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Understanding Technology-Enhanced Construction Project Delivery: perspective from expansive learning and adaptive expertise

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ABSTRACT: The architecture, engineering, and construction (AEC) industry is yet to formulate a holistic strategy to realign the evolving technological infrastructures with organisational ambitions and adaptive knowledge of the workforce. This study attempts to create an understanding of the underlying processes adopted by technology-enhanced construction organisations to disseminate and maintain knowledge within the workforce in order to keep pace with the evolving construction technologies. The study adopted expansive learning and adaptive expertise constructs to help better explain workplace learning support structures for organisational effectiveness in a turbulent situation. The two theories were tailored to empirically evaluate three case study construction organisations that have embarked on technology-enabled organisational changes. The study concluded on the creation of a facilitating workplace learning environment to enable the workforce to adapt into and resolve any inherent contradictions and cognitive ambiguities of the changing organisational conditions. This could ensure that novel and conflicting features of the emerging technologies can be adapted across the myriad multi-functional project activities in order to expand the frontiers of the technological capabilities to address the eminent issues confronting the AEC sector.

Keywords: Construction organisations, disruptive technologies, knowledge management, expansive learning, adaptive expertise, case studies

I. INTRODUCTION

The contemporary construction work setting is currently inundated with rapidly evolving technological systems, from simulation software tools, to modelling tools, to collaborative working platforms and web-based objects repositories. These technological tools are disruptive to the well-established work structures, mainly due to the rapid pace in which they consistently evolve to adapt to new technological expansion. The recognition that advanced technological infrastructure is permeating every aspect of working life has prompted some studies to question the extent in which these technologies determine work patterns (Leonardi) [1] and how organisational knowledge management need to adapt to the changing pace (Ehie & Madsen) [2]. New and evolving technological solutions are described as "disruptive" when they emerge out of a niche market to disturb the status quo by appealing to the mainstream end users and often leading to incumbent vendor products being pushed out of the market e.g., Christensen et al., [3]; Jan van der Veen, et al., [4]. Example of incumbent technology disrupted by a new entrant within the architecture, engineering and construction (AEC) sector is the evolution from computer aided drafting (CAD) to building information modelling (BIM) (Eastman, 1989) [5].

Unlike CAD, a BIM project is not drawn in a traditional sense with lines, dots, and texts in multiple documents. Instead it is built digitally as a database in a BIM-based technological platform (e.g., Sackey et al.) [6]. BIM has been referred to as 'a revolutionary building design and construction technology' (Osan et al.) [7], because it is purported to bring wholesale changes to every phase of the project delivery lifecycle. The successive BIM technologies are causing paradigm shift in practical application and work processes.

This situation, in turn, has created a paradigm where the introduction of a construction technology, targeted toward a particular work function, is faced with a constant release of upgraded versions (often annually), in parallel with other evolving technologies (Sackey et al.) [8]. This phenomenon can be disruptive to the existing organisational status quo. Thus bringing changes to existing roles and also, the creation of new roles. For example, CAD drafters giving way to BIM modellers and the introduction of new roles such as BIM coordinators - with the specific function of integrating federated models and resolving clashes. These disruptive construction technologies are steadily being mandated in the AEC settings e.g., Plesner & Horst, [9]; BIM task group, [10].

In order to reorganise the functional structures of the AEC organisations to align with the evolving technological solutions and disruptions, the knowledge workforce need to have the ability to change their occupational routines and responsibilities (Zack & McKenney) [11]. Indeed, most studies depict that human agency reacts to technological changes in organisational processes by producing changes in routines, sometimes in unpredictable ways e.g., (Schultze & Orlikowski) [12].

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The unpredictable outcome is partly enacted from the distinct discretion of the human agent, based on several factors such as knowledge, exposure, experience etc. Orlikowski [13]. Literature on technology transformation acknowledges that business benefits are secured only if new systems are accompanied by organisational change processes and by the knowledge workforces who are acquainted with the technology e.g., Ashurst et al., [14]; Kohli and Grover, [15]; Peppard, [16]. Without the knowledge workforce, construction organisations will struggle to achieve strong business value from their investments in technological infrastructures.

The limited understanding to adequately prepare the next generation workforce for the challenges and potentials of the rapidly changing working life as a result of evolving technologies are well recognised e.g., Sackey et al., [6]. This study therefore explores how the actors within the AEC sector can be supported in the necessary updating of their knowledge and skills during the organisational and technological transformation. This paper takes a knowledge-based view and seeks to understand how knowledge-intensive construction organisations influence the attainment of their organisational ambitions through learning opportunities afforded to the workforce (Reich et al.) [17]. This objective is achieved by studying three case-study construction organisations that have deployed BIM to augment the successful delivery of projects.

The paper is presented in three parts. First, knowledge gap and related works in acquainting with disruptive construction technologies within the AEC sector is discussed. Second, theories of expansive learning and adaptive expertise are combined as the conceptual position of this paper to help explain the type of new learning prerequisites needed by the contemporary knowledge workforce to handle emerging and surprising phenomena in the current technology-enhanced construction work systems. The third part of the paper uses case studies approach to gather empirical evidence to further expand on the application of the adopted theories and also, to contribute to new knowledge towards the delivery of construction projects within the contemporary work system.

II. LITERATURE REVIEW

A. Knowledge Gap on the Utilization of "Disruptive" Technological Solutions in the AEC Context

Disruptive technologies have found traction in affecting long and established processes and rendering existing practices obsolete (Kinnane & West) [18]. In that regard, the necessity for an informed and equipped workforce is a growing priority. It has been recognised that supply-demand equation for the construction industry workforce has been unbalanced with skilled workforce shortages (Wu & Issa) [19] and as the demand for BIM-enabled projects increases, the demand for BIM professionals with the appropriate knowledge and skills to help deliver projects to meet expectations would be higher. Meanwhile, the fast pace of technological changes has mandated the knowledge workforce to engage in continuous learning and knowledge development. Thus, management intervention in presenting an equally compensatory environment for working and learning for the workforce becomes ever more essential – especially as more sophisticated computer tools emerge constantly (Schweber & Harty) [20]. Such a constant learning support structure has generally lacked in the construction sector (Young et al.) [21].

There is also, a high demand for individuals with experience and knowledge of BIM technology, but higher education institutions are struggling to cope with the demand to produce the knowledge workforce, capable of demonstrating specific BIM technological skills (Smith & Tardif) [22]. It has been suggested that rather than keeping pace with the industry, educational institutions should strive to set the pace by addressing concerns such as the need to consider the collaborative nature of the construction process in the teaching-learning processes. And also, to combat the existing silo-style individualised knowledge development approaches of students who are then expected to practice within a collaborative and inter-dependent project settings. To acknowledge the impact of the rapid technology change on the ACE practice, the educational system also needs to recognise the impact, and make relevant tunings on the subject curricula (Becerik-Gerber et al.) [23]. Indeed, the intrinsic status of the general education system and institutionally-based learning is to transmit pre-established knowledge through a tutor to a learner. However, an accredited arrangement between professional institutions and academia to develop or change some of the practices in the workplace through teaching and learning often trigger a curricula change (Lehtinen et al. [24]; Pring [25]). This conformist conception is considered to be well entrenched within the higher educational institutions (HEIs) in the UK (Underwood & Ayoade) [26]. It is acknowledged that, the fast pace of novel technological rollouts and the associated preservationist role of education delivery do not adequately align with the empirical reality of the contemporary workplace activities.

This orthodox conception of education and training might work relatively well in preparing newcomers into professions where change is slow and incremental and the occupational requirements remain relatively stable (Lehtinen et al.) [24]. Nevertheless, this is not reflective in in the contemporary work setting of the AEC sector. In an industry where staff development, and people management practices are yet to receive more attention (Dainty et al.) [27], an effort to understand knowledge development and management among the workforce due to the impact of technology deployment on roles and responsibilities cannot be overemphasised.

This study therefore attempts to create an understanding of the underlying processes needed by technology-enhanced construction organisations to disseminate and maintain knowledge within the workforce in order to keep pace with the evolving construction technologies from the perspectives of the AEC sector organisations. The study takes the concepts of knowledge acquisition and work delivery in the midst of evolving technological transformations to mediate between task-technology fit (TTF) within the AEC organisations (Goodhue & Thompson) [28]. The knowledge workforce and the technologies are the shared building blocks of the organisational processes, in that they interact with one another to influence organisational routines and work outcomes. It is therefore theorised that the construction organisation must develop a work setting in which knowledge is created, shared, and utilised in order to produce the outcomes desired by the organisation (Reich et al.) [17].

B. Related Works on Preparing the AEC Workforce to Acquaint with the Emergent Disruptive Technologies

It is acknowledged that the pace of technological change is advancing quickly in the work-front than in the mainstream educational institutions. The crucial necessity to invest into new technological implementation and the historical preservationist stance within academia (Underwood & Ayoade) [26] suggest a need to articulate new practical aspirations to help better prepare the future BIM technology workforce for the construction industry to supplement the efforts of the higher academic institutions. More than ever, the construction industry needs a new training system which is flexible and convenient and enables more frequent learning on the part of the knowledge workforce (Park et al.) [29].

Some studies have provided insights on how the stakeholders in teaching and learning should respond to the ever evolving workplace activities within the AEC sector in lieu of the conventional teaching and learning activities offered within academic institutions. Park et al. [29] for instance, discussed the possibility of web-based training (WBT) in the construction industry. They concluded that this could allow learners to successfully access relevant training and knowledge anywhere without being face-to-face with the knowledge provider. In addition, it could potentially give learners a greater control over various aspects of learning (such as pace, sequence, and depth) than the traditional classroom-based learning can offer. Sackey et al. [6] also proposed that within technology-enhanced construction contexts, the knowledge workforce must position themselves on constant loop of learning to act decisively towards the common goal of their work context, whilst recognising the present conditions, as well as future success strategies. This takes into consideration the flux of current technologies as they continue to develop in content and in form. Their study largely connects with the notion of double-loop learning approach where novel versions of available technological artefacts can effectively be used to avoid the repeat of any on-going limitations in work practices. Also, a study conducted by Becerik-Gerber et al. [23] reviewed the emerging subject areas of BIM and how new knowledge areas can be incorporated into the constrained programmes being offered by academic institutions to meet industry demands. Their findings reinforced the notion that there are disparities in the educational programmes which need realignment to help develop the workforce of the future that would lead the AEC industry transformations. They then concluded that some of the emerging challenges faced by the industry practitioners coincide with the challenges faced by the educational bodies. Thus, more than ever, there is a need to close the chasm existing between academia and practice in order to understand both worlds and together, face up to the new organisational challenges within the AEC context.

The previous studies suggest that there is clearly a need to improve understanding of how to disseminate and maintain knowledge within the AEC workforce in order to connect and align with the technology-dependent construction organisational transformations. Building on the previous studies, this paper focuses attention on the mechanisms within AEC sector organisations to construct and reconstruct knowledge expertise to deliver the desired work outcomes during the integration of "disruptive" technological solutions within the work context.

C. Adoption of Expansive Learning and Adaptive Expertise in the AEC Context

The linkage between knowledge management and project success is particularly relevant to technology-enabled construction systems because the lifecycle activity of a typical project is a knowledge intensive activity (Peppard) [16]. The link between task-technology-fit in mediating between knowledge and work delivery is not well understood. The limited understanding to adequately prepare the next generation workforce for the challenges and potential of the rapidly changing working life as a result of evolving technologies are well recognised. In responding to these challenges, this study offers different perspectives for understanding this transformation by invoking Engeström's [30] expansive learning concept – which suggests that knowledge and learning must be constantly integrated within practice through interpretation, formation, contextualisation and performance. Engeström's [31] work on activity theory, and in particular the notion of expansive learning articulated in the context of workplace learning, emphasises change rather than stability. The theory focuses on the dynamics of learning in an established work system. It provides the basis where the knowledge workforce can be supported to consider the contradictions between the old and new practices and technological infrastructures leading to learning, development and change.

The activity system of the construction context is changing rapidly, influenced by changes in technological infrastructures. Hence, the objective of the disparate workforce should be fit for purpose in any given moment in time. The expansive learning as part of the activity system leads to learning to higher level of competence to make sense of the world and to be prepared in some sort for the unanticipated future (Engeström) [30]. Fuller & Unwin [32] identified two characterisations, using the terms "expansive" and "restrictive" to provide a helpful way of analysing Engeström's [30] expansive learning theory. They argued that a workforce characterised by the continuum of expansive learning will create a stronger and richer learning environment than that comprising features associated with the restrictive end of the learning continuum.

The expansive learning concept is supplemented with the theory of adaptive expertise to help better explain the coping mechanism considering the rapid and unexpected changes occurring within the AEC context. Beyond the expansive knowledge concept, the requirement within the AEC context is of how the different, yet interconnected construction practitioners are able to restructure their various disciplinary knowledge and specific skills in adaptive ways to respond to the organisational and technological transformations (Lehtinen et al.) [24].

Ohlsson [33] noted that coping with radical changes in a turbulent world requires non-monotonous learning or adaptive expertise, which is not constrained by the experience that are similar to what has traditionally been described as learning. With the term monotonic learning, Ohlsson refers to additive cognitive growth of knowledge, which is consistent with what is known before, or connected to prior knowledge. Ohlssson indicated that most of the theories of learning focus on clockwise model where learning is described as acquiring representations of known regularities and causal relations. Adaptiveness enables experts to ascertain when prior knowledge and principles that normally govern their performance become irrelevant in any particular situation (Gott et al.) [55]. In this instance the adaptive expert then draws on his “ingenuity” to resolving such unique or novel problems (Crawford et al.) [56].

The application of both adaptive expertise and expansive learning theories have widely been referenced in the extant literature. The expansive learning theory was formulated three decades ago (Engestrom) [57]. But it has since been extended and widely used as a frame of reference for a variety of studies to understand work-based and professional learning. The main essence of the theory is to enrich and transform the work system into a new form of practice through the construction and resolution of inherent contradictions. Hence, the concept has been applied in studies of contemporary work context that demands dynamic approaches to working and learning. Denis et al. [58] acknowledged that Organisations can exhibit an expansive (facilitative) as well as restrictive (disabling) elements to learning. Thus, an appropriate work conditions are required to help workers develop competencies in real workplace situations. Laberge et al. [59] also applied expansive learning construct to gain insights into the actual safety skills learning process of young apprentices. The findings suggest that actual work situation provides unexpected events and variabilities. Consequently, workplace needs to be an enabling setting to develop strategies for coping with unforeseen or atypical situations. Cebrián et al., [60] explore how expansive learning theory can be integrated with other frameworks to inform organisational learning to better understand individual transformation in building learning organisations capable of embracing sustainability holistically. They affirmed that the key value of the contemporary work organisations lies in the knowledge of its workforce. The likelihood that learning would take place in any context is dependent on the learning opportunities afforded by the organisation to the individual, and by how the individual perceives this opportunity in relation to their role (Milligan et al.) [61]. Organisations must therefore provide an appropriate environment and structures that encourage expansive learning, where the workforce is able to effectively learn and integrate their experiences into the work practice (Fuller and Unwin) [32]. The question whether the contemporary construction work settings are sufficiently supportive of expansive learning still remains to be answered.

The theory of adaptive expertise has also been widely referenced and applied for various studies since its conceptualisation. The theory emphasises on how prior knowledge is transformed through a cyclical sequence into new, internalised and transferable knowledge. Across disciplines such as engineering, medicine and education, adaptive expertise has been shown to offer good insights into knowledge building (Crawford et al.) [56]; adaptation and resolution (Hayden & Chiu) [62]; flexibility and deep understanding (Yoon et al.) [63]; and adaptive, cognitive and routine skills orientations (Bohle et al.) [64]. The relevance of adaptive expertise to knowledge development is evident through emphasis of adaptive skills in various professional practices. Crawford et al. [56] argue that the concept of adaptive expertise that addresses knowledge development is necessary because current tools, practices and context are no longer static in the 21st century. They asserted that adaptive experts should maintain an epistemic distance between knowledge and problem representation. This would ensure that the correct adjustment or correction is made in one or the other (i.e., the right cognitive approach to resolving the problem on hand), as the two are coordinated dialectically in the problem solving process. Bohle et al. [64] synthesised the literature on adaptive expertise when they sought to understand how the degree of task variety within the work domain and years of work experience related to adaptive expertise scores of working professionals. Their sample data was across a diverse work setting and concentrated on grounding participants’ responses within their specific work context. Their findings revealed two main dimensions of adaptive expertise, they comprise, domain-specific skills, and innovative skills. Their study concluded that greater task variety in any specific work setting could yield greater adaptive expertise. In addition, a workforce with a long-span of work experience is able to demonstrate domain-specific skills dimension of adaptive expertise but not the dimension relating to innovative approaches to a given task. De Arment, [65] also averred that adaptive expertise based solely on experience would be flawed, but deliberately designed learning environment and experiences can promote the development of adaptive expertise.

The present study explores how the combined theories could provide a better insight into understanding workplace learning opportunities within the contemporary construction contexts. An enabling workplace learning environment through the provision of support structures could help practitioners develop innovative ideas to handle emerging and surprising phenomena in their roles.

III. DATA COLLECTION STRATEGY

Taking a practice lens on strategy guided the research to focus on the everyday activities of the knowledge workforce who make work-based decisions to help meet organisational goals (Kaplan & Orlikowski) [34]. A practice lens recognizes that practice is a central focus for organizing, and it is through situated and recurrent activities that organisational consequences are produced and become reinforced or changed over time (Feldman & Orlikowski) [35]. The data collection strategy for the study was to gather information of daily practices and organisational transformation by examining what the case organisations did, in regards to developing the knowledge workforce's capabilities to cope with disruptive technological transformation and also, to produce the organisational choices and the resultant organisational outcomes. Such a focus requires deep engagement within the source of data, observing and interacting with practitioners in action (Kaplan & Orlikowski) [34].

As a result, a multiple case study research design (Yin) [36] was adopted to track the unfolding organisational patterns for the knowledge-workforce management during the process of organisational and technological transformations within the AEC sector. The reason for adopting the multiple case study design is to add confidence to the emerging theories. Herriott & Firesstone [37] assert that the evidence from multiple cases is often considered more persuasive, and the overall study is regarded as being more robust. Yin [38] also contends that greater certainty lies with multiple cases for theoretical replication purposes (two or more cases selected on the basis of predicting contrasting results).

Iterating among three in-depth analysis of cases, comparisons across cases and connections to the literature (Dougherty [39]; Vaughan [40]), provided a useful insight into how the selected organisations for this study cope with change in "turbulent" organisational situations. This strategy also allows for "literal replication" (similar conditions/criteria are used to guide the selection of cases in order to predict similar results), and generalisation of the first findings to the other two case organisations on the basis of a match to the underlying themes (e.g., Yin) [38].

A. Data Analysis

Data collected from the selected case organisations was transcribed and coded e.g., Kendall [41]. Transcripts of the interviews, documents and observational data were stored in Microsoft word database. The analytical process was very iterative involving coding that depicts the development of chronologies of the ongoing organisational transformation and the emergent strategies to cope with the change, and frequent iteration between extant literature and the transcribed data in reference to the proposed theories as different themes emerged. Axial coding procedure (Strauss and Corbin) [42] was used to piece together the connections between different categories and subcategories of the transcribed data. The findings are presented in the analysis section. The coding aided in making comparisons and connections between and among the identified themes and in connection with the existing literature and the described theoretical position of the paper.

B. The Case Study Organisations

The selection of the case study organisations seeks to access the empirical reality of technology rollout of three different organisational conditions which are of relevance to the AEC environment. Two main reasons are used to guide the selection of the three case study organisations. It was decided to stratify the selection of the organisations based on; 1) the nature of the work they are engaged in, with regards to BIM projects, and 2) demonstrable evidence that the organisations were in the process of (or had already) implemented BIM technology and associated processes within their settings. The three organisations that satisfied these criteria are anonymized as follows:

Case study 1 (CS-1) is a multinational civil and building engineering firm with annual turnover exceeding £1billion.

Case study 2 (CS-2) is a large construction product manufacturer and inherently aims to maintain a competitive position in the zero-carbon product market.

Case study 3 (CS-3) is a UK-based structural engineering specialist with annual turn-over not exceeding £5 million.

Table-1 briefly highlights the profiles of the selected case study organisations.

The case organisations present interesting but different scenarios in that they all have undertaken measures to develop their respective BIM capabilities to fulfil the overall strategic organisational aspirations. They are BIM-enabled, and have either completed or have ongoing BIM projects to demonstrate their technology-enhanced capacities, yet they all operate in different organisational realities

TABLE I

Profile of the case study organisations

	CS-1	**CS-2**	**CS-3**
Nature of organisation	Civil and building contractor	Building products maker	Structural engineering specialist contractor
Scope of operation	Multinational	Multinational	National (UK)
[a] Size	Large	Large	Small
Years in business	>160	>40	18
Annual turnover	>1 billion	>1 billion	<5 million
Technology in use	Mix and match best-of-the-breed BIM solutions	Off-shelf BIM collaborative tools to match clients' needs	Products authored as BIM objects into web-based repositories; TEKLA structural licence; AUTOCAD workstations; production equipment, e.g., automatic assembly lines molding machines

[a] Note – Small to medium-size enterprises (SMEs) have been defined within this study as companies employing less than 250 people and have a turnover of less than £50million per annum: large organisations are those

that employ over 250 people and have a turnover above £50million per annum e.g., Ward & Rhodes, [43].

In the section that follows, the findings from the case organisations are discussed and analysed within the lens of the adopted theoretical positions of the paper.

IV. BIM-ENHANCED PRACTICES WITHIN THE CASE STUDY ORGANISATIONS

A. Finding in CS-1

At the time of this study, CS-1 was in the process of transforming the entire business offices into fully BIM-enabled entities, with the capability to deliver BIM projects. The goal of the organisation as stated in its BXP (BIM Execution Plan) document is: "To be the premier contractor for complex design and construction projects, in which meeting challenges through a combination of BIM technology and people and process management sets us apart from our competition." It is also stated that BIM tools and its integration with the management of information, people and processes will allow the company to have competitive edge in the market by providing clients with the additional product solution as enabled by today's construction technologies. Accordingly, the set goals have driven CS-1 to define a deliverable timeframe and a means of measuring progress. Nevertheless, it was also recognised that, the ambition of developing wide-scale BIM capability across the entire business is a complete departure from the established organisational processes. The facilitative approaches to learning derived from CS-1 to help counter the challenges associated with the rollout of the "disruptive" BIM technologies are indicated as follows:

- Commissioning of in-house centralised BIM support team
- Ongoing external technical support
- Development of generic organisation BIM protocols
- Development of local BIM champions

Recognising that BIM implementation is a catalyst for corporate business process change, a BIM implementation strategy team was commissioned in CS-1 to provide a direction and a strategy to govern the implementation process. The team consists of a whole mix of membership and headed by a BIM manager who was in the organisation as the head of design management, until he took on his new role. He explained that "*I was transferred within the [CS-1] group to lead a small team of expert, together we engage with other private organisations to promote the most efficient processes and technologies to deliver BIM within the company".* From the response, it was noted that the central corporate BIM team was established to help develop and roll out a standard BIM methodology across the company. The team was tasked *inter alia*: to ensure a gradual and continuous BIM implementation until it becomes the standard of project delivery across the wider business; to provide organisation-wide support on how to utilise new and emerging BIM product suites to provide efficiencies in the process of BIM project delivery, and; to develop BIM implementation protocol that can be followed to successfully deliver BIM projects throughout the business on a national scale. Consequently, the team developed a BIM implementation guide, referred to as BXP (BIM Execution Plan) document. It was intended to be used as a support tool by all the local construction project delivery teams across the organisation. A BIM manager indicated that "*Our new BIM protocols and execution plans define the required way of working with our project partners in order to deliver projects using BIM and virtual construction (VC) techniques"*. The document provided some guideline on how the organisation intends to deliver BIM projects at different phases of the project using collaborative BIM applications.

Although the central corporate BIM team was established to develop and roll out an organisation-specific standard BIM methodology across the business, CS-1 also solicited the services of an external expertise to augment the capability of the internal team. The external support is provided by a consultancy firm that has expertise in IT systems supply and implementation, training and support in BIM and other related construction IT solutions in design, construction and assets management. It also has technical accreditation from some of the IT solution providers such as Microsoft, HP, ARCHIBUS and Autodesk. The external team was tasked to provide technical assistance in the selection and installation of new software and hardware to fulfil CS-1's BIM requirements. The external expert team was well-positioned to configure CS-1's hardware and software having first-hand knowledge of the organisation's requirements from the outset. Overall, the external consulting team helped to fine-tune the corporate BIM team's understanding of the significant changes BIM required from a traditional 2D construction environment. By extension, such knowledge was eventually shared within the broader setting of CS-1.

It was noted that, by virtue of having a team of external experts and internal corporate BIM team to develop the organisation's BIM strategy was not necessarily sufficient to invoke change at the operational level. Both the centralised BIM experts and the local project teams needed to work together to develop a clearly prioritised work plan to implement the vision throughout the business operations. The central corporate BIM team was widely considered in CS-1 as the in-house BIM resource team that provides technical support and systemic training for staff development – particularly focusing on the specific BIM skills of the operational staff such as 3D knowledge of BIM, component-based design and analysis, or experience with the use of BIM software. Thus, an awareness training programme has been instigated for senior management staff including those that one way or the other, engage in BIM activities. Also, knowledge sharing workshops are organised for staff across the company's branches during which the corporate BIM team presents the organisation's BIM strategy along with demonstration of how some case study BIM projects are run. These workshops give the staff a great insight into, and instigate a lively discussion regarding, the use and future of BIM in the organisation. There is also a computer-based training tool-kit designed to simulate BIM delivery processes, particularly targeted at the project delivery teams at the operational / 'shop-floor' level. Through this training tool-kit, which is accessible in the company's intranet, the organisation's vision for BIM implementation has been communicated to every staff member of the organisation.

Of a particular significant to the BIM knowledge development strategy within CS-1 was the active participation of "local BIM champions" in the BIM support structure to provide a strong boost to those at the operational level that struggle to cope with the change uncertainties, complexity of, or concerns related to, software use, hardware issues, and difficulties related to process change. A BIM manager emphasised that: *"…BIM champions and users are identified within our local company offices to drive its implementation and raise knowledge at a local level…He could be someone who understands the process, knows where to get information, and knows how to find solutions to complex problems. They are the ones, where it is almost like a hobby wanting to learn more, wanting to use the latest technology. What you are trying to achieve is to take their passion and enthusiasm, add the technology to it, and get some organisation standard, to form - this is the way that we actually want to work."* The local BIM champions are therefore strategically placed at the operational levels and are empowered to counter BIM implementation resistance or any concerns and dilemmas raised by the local workforce pertaining to the organisation's BIM agendas.

B. Finding in CS-2

The main organisational objectives of CS-2 is to focus on higher growth in the energy sensitive segment of the building industry, thereby providing modern, zero carbon building solutions. Thus, the company has secured a unique niche in the design, manufacture and construction of environmentally friendly building components and has specialised in building low-carbon infrastructure projects from power plants, roads and bridges to housing, schools and hospitals. In order to sustain its sustainability agenda in the provision of low energy building solutions for its clients, CS-2 recognises the need to continually engage with innovative construction technologies. Accordingly, the company has committed internal resources to, and emphasis has been placed on, nurturing a continuous flow of new and cutting edge construction technologies as enablers in the most highly efficient design, manufacture and installation possible. BIM is perceived to play a central part in helping meet the company's strategic goals. This was emphasised by a Technical manager when he stated that: "*here at [CS-2], the application of BIM is a key driver behind our philosophy to provide the best service for our clients"*.

However, upon creating the necessary smartBIM objects with the company's products, it became clear that the products innovation was stimulating revolutionary changes in most aspects of the organisation's processes, which were contrary to the inherent status quo. These encompass, training, human resource management and external relation. Such facilitative structures are needed to ensure that the workforce revolves with and adapts into the inherent contradictions and appropriate resolutions required for the new organisational configuration. The emerged themes associated with the expansive elements to learning to help cope with the change uncertainties within CS-2 are broadly discussed under;

- Motivation of staff to engage in continuous learning and knowledge development
- HR involvement to help in staff retention and to avoid vague approach to knowledge enhancement
- Collaboration between in-house technical team and external support team to leverage organisational BIM processes

In order to deliver high quality BIM products and services, it was recognised that the company had to train and retain its staff in order to become BIM competent organisation, and to optimize the associated benefits "*just as part of doing business".* This was reemphasized in a statement made by a director; "we *view expertise in BIM processes as an extension of our people's skill set. Our goal with these roles is to fill a need in developing BIM competencies for our construction professionals in order to maintain a strong market position"*.

The above statement indicates that in order to maintain its market position as a large manufacturer of building components, the organisation identifies the need to evolve with the changing times by maintaining full compatibility with evolving software platforms and its product range and staff competencies.

One of the biggest changes was a "*behavioural change*" in employees' learning habits. According to a technical manager, *one-off training*, and the depth of knowledge in BIM tools alone is not enough because the BIM tools are continuously being improved in an evolving cycle of technological development. As a technical manager put it, it is more about "*problem solving, working in a team, and a sense of exploration*". Those are the qualities expected from the BIM users because the technology keeps evolving and the organisation is "*constantly pushing the envelope*." Thus, CS-2 ensures that the skill-set available is continuously assessed and work is put in towards maintaining consistent knowledge across time.

The head of the engineering department believes that due to demand-supply deficit of BIM experts there is currently "*BIM personnel poaching*" going on among competing firms. This calls for the organisation's human resource management (HRM) team to "up it game" by assisting in the development of a comprehensive employee retention strategy for the business. One of the challenges the company did face, initially, was a disconnect between the HR practices and the human resource needs of the different departments - to the extent that a technical manager criticized the HRM by describing it as concocting some "*other cocktail of values*" irrelevant to the present training needs of the workforce.

A BIM manager opined that; *"If you ask CAD managers what the company expects from them moving to BIM, do they know how their performance equates with their counterparts in competitive organisations… Is reference made about staff retention by increasing talent development metrics or some other cocktail of values?* This phenomenon calls for the company to review its HR policy with respect to BIM. Clearly, in order to properly develop BIM proficiency and to maintain good employee retention, especially the best, well trained and experienced ones, Human Resource (HR) actions are preeminent. One noteworthy change adopted in CS-2 was to ensure that the HR department was fully involved in the decision to develop and sustain a BIM competent workforce.

The HR team's subsequent involvement encompasses liaising with each of the departments in creating high-level business goals with respect to improving knowledge development and increasing staff retention. This is done via a performance-based competitive rewards and training opportunities. It is targeted at the relevant needs of employees and their job requirements**.** The HR department is also the pivot through which skill development and new recruits are organised within the company among other important assignments, such as, managing BIM training programmes, leadership development, and performance assessment criteria of all staff across each organisation. The HR thus helped in the BIM knowledge development process within the company by managing individual progression through different managerial levels, and sustaining employee retention through performance-based rewards and competitive salary structures.

The organisation's BIM platforms are oriented to the specific workflows of each department. The technical (design and engineering) department of the organisation was responsible for facilitating the growth of BIM expertise and also, to leverage best practices and over BIM best practices across the business. The technical department has a dedicated team that organizes workshops to educate staff members on pertinent issues which include; operating the smart object library; organising BIM workflow; computer workstation upgrades and utilizing the various functionalities of the preferred BIM platforms. The workshops are aimed at bridging the learning gaps as well as providing clearer understanding about BIM work processes amongst the workforce within the organisation.

The technical department's efforts were buoyed by an external support services team. CS-2 established a relationship with its preferred external BIM vendor to help incorporate BIM technical competences and technological artefacts to suit individual needs of the various internal functional departments. CS-2 also initiated an 'accreditation appraisal scheme' that guarantees that any new system upgrade from its BIM vendor would be recompensed with staff competency training so that staff would be consistently up to-date with the use of their preferred BIM products released by the preferred vendor.

C. Finding in CS-3

The CS-3 prides itself as one of a few specialist firms in the UK that provides building information modelling services for structural steelwork and architectural metalwork. Despite being a small construction firm, the company has played a specialist and a significant role on high profile construction projects across the UK ever since it enhanced its capability to encompass BIM. Commenting on the company's current status, the managing director emphasised that "*we are growing faster than the capital with both enquiries up and orders up, we continue to grow with the investment in more Tekla stations [BIM platform] and our in-house engineers now up to 14 fully employed."*

The statement of the managing director highlights the extent to which the company's investment in BIM protocols has impacted on the business as a whole. The main themes associated with knowledge development strategies attuned to BIM deployment within CS-3 are discussed under;

- Selection and appropriation of compatible BIM technological platforms
- Tailored training and management development structure across various ranks
- Liaising with local college in combination with 'learning by doing' approach in developing its knowledge workforce

As part of the programme of introducing BIM to its work system, CS-3 evaluated some of the popular BIM software products until deciding on the platform most suited to the business. After a comparison exercise between the various BIM platforms, Tekla was found to serve useful purposes in the organisation, because it was seen to be relatively intuitive and it gave reasonable flexibility for structural detailing and accurate prefabrication information via Numerically Controlled (NC) data production. CS-3 thus signed a flexible licencing agreement with Tekla. The agreement covers technical and maintenance support, and access to the latest versions of Tekla products on a web portal. This enables the engineers to access the product best suited to their project from a portfolio of Tekla software which are useful for structural design, modelling, viewing, coordination and information sharing. These products include Tekla structure, Web Viewer and BIMsight.

Beyond the appropriation of BIM into the organisational processes, the extent to which the BIM vision is realised is also dependent on the employees' skills and attitudes to learning. This is very alarming to the business, because, very often, the employees that join the company do not have the specific BIM skills the company requires. There is also a lack of industry relevant BIM training courses in the conventional academic institutions. To address this gap, the company developed internal training and management structure to support the employees across the ranks, from apprenticeship, through engineering to senior-level positions. The training structure provides opportunities for employees to work their way up from apprenticeship level to senior management level. The apprenticeship scheme, according to a contracts manager, "*aims to train, develop and mentor the future structural engineers and detailers of the business by offering them vocational training and hands-on-experience*." The company also created a partnership with the local college where the apprentices receive some of their trainings. After attaining the necessary qualifications, the employees are then assigned to a project with a skilled engineer as a mentor.

The whole BIM ethos is also incorporated into the company's training and support structure. As mentioned previously, vendor supports and Tekla systems maintenance are a part of the license agreement the organisation and its preferred BIM solution providers negotiated on. A manager affirmed that; *"the added value of the licensing agreement is that consultancy and training included, this ensures that our staff have the competencies to deliver quality services. To complement this, we attend annual trainings and presentations with Tekla on their latest products. We also get all the documentations towards what new features there are and train our staff on them*." This statement clearly indicates that a well configured BIM platform is intrinsically linked to the functional performance of the BIM workforce. Hence, CS-2 relies more on its BIM solution providers to support its workforce with their training requirements, especially with the launch of any new product version. According to the managing director, there are ample opportunities for employees to climb up the hierarchy within the company as it aims to "train, develop and mentor the future structural engineers and detailers of the business by offering them vocational training and hands-on-experience."

However, the training and support system, and the corresponding opportunities mean that employees are expected to often learn new skills and take more responsibility. This it is considered to be significant for a small firm like CS-3.

The next section presents the analysis of the findings, relative to the theoretical position of the paper.

V. ANALYSIS OF THE EXPANSIVE LEARNING AND SUPPORT STRATEGIES FOR LEVERAGING BIM ACROSS THE ORGANISATIONS

Learning and knowledge development are considered as a vital underlying driver for technology implementation success and as "the leading indicator of a successful transition" to BIM-compliant best practices within the respective case organisations. The attention of the study has focused on theorizing how expansive learning can serve as an asset to the construction sector by empirically examining the manifestation of expansive learning in an adaptive work context where BIM and its related disruptive construction technologies have been deployed. It is argued that, these theoretical ideas, in combination with learning and employees' development that link theory and practice could provide a useful basis with which to better understand the transformation associated with technology-enabled best practices within the construction work systems.

Expansive learning has been shown in the academic literature to offer positive results through effective adaptation to environmental changes and improved organisational efficiencies (Guha et al.) [44]. Adaptive expertise is also facilitated by making fitting responses to technological changes (Freeman & Perez) [45], such as, "learning by doing" (Arrow) [46], "examining and engaging with external expertise" (Guha et al.) [44] and via empowering "technology gate keepers" who constantly review the environment for new development and opportunities, and "boundary spanners" who span the boundary between the environment and the organisation (Motwani et al.) [47]. These antecedents have been found to be predominant in the case organisations in their strive to incorporate BIM into their work processes.

The responses from the cases pointed to a varying expansive learning and knowledge development strategies that lead to the development of technology-enhanced workforce. The main themes from the responses are highlighted below in Table II.

TABLE II
Emerging themes on expansive learning and support strategies across the case organisations

Main themes	CS-1	CS-2	CS-3
Dedicated in-house technical support team	√	√	√
Engagement of external technical expertise	√	√	√
Development of local BIM champions	√		
Technology gate keepers	√		
HRM support strategy and performance-based competitive reward		√	
'Learning by doing' employee development strategy			√
Tailored training via partnership with academic institutions			√
Tapping expertise from the preferred BIM product vendors		√	√

Engestrom's activity theory as it relates to expansive learning provides a means of investigating knowledge development within a work system. A central assumption of the theory is that, outcomes are contingent on a network of interrelated attributes within the work system (Anthony et al.) [48]. This is clearly manifested in the eclectic approaches for learning within the three organisations.

The study has shown how the organisations' in-house expertise that drives BIM best practices liaised with external agents to develop local BIM champions to leverage the various BIM ambitions. For instance, CS-2 liaised with web-based BIM objects developers to create a range of its building products into smartBIM objects and hosted these on web libraries for designers to upload into project models. Likewise, CS-3 engaged with external knowledge institution to help the workforces attain their formal qualifications, at the same time providing learning-by-doing support structure to give the operatives hands-on training experience.

One of CS-3 BIM knowledge development strategy was to avoid the situation where BIM would be considered more or less, as a “bolt on attachment” rather than a language the entire company had learnt to speak and understand. Thus, the BIM concept was incorporated in the “syllabi” of the apprentices, engineers and senior engineers as encapsulated in their “training and management support structure”. Opportunities existed for some form of skill sharing and knowledge transfer through "*learning by doing*" on the job for those less familiar with the BIM work processes. They also initiated a flexible licensed agreement which covered technical support, training and access to a range of BIM products from its preferred BIM vendor. The agreement ensured that any upgrade to existing BIM technologies or new product launched by the external vendor would be recompensed with staff competency training so that staff would have access to, and be consistently up to-date with, the use of these technological platforms. The in-house teams, acting as boundary spanners (Whyte & Sexton) [49] worked very closely with external agents to integrate technical knowledge into their respective organisations.

Thus, the contemporary construction setting can be conceptualized as a nested work system, connected with the broader environment. Thereby, the market trigger of concomitant construction technological artefacts in the broader environment can elicit a corresponding change within the construction work system. This causal relation is enabled by virtue of the internal cum external experts’ relationship and dynamics. The evolving nature of technological development also invokes a process of deliberate interaction between specific work context and broader external influences, leading to a constant pursuit of novelty and innovation within the contemporary work system (e.g., Paavola et al.) [54].

Another way that the expansive learning notion manifests in the case organisations was via “technology-savvy gatekeepers”. It was evidenced in the analysis of the findings how technology-savvy employees were nurtured and developed into becoming “local BIM-champions. The criteria for the development process typically encompass performance assessment which leads to career progression that is connected to a “personal development plans” (PDPs). In CS-2 for instance, there was a staff retention strategy via performance-based competitive rewards and training opportunities.

Technology savvy individuals within the organisation were also identified and trained to be “BIM champions” to drive the implementation process at the local or the “shop-floor” level. The active participation of “local BIM champions” in the BIM support structure provides a strong boost to those at the operational level that struggle to cope with the change uncertainties, complexity of or concerns related to software use, hardware issues, and difficulties related to process change. These underscore the importance attached to training and development and retaining core BIM competent staff across the case organisations. The technology-savvy “local champions” acted as gate-keepers in ensuring that the knowledge-capacity was gradually adapted and retained within the operations of the organisations. These “gate keepers” were also incentivized with highly competitive salary and work benefits commensurate with their BIM competences and performance.

The analyses of the three case studies have shown that the organisational norm for coping with disruptive technologies on a sporadic basis calls for continuous knowledge and skills development that transcend preceding experience and monotonic enrichment of previous knowledge and practices. This is consistence with Korkmaz et al. [50] assertion that innovation is more likely to be adopted in the intended manner if actors have skills to master the innovation, have incentives to implement, and are beneficiaries of managements’ efforts to remove structural and procedural obstacles to implementation. Engestrom and Sannino [51] also assert that, it is essential to engage in collective knowledge generation by expanding and penetrating new boundaries. The theory of Adaptive expertise aligns with a need for a novice in a specific knowledge area to develop through a cycle into a skilled resource, with the flexibility to solving emergence problems. Thus, an adaptive expert ought to partake in task-relevant opportunities that push the practitioner towards a new level of understanding and performance (Raufaste et al.) [52]. A work organisation that is at the expansive end of the learning continuum presents a conducive environment for both domain-specific and innovative skills dimensions of adaptive expertise to manifest (e.g., De Arment [65]; Bohle el al. [64], Fuller & Unwin [32]. The two theories are therefore not mutually exclusive; hence an expansive learning work environment could leverage the manifestation of adaptive expertise within the same work context.

The analysis so far, has presented an attractive proposition to conceptualise the contemporary AEC work organisation as a learning environment, thus ensuring that the knowledge workforce is engaged with and consistently aware of the turbulent organisational situation when dealing with change. The next section presents the discussion and conclusions.

VI. DISCUSSION AND CONCLUSIONS

It has been acknowledged that digital technology has provided workplaces with an informational system that is the most rapidly growing technical system in human history. But there has not been an equally corresponding manifestation in professional learning and knowledge development within the workplace (Margaryan & Littlejohn) [61]. This implies that workplace can no more be viewed as a place where knowledge is applied, but rather, the two become closely intertwined (Harteis & Billet) [66], where learning becomes an integral component of the work routine. The theoretical position, coupled with the empirical analysis attempt to describe processes that not only mediate existing knowledge and practices, but also create new innovative practices. The assumption is often made that experienced practitioners with prior knowledge and skills understand the capabilities of technological instruments and consequent application in their affiliated organisations. This study has however argues that where this is the case within the contemporary organisational setting, any cognitive dissonance with the emerging disruptive technologies is likely to result in a drag on overall organisational performance. The study is therefore on the premise that, the emerging technologies are disruptive to work practices, in that they transform the work infrastructure in the form of routines that the knowledge workforces rely on to carry out their work.

From the responses of the three case study organisations, it was clear that the organisations deploying disruptive, but relevant construction technologies undoubtedly have to upgrade their existing professional workforce's knowledge status as a continuous cycle of standard routine. This is to help leverage the desired outcomes embedded in the appropriation of the technologies.

Within the case organisations, expansive learning approaches that augment experts' adaptation to changing work patterns were witnessed. Facilitative workplace learning environment mainly help adaptive experts to effectively learn to integrate their experiences into the work practices to counteract the disruptive technological challenges. For instance, the organisations worked very closely with external agents who acted as boundary spanners to integrate technical knowledge into organisational settings. In other instances, technology-savvy BIM champions were nurtured and developed to act as gate keepers in disseminating the technical knowledge into the business operations. The organisations also engaged with external knowledge institution to help the workforces attain their formal qualifications, at the same time providing learning-by-doing support structure to give the operatives hands-on training experiences. In particular, the appropriateness of the expansive learning combined with adaptive expertise constructs appear to better encapsulate the underlying dynamic links of the values and belief systems the workforce ought to adhere to, the emergent disruptive artefacts they have to use, and the community (organisational) patterns they are part of.

Although the case organisations exhibited some expansive learning approaches to ensure adaptation into the changing work patterns, for instance, by forming alliances with external consultants, educational institutions and technology vendors - these characterisations seemed to be transient. As such, CS-3's licence agreement with Tekla to provide technical support and products maintenance was temporary but subject to annual review and renewal. Hence, it was not so explicit within all the three organisations whether their expansive learning approaches and the related adaptation to the changing work context would be a continuous cycle or an organisational norm. A lasting organisational transformation to suit the technological development and market demands may not be guaranteed if the organisational status does not sustain expansive learning, thereby enhancing adaptive expertise.

The study represents a promising avenue for assessing expansive learning in an adaptive manner within the context of technology deployment in the contemporary construction setting. An enabling workplace learning environment can better equip the workforce to tolerate cognitive ambiguity in the construction and resolution of inherent contradictions of the changing work patterns (Frenkel-Brunswik) [53]

The contribution that this study offers, is that it clearly illustrates the dynamics of the organisational learning modes within the case organisations to augment the technological advancement and organisational change processes. It is hoped that this paper will trigger a further discussion within the academic sphere on reconsidering the knowledge development protocols of the next generation workforce in order to cope with the rapid changes seen in the technology-enhanced contemporary AEC settings.

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