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Digital Transformation and Organizational Learning: Situated Perspectives on Becoming Digital in Architectural Design Practice

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The architecture, engineering, and construction (AEC) industry is negotiating a slow and fragmented shift toward digital transformation (DT). To identify the drivers and barriers to DT in the AEC industry, this article draws on organizational learning theory. More specifically, it investigates learning dynamics related to digital technology knowledge and skills development in organizations in the architecture sector. Adopting an empirical approach, the research has collected data through a series of semi-structured interviews (n = 17) with employees from four large-scale architecture organizations in Sydney, Australia. The article conceptualizes the interviewees' experiences of engaging with digital technology knowledge and skills in their workplace along a learning loop continuum and in relation to modes of single-, double-, and triple-loop learning. It finds that organizations are primarily fostering modes of single-loop learning and potentially missing opportunities to innovate. The research highlights the hybrid, extensible, and platform nature by which individuals "learn" digital technologies and computational systems in the architecture workplace and identifies opportunities for intervention. The research demonstrates the utility of organizational learning as a method to rethink approaches to DT in the AEC industry.

Keywords: digital readiness, digital transformation, organizational learning, architecture, computational design, design, sociotechnical systems, workplace learning

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INTRODUCTION

By 2023, it is predicted that 52% of global gross domestic product (GDP) will be driven by "digitally transformed" enterprises, and by 2024, "51% of IT budgets will be focused on digital innovation and transformation" (Miller, 2020). Unlike other major industries such as manufacturing, finance, law, retail, hospitality, and transportation, the architecture, engineering, and construction (AEC) industry is negotiating a slow and fragmented shift toward digital transformation (DT) (Sepasgozar et al., 2016; Maali et al., 2020). REMOVED FOR PEER REVIEW. While the AEC industry is engaging with processes of digitalization, such as the use of federated 3D building information models (BIM), this evidences a new norm as opposed to radical business innovation and transformation (Olanipekun and Sutrisna, 2021). In general, the "... AEC industry is not considered an industry that fosters innovation" (Maali et al., 2020, p.326). Low levels of investment in digitalization and research and development are common across the industry's three professional sectors, and this suggests that the industry is illprepared for DT (Raisbeck, 2010; Kraatz et al., 2014; Loosemore, 2014; Agarwal, 2016; Burke et al., 2016; Cann, 2019).

Of the three professional sectors that make up the AEC industry, the architecture sector has a particularly robust reputation for conservatism and ambivalence, especially when it comes to digital technology innovation (Ramsgaard Thomsen and Tamke, 2020). At an organizational level, As Maryam Abhari and Kaveh Adhari reflect, "Architects and design professionals . . . tend to use new technologies without changing their traditional design approach . . . " (Abhari and Abhari, 2019, p.6). In an Australian context, the architecture sector is characterized as risk adverse and rigid in terms of its business structures (Burke et al., 2016). Inside architectural organizations, path dependence and a dogged focus on project work leave little room for long-term strategic thinking, planning, and innovation (Criado-Perez et al., 2022; Gardner 2019). As a result, many organizations project a "wait and see" attitude to DT (Mugge et al., p.28). In a global knowledge economy, this is problematic as ". . . the pace of competition is savage and swift, [and] . . . whole industries can disappear or suffer decline because they fail to detect and respond to early warning signals for rapid change" (Argyris and Schön, 1996). But it is also a missed opportunity as architecture organizations are typically engaged at the front-end of built environment projects where design process innovation can have substantial flow on effects for the broader AEC industry and economy.

Diagnosing and strategizing ways to overcome barriers to DT in the AEC industry has been investigated in both commercial and academic settings. But many studies that purport to problematize DT are often a guise for digital products, services, and/or technical implementation plans (for example, see Daniotti et al., 2020). A deeper engagement with the problem of DT in the AEC industry exists in the form of empirical technology adoption and acceptance studies that have been carried out at organizational, sector-wide, and national scales (Ongori and Migiro, 2010; Sepasgozar et al., 2016; Lavikka et al., 2018; Sepasgozar et al., 2018; Chowdhury et al., 2019; Gardner 2019). Studies those document and report technology adoption and diffusion rates in organizations and industries often report these as a measure of DT progress or a lack thereof. But these empirical studies also highlight the need to better understand how socio-organizational dimensions influence processes of technology acceptance and sustained technology diffusion (Loosemore, 2014; Lee and Yu, 2017; Maali et al., 2020).

In an early and formative study of BIM adoption in the AEC industry, Gu and London (2010) stressed that the barriers to technology implementation in practice are both technical and nontechnical. Yet, the nontechnical or socio-organizational dimensions of DT in the AEC industry have typically attracted less research attention. More recently, scholars of business studies have investigated DT in the AEC industry from the perspective of organizational change and strategic leadership thinking (Criado-Perez et al., 2022). Still, rapid technological change presents a complex challenge for strategic organizational (re)design. Top–down strategic approaches as well as foresight and futuring methods have been criticized as costly, ineffectual, disconnected from organizational processes, and distanced from workplace practices (Smith and Ashby, 2020, 2020). Given the limitations of these existing approaches, this research draws on tenets of sociotechnical systems (STS) thinking to investigate technological changes in organizations in the context of DT. STS thinking centralizes the creation of empirically constructed understanding of the behavioral world of organizations and the "theories-in-use" of its individuals as a participatory approach to managing technological change. STS thinking is relevant to the problem of DT as it aims to balance "the needs of human beings and social systems . . . with the advantages that technology offers" (Pasmore et al., 2019, p.83).

More specifically, this article focuses on investigating the learning dynamics in architectural organizations in the context of DT by drawing on organizational learning theory originally developed by Chris Argyris and Donald Schön (1978; 1996). It brings perspectives and concepts from organizational learning theory to bear on the analysis of data collected from 17 semi-structured interviews conducted with employees from across four large-scale architecture organizations in Sydney, Australia. In so doing, the article conceptualizes the interviewees' experiences of engaging with digital technology and computational methods in their workplace along a learning loop continuum and in relation to single- and double-loop learning (Argyris and Schön, 1996) and triple-loop learning (Foldy and Creed, 1999; Wang and Ahmed, 2003; Peschl, 2007; Coudel et al., 2011; Loosemore, 2014). Foldy and Creed (1999) neatly summarize these loop-learning categories as "tinkering with current conceptions about how things should be done (single-loop learning), thinking outside the box of the actor (double-loop learning) and questioning the encompassing box (triple-loop learning)" (p.208). The organizational learning loop continuum (**Figure 1**) is deemed relevant to DT in organizations as its notions of double- and triple-loop learning find close alignment with accepted definitions of DT as an organizational process of value change creation (Dörner and Rundel, 2021).

Given this, it is reasoned that the empirical investigation of the learning dynamics of organizations constitutes a significant but underexplored dimension of DT. In the following sections, the alignment between organizational learning theory and DT is further established. This article then details the data collection method of semi-structured interviews and its analysis through the lens of organizational learning. It concludes by outlining learning insights and identifying potential intervention points to advance DT in the AEC industry.

ALIGNING ORGANIZATIONAL LEARNING AND DIGITAL TRANSFORMATION

DT is a widely used concept that describes how societies, industries, and organizations, adopt and implement digital technologies in ways that introduce change into those contexts. It has evolved as an important cultural and business phenomenon and is thus a subject of study across multiple disciplines. In a professional context, DT is seen as a strategic

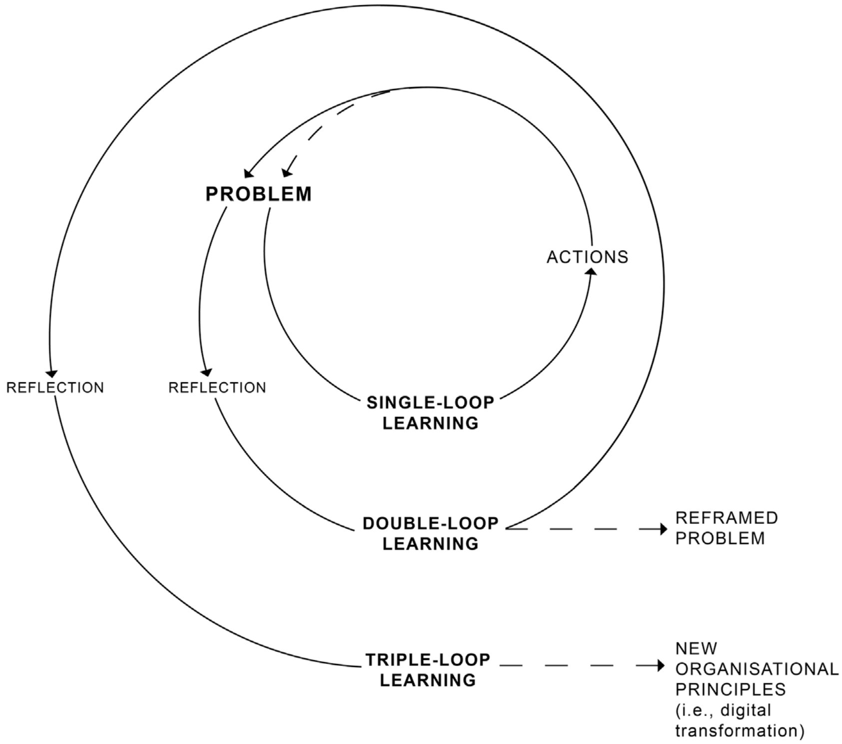

FIGURE 1 | Organizational learning loop diagram.

goal for industries and organizations. For Nambisan et al. (2017), DT is characterized as "the creation of, and consequent change in, market offerings, business processes, or models that result from the use of digital technology" (p.224). Following a systematic review of DT definitions in information systems (IS) literature, Vial (2019) defines DT as "a process that aims to improve an entity by triggering significant changes to its properties through combinations of information, computing, communication, and connectivity technologies" (2019, p.118). As Vial's definition is not "organization-centric," it allows room for DT to be understood as a phenomenon that is experienced, enacted, and made material by and through people. This recognizes that while digital technologies can be leveraged to catalyze change in organizations, sustained transformation occurs when those processes interconnect across social and technical domains. From this perspective, successful approaches to DT are those that engage a multipronged approach to the introduction of change that encompasses and connects business processes, workplace cultures, and work systems (Bonanomi et al., 2020; Olanipekun and Sutrisna, 2021).

The rapid pace and convergence of digital technology and computational system development are outpacing the capacity of many organizations in the AEC industry and beyond to adapt to and leverage digital technology to create new value. In particular, path-dependency and top–down approaches to technological change in organizations have exacerbated a gap between technical and social capability (Pasmore et al., 2019). Pasmore et al. (2019) argue that "even the successful tech firms . . . have not found ways to keep their social systems advancing as quickly as their technology" (p.72). Redesigning an organization's mindset, culture, systems, and processes is time-consuming and generally a long-term strategy. Furthermore, while quality and process improvement frameworks such as Six Sigma have found success in large organizations with the requisite economic resources, they are typically less suited to small- and medium-sized enterprises (SMEs) that characterize the Australian architecture sector (Sony et al., 2020).

A key tenet of STS design is that it advances a collaborative approach to managing technological change in organizations (Trist, 1981; Pasmore et al., 2019). In this way, STS design is akin to a "middle-out" method that extends from the space between the emergent phenomena that is produced through bottom–up processes (social organization and workplace practices—self-regulation) and top–down processes (organization strategy, leadership, rules, standards, and codes of conduct). To do this, STS design adopts a practice-oriented and empirical approach to understand organizations wherein the notion of learning is central (Argyris, 1974; Argyris and Schön, 1978; Trist, 1981). More specifically, Argyris and Schön's (1978; 1996) work provides an empirically informed theoretical base for investigating learning in organizations in the context of DT. This is because organizational learning theory connects the drivers of learning in organizations to the capacity for organizational change and innovation.

Organizational learning theory establishes an important conceptual bridge ". . . between learning in the workplace and

TABLE 1 | Organizational learning loops.

Types	Scholarly Definitions	Example
Single-loop learning is . . .	". . . **instrumental** learning that changes strategies of action or assumptions underlying strategies in ways that leave the values of a theory of action unchanged" (Argyris and Schön, 1996, p.20) ". . . **tinkering** with how things *should* be done . . ." (Foldy and Creed, 1999, p.208) ". . . **exploitative** learning to do what is already done better" (Turcotte et al., 2007, p.4) ". . . the learner (worker) simply **reacts** and **adapts** to organizational change" (Fuller and Unwin, 2013, p.54) ". . . the actor's theory of action changes, but no organizational learning takes place" (Dörner and Rundel, 2021, p.68)	***Learning narrative 2*** (*Interviewee 3*) *The individual adopted new strategies of action to solve design process problems, however, these approaches were not more broadly adopted by the organization*
Double-loop learning is . . .	". . . learning that results in **change** in the values of theory in use, as well as in its strategies and assumptions" (Argyris and Schön, 1996, p.21) ". . . thinking outside the box of the actor . . ." (Foldy and Creed, 1999, p.208) ". . . the learner uses **reflection** to engage with and **change** to develop novel solutions or to create new knowledge" (Fuller and Unwin, 2013, p.54) ". . . processes, external requirements set new priorities within the company" (Dörner and Rundel, 2021, p.68)	***Learning narrative 3*** (*Interviewee 15*) *Individual inquiry converted to organizational inquiry. The organization subsequently developed a high-level strategy to change organizational practices*
Triple-loop learning is . . .	". . . when the essential principles of which the organization is founded come into discussion" and "the development of new principles" (Swieringa and Wierdsma, 1992, pp.41–42) ". . . a change in the embedded tradition system which the governing values of a behaviour can be nested" (Nielsen, 1993, p.118) ". . . questioning the encompassing box . . ." (Foldy and Creed, 1999, p.208) ". . . combined with organizational unlearning, leads to knowledge creation" (Wang and Ahmed, 2003, p.12). ". . . change that occurs at a more fundamental level—an existential level . . ." (Peschl, 2007, p.138) "When . . . something additional happens; as actors change their guiding principles they challenge and re-frame the rules of the game in which they have been engaged—they introduce a new game . . ." (Torcotte, 2007, p.4)	***Learning narrative 1*** (*Interviewee 1*) *Individual inquiry intersected with organizational inquiry to reconceive and generate new business opportunities for the organization*

organizational performance" (Fuller and Unwin, 2013 p.54). It gives focus to how processes of knowledge management and sharing in organizations can influence an organization's adaptivity and responsiveness to changing externalities. A core conceptual contribution of organizational learning—also described as action learning and learning loop theory—is its distinctions between learning types in organizations as single- and double-loop learning. According to Argyris and Shön (1996), single-loop learning is instrumental learning that takes place within "existing systems of values and action frames in which values are embedded" but where underlying assumptions and strategies remain unchanged (p.xxiii). It entails new behavioral capacities that maintain existing insights. For example, in an architecture organization, single-loop learning occurs where new knowledge informs the design of a workflow that is used by a project team to improve the efficiency of an existing routine without changing the status quo. Put another way, "single-loop learning enables exploitative learning to do what is already done better" (Turcotte et al., 2007, p.4).

Argyris and Schön (1978) liken single-loop learning to a thermostat that receives information and takes corrective action but remains otherwise indifferent. Double-loop learning, by contrast, is learning that results in changes to underlying assumptions and strategies. It is learning that in turn challenges the status quo. When knowledge is used to redefine problems and solve them in new ways and new routines are established, the scenario corresponds to double-loop learning. In double-loop learning, reflection is harnessed as a double feedback loop that connects "observed effects of action with strategies and values served by strategies" (Argyris and Schön, 1996, p.21). Extending the learning loop schema, Wang and Ahmed (2003) and others like Foldy and Creed (1999); Peschl (2007); Turcotte et al. (2007) have conceptualized triple-loop learning as a process of profound change that radically shifts perspectives and values in ways that reconfigure and create new collective structures that transcend existing societal frameworks. For example, this could include changes in industry and customer expectations about the range of services that architectural organizations provide.

In single- and double-loop learning, organizations inquire and correct to prevent errors, but in triple-loop learning, organizations question "existing products, processes, and systems by strategically asking where the organization should stand in the future marketplace" (Wang and Ahmed, 2003, p.13). Triple-loop learning extends what is inferred by the concept of organizational learning as processes of knowledge acquisition, retention, transfer, and diffusion to knowledge creation that converts to radical innovation (Wang and Ahmed, 2003). Furthermore, triple-loop learning implies a deep form of learning that involves questioning and also "unlearning" extant ways of working (Wang and Ahmed, 2003; Tsang and Zahra, 2008; Loosemore, 2014; Tsang, 2017). In this way, triple-loop learning finds close alignment with definitions of DT as a process of radical value change creation in organizations (**Table 1**).

Therefore, surfacing structures of learning and learning behaviors in organizations can help inform learning-oriented strategies to advance DT.

Notions of progression and conversion are important dimensions in learning loops. Argyris and Schön (1996) note that the passage from new knowledge and learning at the individual and project team level to the organization level to realize "organizational learning" depends on the organization's collective decision-making procedures and capacity to delegate. Given this, practitioners or organization members (individual employees) are centrally important to the investigation of organizational learning because their "thinking and acting" is connected to the capacity for productive learning at the organizational level (Argyris and Schön, 1996). Critically, investigating learning dynamics in organizations aims to "not only ... describe the patterns of behaviour that threaten productive organizational learning but ... learn how to change them" (Argyris and Schön, 1996).

RESEARCH METHOD

Giving voice to the experiences of employees trying to make sense of their experiences with technology in the workplace reflects a core commitment to STS thinking. Equally, interpretive qualitative research methods capable of generating rich descriptions and thus deep insights are well suited to surfacing the complex factors that influence DT in industries and organizations. From an organizational learning perspective, the collection of observable data is used to construct "theories-in-use" of members of an organization. To this end, organizational learning researchers typically adopt qualitative research instruments such as observation, recording conversations, questionnaires, projective tests, and structured interviews (Argyris and Schön, 1996). In this research, to explore learning dynamics across multiple organizations, data have been collected using semi-structured interviews. As this research forms a part of a larger research project, the interview participants were recruited from the author's preceding survey research, where participants indicated their willingness to be contacted for a follow-up interview (Gardner 2019). The initial survey research adopted a purposive sampling approach to recruit participants from large-scale architecture organizations (defined as >100 employees) with offices located in Sydney, Australia. The industry recruitment approach as opposed to a professional body avenue such as the Australian Institute of Architects aimed to capture the widening cross-section of specialists working in the sector, namely, design technology specialists and nonarchitects, and/or those not legally permitted to call themselves architects. Consequently, in the previous and current studies, participants were required to be working in design-related roles within an architecture organization. The recruitment criteria excluded those working in architecture organizations in areas of administration, human resource management, and financial management.

Interviews were conducted with 17 participants (7 male/10 female) from 4 large-scale architecture firms with offices located in (Sydney, Australia) between December 2018 and February 2020. Face-to-face interviews were conducted with participants in private meeting rooms in their organization's workplace, except for one interview that was conducted at the author's office. The interviews were audio-recorded and transcribed, and the transcriptions were de-identified. The general demographic profile of the 17 interview participants and their career stages are shown in **Table 2**.

The core themes and findings derived from the survey data collected between 2017 and 2018 (Gardner 2019) informed the design of a semi-structured interview question guide sheet. The conducted interviews followed a tripartite structure. Interviewees were first asked about key demographic information such as their age, followed by questions about their tertiary educational qualifications. The second part of the interview focused on questions about the interviewee's experiences engaging with digital technologies in educational and workplace contexts. The interviews typically concluded with a final question on what the future of the architecture profession might look like in 5–10 years into the future.

The analysis of the interview data adopts a theoretically driven thematic approach (Braun and Clarke, 2006; Clarke and Braun, 2013), informed by a core question that asks, what are the dynamics of learning related to digital technologies for individuals and teams in architecture organizations? The interview data analysis adopted an open-coding approach. Analytical codes were generated and revised throughout the process to identify patterns and themes across the data. NVivo 12 qualitative data analysis software was used to organize the data and input codes as variables for further quantitative analysis.

ANALYSIS THROUGH THE LENS OF ORGANIZATIONAL LEARNING

Interview participants in this research varied in age, gender, educational and professional qualifications, and career stage (see **Table 2**). Collectively, the data captured an illustrative cross-section of employees working in the architecture profession in Australia between 2019 and 2020. The analysis of the interview data is centrally interpreted through the lens of learning. The organizational learning schema of single-, double-, and triple-loop learning and associated notions of learning systems, learning structures, and entrepreneurial learning (Nogueira, 2019; Rupcic, 2019) are bought to bear on the interpretation of these data. The learning loops described by Argyris and Schön (1996) are conceived of a continuum, where each type of learning presupposes the other. Given this, scholars caution against reductively analyzing types of learning separately

TABLE 2 | Interviewee profiles.

No.	Gender	Age range	Job title	Education/qualifications	Career stage
1	M	40–49	Project Architect	Undergraduate + Masters Registered Architect (Australia)	Mid career
2	M	30–39	Undefined	Undergraduate + Masters	Mid-career
3	M	30–39	Associate	Undergraduate (Honors) Undergraduate	Early to mid career
4	M	20–29	Graduate Designer	Undergraduate	Early career
5	M	20–29	Graduate Designer	Undergraduate + Masters	Early career
6	M	30–29	Associate	Undergraduate + Masters	Mid career
7	W	18–24	Graduate Designer	Undergraduate	Early career
8	W	18–24	Graduate Designer	Undergraduate (Honors)	Early career
9	M	45–54	Director	Undergraduate + Masters Registered Architect (Australia)	Mid to late career
10	W	20–29	Associate	Undergraduate	Early career
11	W	45–54	Director	Undergraduate + Masters Registered Architect (International)	Mid to late career
12	W	20–29	Architectural Assistant	Undergraduate + Masters	Early career
13	W	30–39	Senior Architect	Undergraduate + Masters Registered Architect (Australia)	Early to mid career
14	W	30–39	Computational Design Specialist	Undergraduate + Masters	Early to mid career
15	W	30–39	Senior Designer	Undergraduate + Masters Registered Architect (International)	Mid career
16	W	30–39	Principal Associate	Undergraduate (non-cognate) + Masters	Mid career
17	W	30–39	Principal	Undergraduate + Masters Registered Architect (Australia)	Mid career

(Foldy and Creed, 1999; Coudel et al., 2011). Consequently, in this article, the data analysis is organized and discussed in three key sections 1) learning contexts, 2) learning systems, and 3) learning narratives.

LEARNING CONTEXTS

The learning contexts for interviewees in this research, and in contemporary workplaces more generally, extend beyond traditional or normative definitions of the workplace as a geographically located office environment with fixed working hours. Interviewees described learning contexts such as the traditional situated workplace, home, and commute. In this section, the notion of a learning context extends to take account of the interviewees' digital technology knowledge skill experiences during their tertiary level architecture and design education. This is because learning behaviors, as well as attitudes and beliefs, about technology can be seeded in educational contexts. Consequently, the interviews began by briefly exploring participants' experiences of engaging with digital technology knowledge and skills in tertiary education contexts.

When describing the purpose of this research to the participants, the notion of "digital technology" was deliberately left open and undefined. But for the most part, interviewees framed digital technology as software. Interviewees who discussed digital technology in terms of hardware such as virtual reality (VR), digital fabrication machines, or robotics predominantly did so primarily in the context of discussing their tertiary education experiences, apart from Interviewee 1. For many, digital technology knowledge and skills did not constitute a substantial focus of tertiary level curricula. Seventy-six percent of the interviewees had studied in Australian universities. Notably, the four interviewees who had studied architecture at tertiary institutions in Europe and the Middle East described how the notion of technology in architecture was largely framed as building construction systems rather than design process technology. While two late-career interviewees who had studied architecture in the early 1990s understandably experienced low exposure to computing technology for architecture, others who had studied more recently also reported limited engagement with digital technology in their tertiary architecture and urban planning programs. Interviewee 2 noted that during their education, lecturers did not "…really ever teach you to draw with a computer. That was expected to be something that the profession would teach you when you get out into the world."

Numerous interviewees described being actively discouraged from engaging with digital technology during their architecture and design education. Interviewee 3 noted that the architecture school that they attended was renowned for its conservative and traditional approach. Interviewee 6 stated that "... we were discouraged from using computers. Every time I used a computer, I had to argue the case of it being used … ". Interviewee 14 described the architecture school that they attended as "very low tech, I didn't use a computer." Interviewee 12 recalled that there had been a significant "… focus on doing things by hand" in their tertiary education. This was echoed by Interviewee 13 who reflected that "We weren't actually allowed to use technology in undergrad. So it was a lot of heavy sketching, which you don't see more often anymore." Interviewees 12 and 16 both described a "basic" introduction to digital technology during their tertiary studies, and from there, it was "kind of up to you to continue." Interviewee 17 described that in their experience at university "…the sort of encouragement, to use the technology was pretty absent." Interviewee 5 noted that digital technology knowledge and skills were not seen as "…relevant to what they value within that context of [architecture] registration." For most interviewees, learning digital technology skills during their architecture education was largely optional and, in some cases, actively discouraged.

Despite evident barriers to digital technology knowledge and skills in the context of tertiary education, numerous interviewees described being self-motivated to grow their digital technology

TABLE 3 | Interviewee learning motivations, systems and structures.

No.	Learning motivation	Learning system	Learning structures
1	Individual inquiry/curiosity	Training/upskilling	Accredited training
	Design process quality	Project-based exploration	Community of practice (situated)
	Organizational competitive edge/value add		Competition experiment
2	Individual inquiry/curiosity	General exploration	Teaching others
	Design process quality	Problem-based exploration	Community of practice (online forum)
	Efficiency/productivity		
3	Individual inquiry/curiosity	Problem-based exploration	Teaching others
	Individual competitive edge		Community of practice (online forum): Stack Overflow, Googling
	Design process quality		
	Efficiency/productivity		Community of practice (situated)
	Organizational value-add		
4	Technical proficiency	Problem-based exploration	Community of practice (online forum): YouTube, Code Academy
	Efficiency/productivity	Project-based exploration	Community of practice (situated)
	Stay up to date		
5	Individual inquiry/curiosity	General exploration	Teaching others
	Efficiency/productivity		Community of practice (online forum): Twitter
6	Individual inquiry/curiosity	Training/upskilling	Teaching others
	Technical proficiency	Problem-based exploration	Community of practice (online forums)
	Efficiency/productivity		
	Solving a problem	Project-based exploration	Stack Overflow, YouTube, open-source Python community
	Design process quality		Community of practice (situated)
7	Technical proficiency	Problem-based exploration	Community of practice (situated)
	Efficiency/productivity	Project-based exploration	Community of practice (online forum)
		Training/upskilling	Online subscription
8	Technical proficiency	Problem-based exploration	Community of practice (situated): company intranet
9	Efficiency/productivity	Project-based exploration	Community of practice (situated): new staff/students
	Stay up to date		
10	Individual inquiry/curiosity	Training/upskilling	Community of practice (situated)
	Efficiency/productivity		
	Design process quality		Organization-led training
	Individual competitive edge		
11	Stay up to date	Project-based exploration	Community of practice (situated)
			Competition experiment
12	Efficiency/productivity	Project-based exploration	Community of practice (situated)
	Technical proficiency	Training/upskilling	Organization-led training
13	Technical proficiency	Project-based exploration	Online subscription: Lynda
	Stay up to date		Online free resource: YouTube
14	Individual inquiry/curiosity	Training/upskilling	Teaching others
			Community of practice (situated)
			Online free resource: Google
15	Individual inquiry/curiosity	Project-based exploration	Community of practice (situated)
	Efficiency/productivity		Community of practice (industry)
	Organizational competitive edge/value added	General exploration	Community of practice (online forum)
			Competition experiment
16	Organizational competitive edge/value added	Training/upskilling	Community of practice (situated)
			Organization-led training
17	Design process quality	Project-based exploration	Community of practice (situated)
	Efficiency/productivity		

skills. The reasons given for this included the opportunity to establish a point of difference between themselves and their peers in their studies and when applying for positions. When describing why they thought their organizations engaged with digital technologies, several interviewees saw the use of digital technologies as a competitive strategy and marketing mechanism. This is reflected in Interviewee 10's description of using data visualization software in their projects to "…differentiate us from competitors, but also just make more compelling projects and cases for projects." Interviewee 8 described their organization's motivation "…to stay current and contemporary and there's an image thing, presentation to the public … you don't want to be left behind." Interviewee 16 described the drive for digitalization in their organization as consistent with their organization's overall brand and connected to the organization's objective to be leaders in design technology innovation. They argued this underpinned their ability to "attract really talented architects to our studio."

Others described digital technology skills from the perspective of augmented design intelligence. Several interviewees referred to digital drawing and modeling tools as extensions of a designer's capacity to think and solve problems. Interviewees described scenarios where digital technologies and computational design methods were used in design practice as mediums to extend the design problem space. Interviewee 9 observed that employees in their organization with software skills were valued as they could quickly test design options and undertake rapid "optioneering." Interviewee 12 described the value of digital technology as affording the possibility to "... see design through a different medium and to design through different tools and the different effects or efficiencies that it gives you." For Interviewee 2 and Interviewee 14, digital technology skills were described as empowering, affording individuals in organizations a greater sense of agency and status. Interviewee 14 reflected that "... I think that learning how to use software and be proficient at software opens up new possibilities for design and that's a really exciting thing, but I don't feel like I have less agency because I'm proficient in software. I feel like in some ways I have more because I have more options on the table." Interviewee 2 argued that "You can get [agency] from having a kind of mastery of the tools that you have much more quickly and much earlier in your career than you can form being handed agency through some sort of hierarchical process." But this was not the case for some of the early career level interviewees who were design technology specialists. These interviewees pointed to a limited sense of agency as short-term project troubleshooters. Consistent across most interviews was an association between digital technology and efficiency and productivity gains. Interviewee 7 argued that "... I think the better that your software knowledge is, the more efficient and the less time that you're using to work on a project." Interviewee 3 emphatically stated that "... I think main reason is just obvious. We do it much quicker and much cheaper, and much better."

LEARNING SYSTEMS

Organizational learning theory connects between structures of work organization, learning, and organizational outcomes. An organization's "learning system" comprises structures that, combined with the behavioral features of individuals, interact to determine levels of organizational inquiry. The ideal output of organizational inquiry is a change in thinking and acting and, in short, changes to ways of doing things in organizations. According to Argyris and Schön (1996), "inquiry does not become organizational unless undertaken by individuals who function as agents of an organization according to its prevailing roles and rules" (p.11). The structures of an organization that scaffold inquiry are both dynamic and static and include situations (events, meetings, and workshops), information technology systems, as well as codes of conduct, policies, procedures, and spatial organization. Interviewees in this research referred to structured and timetabled skills training in the workplace, institutional/commercial skills training, subscription-based and free online tutorials, and learning through situated, online (forums), and industry-based communities of practice.

Influenced perhaps by attitudes to digital technology that were seeded in tertiary education contexts, learning "on the job" and project-based learning emerged as key themes in the interview data. Interviewee 4 commented that at

> "... university, we were taught the basics of the software, but not really how to use them for a work environment. So, when I started working here ... that's really, really the best way to learn for me was to actually work and do learn the software in that way. Because then you get to learn more about how project management in terms of software, file sharing and stuff like that. Working with other people, it's more of a thing you have to learn on the job, I would say."

Numerous interviewees described "live projects" as key sites for the applied learning of digital technology knowledge and skills. A recent graduate of architecture, Interviewee 12, noted that "... I think architecture school teaches you how to design and how to think in terms of design ... A lot of the programs and skills you can learn on the job." Others echoed a similar sentiment arguing that the "... majority of acquired [digital technology] skills happened in practice" (Interviewee 16). Software such as Autodesk Revit was described as easier to learn when connected to real-world design problems and projects. Interviewee 11 noted that "... we do train people if they come to the office and they haven't got high Revit skills we will train them. But as I said, it's now more on the job training."

More generally, these perspectives concur with existing workplace learning research that indicates a significant "... amount of learning takes place in direct connection with the performance of the work and ... employees typically experience that this learning is of greater importance for them than learning in institutionalized education" (Illeris, 2013, p.39). However, as Illeris cautions, this kind of workplace learning is often "accidental in nature ... it is usually narrow and without theoretical foundation" (Ibid). Indeed, while interviewees generally *expected* to learn "on the job," it was also evident that the quality of on-the-job learning depended on the individual's situation such as their role on a project and relationship with their team members and leaders. Many interviewees expressed that limited resources in terms of time and senior leadership buy-in constrained opportunities for learning within the "workplace" beyond incidental forms of learning associated to project work.

Generally, the mid- to late-career level interviewees equated "learning" with structured modes of skills training, upskilling, and a mastery of software. Interviewee 6 alluded to an inadequate provision of structured and targeted training in their organization. They further described a disconnect between the organization's strategic vision connected to digital technologies and the experiences of individuals, noting that the

> "[organisation] is probably really good at talking about how they want to up-skill everyone, but when push comes to shove the projects always take priority ... I've been arguing ... making sure that we've got happy staff that know how to do things is just as much a priority as the project work. And at the moment, my only way of making sure that we've got the skills in the office is by hiring them and not developing them. I have had people that have developed skills but they have been proactive initiative takers."

But from Interviewee 3's perspective, organized training offered little value,

> "... my observation again, is it doesn't actually work. Because if people don't want to use the technology, they won't. Or they'll use it poorly forever, no matter how many training afternoon ... You know what I mean? If there's not a ... Not a passion for it, but if there's not a liking for it, people generally want to do what they do. Because often technologies can be tangential to someone's job, if you know what I mean?" (Interviewee 3)

Interviewee 10 described the frequency of training as "once a month," but in reality, "...every two months by the time we get around to it ... ". Interviewee 14 who had been hired as a computational design specialist and tasked with changing the organizational culture around design technology described developing a "training pitch" and asking employees when they would like to "train." Interviewee 14 argued that "People like a little bit of structured training so I've offered a multi-week—a six week—training course already that ran from eight am to ten am on a Wednesday morning. That way it's 50% their own time and 50% practice time." When asked to explain this further, they described the training as "Time that [employees are] not being paid for, so it's something that they're personally interested in. The practice will support an hour of that if they come in and do an hour." Interviewee 14 not only went on to describe a range of formalized but also socially oriented extra curricula training initiatives, such as model making and a reading group, that had failed to attract participants. By contrast, short lunchtime presentations on computational tools or techniques used on projects were reportedly well attended.

It would be convenient to argue that limited structured learning opportunities in the workplace compel employees to fill the void with modes of "informal learning" (Marsick and Watkins, 2015) such as *ad hoc* and on-demand online learning. But in the contemporary workplace, formal and informal learning modes are not usefully conceptualized as oppositional (Malloch et al., 2013). Rather, the global digital information economy has created the conditions for more extensive, on-demand, and "continuous" modes of learning. As McRobbie (2016) reflects, we now "live in a work regime of constant training ... that takes the formal shape of curriculum and the informal shape as "edutainment" (p.9). For numerous interviewees, online forums, YouTube tutorials, and Google were integral to their everyday work. In addition, while the mid- to late-career level interviewees in management roles described their organization's provision of subscription-based online tutorials such as LinkedIn Learning, Lynda, and Billy Blue College of Design, the early career interviewees were more likely to cite free online resources. For example, Interviewee 4 referred to "... trying to learn how to write Three.js. And that's mainly just me Googling stuff. I use Codeacademy for a bit, which is a free resource, YouTube and stuff, doing it pretty much is just the best way to learn." In addition, given mobile device connectivity, the contexts for these modes of learning extended beyond the situated workplace to include employee commutes and their home.

But the interview data also evidenced problematic assumptions about the role of on-demand, online learning and training. Mid- to late-career interviewees in management roles inferred that Google made solving problems related to digital technology "easy." Interviewee 11 commented that learning about digital technologies in architecture is "... self-motivated and self-driven most of the time ... you just Google, "how do I do this in Revit?" And it tells you how to do it." Moreover, there was a sense that making on-demand and subscription-based online learning available thereby exonerated organizations from providing other scaffolds for continuous learning. This is problematic, as shunting digital technology knowledge and skills to the periphery and framing it as discretional (Gardner 2019) is a fundamentally inequitable learning system that delimits the potential for organizational learning and, in turn, DT. In a scenario told by Interviewee 11, a junior staff member was keen to learn about parametric design, but the project they were working on did not require a parametric approach. As a result, the junior staff member was advised to "...go to the people who are really keen [on parametric design] and chat in the lunch hour..." (Interviewee 11). It was reasoned that allowing the staff member to explore that knowledge "wasn't really going to give us an outcome ... at that particular stage." Equally, where those without the social and economic capital to support learning in their own time become de-skilled, this in turn places pressure on others. This is evident in Interviewee 5's comment that "... it is a vicious cycle of, oh, we need to train someone in this so that they can do X task. Oh, we don't have any time, because only you can do this X task, so you do that X task, instead of teaching others to do it." In short, without strategies to advance digital literacy across organizations, individual employees risk becoming narrow specialists, in turn limiting an organization's capacity to learn.

While the data collected in this research do not point to gender as an explicit determinant of learning behavior, differences in learning behaviors were evident in relation to the interviewee's career stage. Mid- to late-career level interviewees in this research generally expressed a sense of disconnection from the tools of architectural production. This is because few remain "on the tools" once they ascend the leadership ranks. Interviewee 9 expressed frustration that they could not understand the software that junior members of staff used stating that "...let's be honest here. I get people to do it, and they come to me and they show me ... I sit behind the computer and I say 'Move this here, move that there'." Similarly, Interviewee 13 commented that "I don't draw anything anymore because you're just sketching and giving plans to people, and then writing emails ...." But being 'off the tools' does not equate to being disengaged from learning about digital technologies. While the mid- to late-career interviewees in this research indicated less participation in learning activities, they nonetheless described being motivated to learn about digital technologies in relation to design practice. Moreover, the mid- to late-career interviewees were more likely to connect the value of learning about digital technologies with wider organisational performance goals such as positioning in the market and market competitiveness (**Table 3**). This points to the need to develop digital literacy learning systems in architectural organizations that can address and support different career stages, roles, and needs rather than a one-size-fits-all approach.

Multiple interviewees identified interpersonal interactions with colleagues and participation in communities of practice within organizations, within the industry, and through online forums such as Stack Overflow and Twitter as significant scaffolds for learning digital technology knowledge and skills. To scaffold these socially situated communities of practice within organizations, interviewees further described using communication and messaging platforms such as Microsoft Teams and Slack to explore, troubleshoot, and extend their skills. Here, the value of teaching others as a mode of learning was highlighted. Interviewee 2 described participating in online forums to help solve "... other people's problems [as it] pushes you into ideas that you hadn't had before." This matters because learning loops are a continuum, and shifting between each loop to realize a radically transformed practice can hinge on the relationships and exchanges between actors in organizations, as well as actors in wider networks.

The social dimensions of the workplace can significantly influence learning dynamics in organizations. Examples of colleagues assisting, teaching, and mentoring others were evident in numerous interviewees' accounts. Interview 11 described how they "... just sat next to somebody and just said, 'Oh, I don't understand why this isn't doing this,' and they'd explain it." Interviewee 13 stated that "you just annoy everyone else who's really good. And eventually get it." Interviewee 8 expressed how they valued learning in the workplace over using online tutorials at home "... because you can talk to someone who has more contextual knowledge any time ... You've got lots of more available resources." When asked how Interviewee 12 learned Revit, they responded "Well, obviously practice, through just working in there and if I don't know how to do something, then I'll go to ... someone who's really good at Revit."

> "I learned from a lot of people who were proficient ... And they'll just like share their knowledge on a daily basis. Sometimes it would be quite informal, they'll just come up to your desk and start teaching you stuff if you don't know. And that exposed me to a whole lot of the technology possibilities and they'd just have a chat about it on a daily basis as well, because it's what they're interested in" (Interviewee 12)

Relatedly, notions of steerage and transformational leadership (Park and Kim, 2018) figure centrally in interviewee accounts of positive learning experiences related to digital technology knowledge and skills. Interviewee 10 referred to a colleague as "quite supportive" and that "... he's also constantly asking us to try and do things that are not project related often, but do some things differently and try and make them faster. They are not usually the immediate problems that we're trying to solve." Park and Kim (2018) refer to the evidence of a "knowledge sharing climate" and "interpersonal trust" as significant indicators of organizational learning. Moreover, the interview data points to the growing significance of social communication skills in the AEC industry and in the collaborative context of working on federated 3D models in Revit. Having undertaken a more technology-oriented undergraduate design program, Interviewee 7 noted that "... the thing that I wasn't really used to and I hadn't really learned before was work sharing environments and things like that, and working on quite large teams." Interviewee 13 noted that when working on BIM projects and Revit models "It becomes so connected that when you mess up, you mess everything else and everyone else's up." In a BIM context, stuffing up becomes a shared problem. Interviewee 17 pointed to disconnected design and project delivery processes as a key problem for the industry. They noted how "... we have a 3D environment that's supposed to be your single source of truth that has all of the information that you need within it," but then the production of design images means the model is taken from Revit into Rhino "... where you can pretty easily change things and make things different. And now you have two single sources of truth ...." The interviewee further reflected that while the future of the industry might rest on the concept of the digital twin, few consultants currently have the requisite skills to productively manage and interact with data-laden "12D" models. They surmised that "It actually is incumbent on all of us to be supporting each other to learn this new stuff." And this underscores the significance of advancing digital literacy across the AEC industry.

ORGANIZATIONAL LEARNING NARRATIVES

Investigating the dynamics of learning in organizations involves consideration of "where inquiry begins but also where it goes" (Argyris and Schön 1996, p.27). To this end, this section draws three exemplar narratives from the interview data and analyses, each in relation to the organizational learning loop trajectory. These narratives highlight key insights about how architecture organizations learn in the context of technological change.

In the first learning narrative, Interviewee 1 describes an initially self-directed inquiry that relates to their developing an interest in virtual reality (VR) and visualization technologies. They describe the motivation for this inquiry as being "interested in the idea that we might be able to get work outside of built work because it's getting more and more challenging in Sydney and in Australia generally." The interviewee was seeking to answer the question "...how do we get better decisions out of clients so that we're not asking them to kind of guess what they're getting at the end of the day?" They further describe how they had "... been looking for a better way to make sure you've got confidence that your client understands what they're getting really."

> "... VR was inspiring basically for better design confidence and decision making, but also for the idea that maybe we could do a virtual space for companies that are going to start engaging in this sort of virtual reality market ...." (Interviewee 1)

This narrative demonstrates the individual's identification of a design process communication problem. Equally, the interviewee saw an opportunity for immersive VR experiences to enhance client confidence and potentially expedite design decision-making and build decision-making trust between designers and stakeholders. Additionally, and significantly, the interviewee saw new market potential for the organization, and the architecture sector, more generally, to extend from using VR as a visualization tool to designing VR environments. While the interviewee added that "…it's an embryonic idea and it hasn't got a lot of support yet from different people," they also described how their organization had purchased some of the earliest VR hardware such as Oculus Rift DK2 to support VR exploration. As few people across the organization had experience with visualization software, the interviewee took the initiative to complete an online training course in Unity and later developed skills in Unreal Engine in their own time. In this narrative, the interviewee refers to being a part of, and learning with, a small group of employees in the organization who held a significant interest in developing skills in VR and visualization technology. For the organization to further support a more significant investment in the VR space, the utility and performance of the VR environment needed to be convincingly demonstrated, and this was achieved by testing systems and ideas mainly in architectural competition work. In this example, individual inquiry intersected with organizational inquiry. Here, individual insights were converted to organizational action to realize a new avenue of service provision. This example evidences a shift through modes of single- to double- and triple-loop learning, as there is evidence of the actors changing their guiding principles, reframing the rules of the game, and introducing a "new game."

In the second learning narrative, Interviewee 3 describes leading the introduction of the visual scripting plugin Grasshopper in an organization to expedite and improve the process of design exploration for a building project with complex geometry. The interviewee identified that the organization's primary computer-aided design software was inadequate for the design's complex geometries. Consequently, the interviewee took the initiative to self-learn alternate software, namely, Generative Components and then Grasshopper. The interviewee described further self-developing their Grasshopper scripting skills during the project's 2-year design development phase as "… there was no one who could teach me in the office, obviously because no one knew about it. But at the same time, they were very passionate and very lovely, and they just sort of let me do my thing." However, after the initial project was completed, the interviewee described how, instead of training others to acquire similar skills, the organization then "always put me on complex geometry jobs" as a specialist.

In the next small-scale organization where Interviewee 3 worked, they described how a sense of organizational pressure "to do more with less" influenced them to learn and write "… a whole bunch of scripts that automated rendering, and view stuff. So that was like trying to survive by writing scripts to automate work." Here, Interviewee 3 indicated that they were self-motivated to develop new and more efficient processes to avoid doing unpaid overtime. Interviewee 3 described how others in the organization resented them for leaving early because "… I could produce, I could keep up with the production, the pace of production, because what I would do is I would set the script up to do the 60 renders when I left, and when I came back in the morning all the renders would be done. So, I had my little night Jeannie." Interviewee 3 described leaving the practice after a short time. When asked whether Interviewee 3 thought that the organization might still be using their automated workflows, they replied "No. No, I couldn't teach anyone. I didn't teach anyone." This narrative fits with the organizational learning notion of a "near miss" or zero-learning as the knowledge remained at an individual level rather than being integrated at an organizational level. Argyris and Schön (1996) note that "almost but not quite" instances of organizational learning are common to small professional organizations such as design offices "wherein staff members habitually move in and out of organizational homes, taking their ideas and capabilities with them" (p.18).

Notably, Interviewee 3 added that they still use the automated scripts initially developed in the small-scale organization. However, they further noted that given the nature of scripting, and computer science culture more generally, the automated workflows are typically shared among a wider network of design technology specialists using online platforms such as Stack Overflow. In this case, learning becomes extra-organizational; learning is developed collaboratively through a community of practice within the architecture sector. Significantly, when discussing their current role at a large-scale organization, Interviewee 3 described a closer alignment between their personal digital technology interests and the organization's motivation to engage with digital technology for data management. Interviewee 3 noted that "a lot of our computational design here is in the service of more pure data rather than geometry." Interviewee 3 described applying computation to automate room data sheets, developing resource management applications and the use of data in urban planning as "… sort of population numbers and juice demand from a train station or sort of number-ey stuff. And then very, very quick feasibility work." Interviewee 3 went on to say that the organization's engagement with digital technology is "… broader and it's much more closely tied to the business of architecture. Not the business of making a profitable architecture firm, the business of what buildings do in the world."

When asked about what direction a focus on data in the organization could take and what the barriers might be, Interviewee 3 replied "So [are] the tools where we want them to be? Probably not. I think the tools are there if you have the time to use them, and the data's largely there, or you can find it if you have enough money, and again, time. But I think the real job … Well, the thing that I'm interested in is how do you compress that time and actually … Because people don't use data because it's too difficult to get, and the skill requirement is too high. So, it's actually quite easy to go to the ABS, download the Shapefile, set up a database, and then you have the data if you want it. But no one's going to do that, so that the job is how you get the data up to the decision makers to actually use it."

The third learning narrative relates to Interviewee 15's work on a large-scale commercial building competition that they described as the organization's "first fully computationally developed project" using Rhinoceros 3D modeling software and the visual scripting plugin Grasshopper. The interviewee described using a computational design approach that allowed the project team to generate many design variations over a short 6-week period. They noted that the project architect lead had little experience with computational design but recognized the interviewee's capabilities and was open-minded. The interviewee relayed how the project lead commented, "Look, I have absolutely no idea what you're talking about, but if you can demonstrate [to] me that you can do a freeform tower in 6 weeks, go for it." This demonstrates the curiosity and willingness of the project lead to take a risk on a new process. The interviewee was given the freedom to explore the design, provided that they sent area schedules to the project architect every day to ensure that they were meeting the net lettable area (NLA) requirements. The interview further described how the success of the approach led senior management to consider implementing computational skills into other projects as they felt it could "bring the [company] to the level of the most important European and American architects." Upon winning the competition, the project was subsequently migrated into Revit as the client had mandated a BIM project. The interviewee was not involved in this process as it was handled by an office in another state. When asked how they felt about this, they responded that "I think if I could go back, I would like to be more involved in the migration process, have more control over it. There were a few difficulties. First of all, I didn't use Revit. I still refuse to use Revit, I don't like it. I know how to import/export things I need, but that's it." The interviewee further commented that ". . . it was a missed opportunity for me to learn more about how we can smooth the process."

In this narrative, Interviewee 15 initiated the inquiry on behalf of the organization and applied their computational design skills to improve efficiency and design optioneering in the concept design phase. The work undertaken on this project demonstrated to the organization the value proposition of using a computational design method for the large-scale building design project. In this case, individual inquiry and practice transferred to organizational inquiry as the organization subsequently developed a high-level strategic approach to integrating computational design methods in projects across their global network of offices. The interviewee further described how this resulted in a think tank initiative for new student employees in their office. Students were required to attend weekly meetings to discuss how computational methods could be applied to projects throughout the office. The interviewee reflected that it motivates the students to "go to [their] project leader and ask 'how can we improve the process, how can we improve the design?' And come back, tell the group on the Monday meeting what your discoveries are."

Several key features are common to these narratives of organizational learning in architectural organizations and in relation to digital technologies. Firstly, each of these narratives began from a position of individual inquiry. In each narrative, the individual identified and framed a problem or opportunity in relation to a digital technology or computational method. As these individuals convey enthusiasm for problem-solving and diverging from the norm, they can be characterized as entrepreneurial learners (Kolb, 2015; Politis et al., 2019; Rupcic, 2019). Secondly, individuals were supported in some way by the organization to trial their ideas and methods. Often this involved trialing digital technologies and computational methods in lower-risk project settings such as architectural competitions. Thirdly, each of these narratives evidenced instances of transformational leadership wherein mid-level leaders created empowered working environments to foster higher performance (Park and Kim, 2018). Interviewee 3's account of design technology leadership evidenced a cultivated (technology) knowledge sharing climate which comprised of open, accessible, and informal internal exchange. The challenge going forward for organizations who are navigating digitally driven change will be the necessity to take care not to unravel these "informal roles and relationships for support and advice about digital technologies, but rather seize the opportunity to align them with the existing organizational structure . . ." (Bonanomi et al., 2020, p.874).

DISCUSSION

This research has used organizational learning as a conceptual lens to empirically construct understandings of the behavioral world of architecture organizations and to surface learning dynamics related to digital technology knowledge and skills. The data have been analyzed and organized under three key headings: learning contexts, learning systems, and learning narratives. The research finds that attitudes and beliefs related to learning about digital technologies knowledge and skills are seeded in tertiary education. Interviewee accounts point to a disconnect between tertiary institutions who do not believe it is their role to teach digital technologies knowledge and skills and professional organizations who expect graduates to arrive with the most up-to-date technical skills. So, while architecture and design graduates expect digital technology knowledge and skills to be learned on the job, the industry relies on a Trojan horse of graduates to be agents of change and digital disruptors (Gardner 2019; Deutsch, 2019). Bongomin et al. (2020) note that higher education systems continue to follow an industrial model of specialism, but the convergence of digital technologies and applications means that today's service industries increasingly demand generalists (p.8).

Few interviewees in this research reported undertaking structured and accredited training to develop digital technology knowledge and skills. Project-based exploration emerged as the core digital technology knowledge and skills learning system within organizations, scaffolded by organizationally situated communities of practice such as project teams and interest groups but also communities of practice formed through online forums. This form of learning is highly valuable but has limits in terms of DT, as it is often narrow and without a theoretical foundation (Illeris, 2013). Equally, interviewees who attended organization-led learning sessions described learning specific and bounded skills that maintained organizational value systems and action frames, and in short, single-loop learning. In addition, while interviewees described developing software tools and automated workflows to solve problems, such as eradicating repetitive tasks and improving design task efficiencies, these are also single-loop examples of learning to do what is already done better and/or faster. Notably, where the experiences relayed by interviewees suggested instances of double- and triple-loop learning they often concerned lower risk project work such as architectural competitions which are characteristically fast and experimental.

The framing of digital technology knowledge and skills as a specialist domain in architecture also presents a key challenge to DT as converting from single- to double- and triple-loop organizational learning relies on an interactive and social process. Interviewees across organizations described similar approaches to embedding computational designers and/or design technologists in or floating across projects. This division of labor between architects/designers/planners and computational designers/design technology specialists can constrain interpersonal and social processes that are central to fostering organizational learning. In each of the learning narratives detailed in the Organizational Learning Narratives section, individual inquiry intersected with and converted to organizational inquiry through interaction and dialogue. Skilled individuals actioned inquiry, but escalating change at the organizational level relied to an extent on interpersonal relations. These examples further highlight the significant role of transformational leadership in shepherding individual and entrepreneurial inquiry into organizational learning. In this way, the interdependence of individual actors is a critical component of organizational learning. But organizational learning as an interpersonal and social process equally extends to client and consultant relations, stakeholders who were curiously underrepresented in interviewee accounts. For example, in learning narrative 2, the interviewee describes how the client was unaware of the computational approach that underpinned the design and its development. Going forward, organizations must address how to engage critical stakeholders in processes of collective inquiry (Senge, 2006).

This research makes two key contributions. Firstly, it establishes a conceptual link between the principles of organizational learning and DT, to (re)position learning as a significant dimension of DT. Secondly, it adopts organizational learning theory as an analytical lens to develop insights about the learning dynamics related to digital technology knowledge and skills in architecture organizations. But while semi-structured interviews are well suited to generating rich descriptions and surfacing complexity through individual accounts of learning in organizations, like any research method, there are limitations. This includes the voluntary nature of interviews, which means the data are limited to those who choose to participate. Additionally, although adopting the method of semi-structured interviews aimed to encourage interviewees to relay their experiences, the questions asked and interactions between the interviewee and interviewer have inevitably shaped the nature of the responses. Furthermore, for various reasons, when talking about the workplace, interviewees can be guarded in their responses, with the result being that the data evidences "espoused theories" rather than theories in use. To address this limitation, future research intends to explore embedded action research methods (Argyris and Schön 1996).

CONCLUSION

The AEC industry is negotiating a slow and piecemeal shift toward DT. This article has adopted an empirical approach to connect the challenges of DT to learning dynamics in organizations. It has done so by bringing concepts from organizational learning theory to bear on the analysis of data collected from 17 semi-structured interviews conducted with employees from four large-scale architecture organizations in Sydney, Australia. The research gives voice to the interviewee's experiences of engaging with and learning digital technologies and computational systems in their workplace. It highlights how instrumental and specialist attitudes to digital technology knowledge and skills are seeded in tertiary education contexts and perpetuated in the industry. The research further illuminates how individuals learn digital technology knowledge and skills in ways integrated with their project work and scaffolded by diverse communities of practice such as organizationally situated project teams, social groups, and online forums and platforms. But while on the job, project-based learning is highly valued, it also places limits on DT as it is often narrow and without a strategic foundation. This research demonstrates the utility of organizational learning as a method to rethink approaches to DT in the AEC industry. It finds evidence of DT in architecture organizations in the form of triple-loop learning and where individual inquiry has intersected with and converted to organizational inquiry. To progress DT, more generally, indicators of individual and collective learning should be defined and connected to strategic organizational objectives.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author [NG] upon reasonable request. The data are not publicly available due to containing information that could compromise the privacy of research participants. Sections of the interview transcriptions may be shared with anonymized information about the names and company affiliation of interviewees. Due to the small sample size the authors will exclude information that may lead to a plausible identification.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by UNSW HREAP Executive, Approval No. HC180235. The participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

The author confirms being the sole contributor of this work and has approved it for publication.

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