction industry. We encountered Australian startups - including FBR, CodeSafe and Ynomia - as excellent examples of how technology can be integrated into the industry successfully when tech innovation, capability and industry need coincide, usually with an as-a-service offering. A key characteristic of the successful startups we found was the strong people-centred focus, suggesting that this growing startup ecology in the construction industry will promote the people-centred principles associated with industry 5.0 and 6.0. However the potential for startups to succeed *only* in Australia has been seen as limited, and as a result many tech start-ups go overseas seeking investment.

"[Startups] need to be in that Silicon Valley area really… [since], that's a key spot sort of thing to have all the people there to set everything up". — MARCUS, ACCOUNT MANAGER, GEOSPATIAL

Implications

Technology startups are likely to play a key role in the future of the Australian Construction industry and are important in bringing home-grown and tailored innovation to both the Australian industry and transferring this overseas. Greater investment in startups could augment this in the future. However the application of digital innovation is sometimes difficult for Australian companies and would benefit from long term thinking and planning.

Future Materials

The future of materials in the construction industry is a fundamental element of digital transition. We consider the endurance of and changes to existing materials used in the industry, dangerous materials, and the possibilities of future prefabrication.

Wood

Participants suggested wood was likely to remain essential to construction, and noted Australia's relative wealth of timber resources. But they also suggested since the pandemic there had been an increase in the importation and use of cheaper engineered timber.

In particular participants noted changes in how timber products were and would be developed, and suggested future uses in prefabricated walls construction. Participants expressed concerns around the sustainability of future uses of timber, as well as possible future shifts in timber production and processing designed to resolve this, and proposed that wall systems and plasterboard composition would be completely different.

"There's not enough timber in the world to build what we build". — EUGENE, BUILDER

> "If you look at the fibre utilisation" if you have a tree "the utilisation is somewhere around 50%, 50% goes into residual waste .. so it's a very low yield, but it's being perceived from an environmental perspective as a very high value product", "[by 2050] we will see a significant change in how a tree is processed … moving towards 90% utilisation". — KARL-HEINZ, CONSULTANT

Bricks

Participants suggested that future materials would always include bricks but they are likely to be used differently. For example, where brick walls could be prefabricated on metal structures and then dropped into a site, rather than having the bricks laid on the site.

Mark (Executive Director and CTO at FBR) explained that "over the last 6,000 years, the bricks have got bigger and lighter per unit volume" and "have been optimised to suit humans and not robots". While contemporary bricks are "sort of the size of a human hand can pick up and handle all day long …a robot doesn't care what weight or size its handling". It had been more effective for FBR to create the larger "robot optimised mega block". He concluded that "we're looking ahead to where the industry needs to go", when "a human couldn't reliably handle that block all day. It'd be a two-person lift, not very efficient, but robots will love it".

Asbestos, silica and engineered stone

In Australia since 31 December 2003, there has been a "total ban on manufacture, supply, use, reuse, import, transport, storage and sale of all forms of asbestos" (*Victoria State Government*, 2021). However there is still a considerable amount of asbestos present in existing buildings and "It is estimated that 4,000 Australians die each year from asbestos related diseases" which include asbestosis, lung cancer, mesothelioma and asbestos related pleural diseases (*NSW Environment Protection Authority*, 2020).

Everyday risks related to asbestos that construction workers involved in renovation and related work face remain often hidden, and moreover, despite the terrible and fatal consequences of introducing this dangerous material into the industry, subsequently new materials - silica and engineered stone - have led to new respiratory health risks for workers.

Asbestos is a part of the history, reality and vocabulary of the construction industry. Our research participants noted how some workers still refer to

"asbestos sheet" when they mean "concrete sheet", even though asbestos is no longer being used. Its legacy was apparent even in basic industry induction (which we participated in as part of our research): the instructor used asbestos as an example of changing standards and practices. Participants felt that asbestos would gradually be removed but would always be present and noted cost challenges to this process.

"We'll never get rid of asbestos, it's here to stay, but we'll be more aware of it and stop using it like we're doing... it will just become negligible in the future". — JOHN, HSEQ MANAGER

"The biggest challenge in asbestos removals is convincing the client it's in the best interest to remove it". — DARREN, SITE MANAGER

Participants noted cases where the removal of asbestos could be incomplete due to cost, and where remaining asbestos may be unreported. They suggested that in the future technological systems could assist in such circumstances, including using digital twins and building biographies, and creating records in all renovation projects to enable better and safer materials tracking.

In the future robotics could be used to monitor and remove asbestos. But there would be challenges and this would only be possible in some tasks and open spaces and difficult in small spaces, especially for removing asbestos pipe lagging, and in roof spaces with electrics.

"Removing asbestos is a very dangerous job. There may be a case for technology to do some of that work. I mean, a lot of that especially in the power industry, you have to scrape it off of these awkward positions. Whether there is a robot that can do that, I mean we're still getting people who are dying from mesothelioma that have worked in the industry". — GERRY, UNION OHSE MANAGER

Implications

Materials used in the construction industry are impacted by robotic and automated systems in a range of ways, including the ways in which they are produced, constructed, installed and removed. Alongside this, materials are becoming increasingly engineered, sustainable and safe. In the future new materials will continue in this vein. However existing materials will remain and will be encountered in renovation and retrofit projects, in some cases automated and robotic technologies will make these materials easier to work with and safer, but in others manual work will still be needed.

Markets and capital structure visions of future tech in the construction industry

A project-based industry makes cost prohibitive

The structure of the industry and flows of capital encourage "a project-based industry" defined by its decentralisation and dispersed working, an emphasis on "price over value", customised projects, long supply chains, subcontracting and short-termism, time-pressured work, complexity, involving multiple organisations (Leiringer & Dainty 2023: 5). This structure discourages investment in the co-design of technology and worker engagement, which could have a longer term and positive impact on workers, and their safety. A project based industry does not support technological innovation, and makes the acquisition of robotic and automated technologies too costly for both large construction firms and SMEs.

John K (Head of Electrics at FBR) commented that using robots to do dangerous electrical work would be easier "if we changed the way that we made buildings". He imagined:

"If you had a robot which got to site before the roof was pitched, then yeah you could absolutely do that sort of thing, or if we had different brick systems which allowed for cables to be set in set locations and laid at the time when the walls were done. Anything's possible with this sort of technology".

But he emphasised that cost was the pivotal question: "It's just whether everyone agrees that it's worth doing now because obviously it's quite expensive".

For small companies the costs associated with new technologies was prohibitive. Gerard (Vocational and Technical Educator) commented that: “if your work drops off, you basically put a couple of guys off. If you’ve got these machines sitting there, and you’re paying them off or something, you’ve got to be careful that way as well”. In his experience, the possible gains of new technology were often stymied by the upfront costs of implementation: “if you had piles of money, you could do it. You could perhaps make it cheaper if your robotics goes for 24 hours”.

Implications

The ways that markets and capital structure the short termism and project base of the industry make cost a determining factor and discourage innovation. For innovation to be effective, it would be necessary to re-think project and innovation models and for the leadership of large companies to partner with innovators.

The future of subcontracting and service models

The construction industry is characterised by its fragmented structures and the predominance of subcontracting. Participants had varied views relating to if the nature of subcontracting would change in the future. However the service model that has emerged in the work of the start-ups we have discussed offers one possibility.

Responsibility and risk will be contingent on the structure of the industry

Participants believed that in the future there will be little change in how responsibility is allocated for existing technologies, and saw the future of risk as related to the future of subcontracting.

Future workers will remain self-employed as sole traders working for subcontractors, but the change will be that rather than being a brickie, a sparky or other traditional role, they will be robot operators, drone pilots or in other technology focused roles, and might be subcontracted through gig or platform work models.

> "All of the companies that create all of the tech will all go 'yeah we meet that ISO [International Organization for Standardization] standing, then it's up to you as the owner of the tech to do the maintenance and do the repairs', you know just like we see in traditional tech like cranes at the moment … If there's a crane incident they don't straight away go to the designer, because the designer goes 'ISO, well, done, was the maintenance done' and that goes back to the crane owner or the crane operator".
> — DANIEL, WHS RESEARCH, STATE GOVERNMENT

Startups and new modes of subcontracting

Engineering literature reviewed earlier in this report in *Perspectives on construction industry futures* suggested that automated and robotic technologies can solve industry problems but are slow to be taken up. Instead, we found that where startups situate technology innovation within the industry and offer it as a service to the industry, in ways that mirror the current subcontracting model, is highly effective.

This subcontracting model is not necessarily a "barrier" to the uptake of robotics and automation. Rather in a context where the structure of the industry seems unlikely to change, subcontracting automation and robotics as part of a service within the industry offers a viable approach that is aligned with existing structures. Most participants in our research did not believe that this aspect of the industry would have changed by 2050.

Mark (Executive Director and CTO at FBR) described how the company "looked at the kind of subcontractors that might operate a robotic bricklaying machine, and they're fairly unsophisticated in terms of technology use, and not using any other robotics and not using anything else automated other than a cement mixer, which has basically got an on and off button, or a pull cord to start it, and you shovel sand and cement in. … So we thought that it would be a pretty big ask for builders or bricklayers to actually take on this new tech". On the basis of this, he told us "we figured that at least in the early days, we would have to not only design and develop these machines, but also operate them and get them out in the industry and prove that robots work in the field".

David B (Cofounder and CRO) described how in CodeSafe, "we provide technology as a service" and elaborated that generally "anything that's a bit more technical in nature, smart customers and smart operators offer it as a package". However, the future of service models, as a replacement for subcontracting, could also lead to new complexities in what is already a fragmented industry. For instance Matthew (Director and Cofounder at Ynomia) pointed out that interoperability could be a serious issue, and that the industry may soon find itself at a crossroads.

> "There's this massive overlap and inefficiency in the way that technology - digitally speaking - gets brought in, and I think it's probably getting to a point where it's going to slow the industry". — MATTHEW, DIRECTOR AND COFOUNDER AT YNOMIA

Digital Contracts

Most participants did not believe there would be great changes in the roles that contracts play in the industry, but anticipated a shift to electronic versions of contracts.

Darren (Site Manager) was "not convinced that the contracting approach will change over the long term". He felt that the whole contract system in the construction industry is "self-correcting" so that "every time someone tries to do something unique with a new contractual style, the industry, you know the procurement people, the lawyers just push it back".

Brett (Senior Manager, transport infrastructure projects) suggested that by 2050 much of the paperwork involved in construction projects, which currently takes hours of work, will be automated. He thought that "contracts themselves will remain in some shape" but there will be "tools to replace the standard paperwork we have", such as reports that are currently signed off on by a human reviewer will be automated, in that "one AI's going to write it and another's going to read it you know".

Participants were divided over the future of the blockchain for payment systems, while some believed they would be used, Mark (Executive Director and CTO at FBR) suggested that the centralised databases approach to payment that already exists in banks and building companies "is just a far more efficient way of dealing with those problems than blockchain" and noted that because "the building industry basically works on a contractual basis, so you've got legal grounds behind those contracts, there is a level of trust that is not existent in the situation when blockchain might be useful". Mark's perspective is echoed in academic literature, which has not identified a pressing need for blockchain-derived (and similar) forms of 'smart contracts'. A recent review found blockchain construction research focussed on technical prototypes, and is yet to meaningfully account for the "awareness and capabilities of personnel" (Elbashbishy et al., 2022). For our participants, the future looked like a steady standardisation of current protocols rather than a significant shift in technology.

Implications

Participants believed that there are unlikely to be disruptive changes in the future in either the structures of contracting or the kinds of contracts which will be made, or in the risks and responsibilities associated with this. They assumed that the services offered by subcontractors are likely to include automated and robotic services and contracts are likely to be digital and potentially automated, and noted a risk of future inoperability. We recommend future-proofed standards are put in place, rather than there being a "race" to be first followed by calls to standardise and regulate.

Sustainability and the Future of Construction

Recent evaluations suggest that as the Australian construction sector grows, so do its carbon emissions, and that interventions are needed to meet sustainability and climate challenges (Adey et al., 2022: 66). There is a "clear desynchronisation" between emission reduction and technology development in the industry (Adey et al. 2022: 67). Often blue-sky materials research is untethered from everyday work practices, and the role of pressing impact of the climate on work.

Retrofit and circular economy will grow

Participants envisioned a future shift towards retrofit and circular economy, where the use of automation and robotics could be complicated. Current commitments to net zero carbon were seen as project-based, and dependent on the client's requirements.

David B (Cofounder and CRO at CodeSafe) emphasised the complications of using robotics in retrofit work, where he is seeing rapid growth. As an example he explained that "we were replacing a 100 year old water mains, now if that was a new pipeline, anyone … can build a new pipeline but when you start replacing existing infrastructure, that is a completely different beast … it's such a dynamic environment that most people don't understand how dynamic it is".

Retrofitting with robots creates challenges related to space and accessibility of spaces. Darren (Site Manager) described how everything in a large building retrofit project they were involved in was logistically complex. The transport of a small demolition robot to work on the upper floors of the building, had required them to take it up in an external lift which had been constructed outside the building with scaffolding.

Karl-Heinz (Consultant) suggested that by 2050 there would be "reduced access to raw materials and therefore drive towards a circular economy" which would lead to "not demolishing buildings to make -place for newbuildings, but reusing existing buildings or finding new uses for them". Using robotics would be challenging in such contexts.

3D printing is part of the growing sustainable tech ecosystem

3D printing (or additive manufacturing) shares with other advanced materials for construction is classed as a 'critical technology in the national interest' (Commonwealth of Australia, 2021: 13). 3D printing minimises various costs and risks, compared to a traditional build. This has been a key drawcard for consultancies, who report significant industry appetite for this form of in-situ manufacturing, rather than relying on strained supply chains (Armstrong et al., 2023). In such cases, the pursuit of technological efficiencies have a compound effect that also makes their application more sustainable. Some participants were involved in developing these technologies locally.

Ahmed (Founder and CEO at Luyten) described 3D printing as a marriage of robotics, materials, and software. With reference to sustainability, he discussed how the products created by Luyten are more recyclable, produce less emissions, and are more durable, making many existing materials seem like 'cardboard' in comparison.

Documentation for future sustainability

Participants noted the benefits of existing documentation of the history of a construction site, to assist retrofit and circular economy building. The creation of "as built" records, could increase safety, and the possibility of using AI to assist searching them, would mitigate limits to capacity, in terms of cost and staff that impact the industry more widely. Keeping these documents up to date would also be important.

Darren (Site Manager) discussed how they now document the stages of the build photographically to create an "as built" record of the building process, which they can go back and check things against. He hopes that within 10 years they will be able to arrive at buildings they are going to work on which will already have "as built records" so they can refer back to work that has been done in the past.

"20 years down the track it [a digital twin] might be out of date, and that is once again a cost and capacity point of view. If you have someone in your maintenance team who can make updates to digital twins you might be able to keep up with that, or else you've got to pay another company to update your digital twin". — JONATHON, PROJECT MANAGER

Implications

As retrofitting and the circular economy are increasingly part of the future construction industry, there will be possibilities to use AI to assist in making records or searching existing documentation.

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