Digitalisation for Occupational Health and Safety in Construction: A Path to High Reliability Organising?

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ABSTRACT

The occupational health and safety (OHS) performance has plateaued in the UK construction industry and the fatality remains three times the all-industry rate. Digitalisation of the construction industry offers increased productivity and new opportunities to reduce some OHS risks or better manage them. However, there is little in-depth knowledge on their processes and outcomes in terms of driving continuous improvement. This study deals with this gap by using high reliability organising (HRO) as a lens for obtaining insights into digitalisation for OHS management in construction. The aim is to investigate whether and how the implementation of digital technologies can help achieve high reliability of construction OHS. 21 semi-structured interviews were carried out, discussing how the process of digitalisation for OHS applied the five principles of HRO. The findings demonstrate that construction tends towards a 'quick fix' adoption process for technology, which falls short to sustain high reliability performance. Two complementary ways for enhancing digitalisation for OHS, based on HRO, were discussed: (1) integrating soft and hard systems to facilitate learning and interactions between hierarchies, at the firm-project interface and across organisations, and (2) empowering the workforce in OHS management through digital tools supported by appropriate systems at firm and project levels. More importantly, to achieve HRO requires the digitalising process generating collective mindfulness and a sense of caring rather than socially intruding among office and site workers.

Keywords: Digitalisation, high reliability organising, mindfulness, occupational health and safety.

INTRODUCTION

The UK construction industry has experienced significant occupational health and safety (OHS) improvement in the last 40 years. The declines of workplace facilities and injuries were largely due to the introduction of OHS legislations, regulations and safety management systems (SMS). Yet the fatality rates have remained at a high plateau. An underlying assumption of prescriptive regulations and their enforcement is that OHS arises from following rules independently of the context (Hale & Borys, 2013). Consequently, the organisational OHS measures are mostly reactive to respond to external pressures from regulations and client requirements and focus on facilities and tools in individual projects. To break the OHS performance plateau requires a more proactive approach beyond compliance and a systemic perspective that considers the interrelations and interactions in the complex socio-technical systems. The specific characteristics of construction projects, particularly the physical, organisational and social decoupling of projects to parent organisations and the temporary multiple organisations, impose challenges in OHS management and monitoring (Harvey et al., 2019). It has been argued that the weak systems at the firm-project interface, across projects and organisational boundaries have caused difficulties in OHS knowledge management, communication, consistent performance and continuous improvement (Duryan et al., 2020). This is further exacerbated by the transactional business model adopted by construction firms where commercial considerations shape the project under and within which OHS is then addressed (Smyth et al., 2019).

It is believed that the development and application of digital technologies offers new opportunities to address the challenges and further enhance OHS performance in construction. There are many examples of usage of digital tools for OHS monitoring and management, from drones, virtual and augmented reality to wearable devices and robotics on construction sites. Whether and how their

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implementations can facilitate the OHS management process and drive continuous improvement needs to be investigated. The aim of this study is to examine the current process and outcomes of digitalisation for OHS in the UK construction industry, from the theoretical lens of high reliability organising (HRO) (Weick & Sutcliffe, 2015). HRO theory provides a means to manage OHS without sacrificing performance. The applicability of HRO in the construction and project management has been discussed in previous studies and the limits of the construction industry to achieve high reliability are identified (Harvey et al., 2019; Olde Scholtenhuis & Dorée, 2014). This study uses HRO principles to gauge whether and how the current digitalisation helps OHS performance in the UK construction industry.

OHS MANAGEMENT AND DIGITALISATION IN CONSTRUCTION

OHS is a major concern in construction. In the UK, one third of all workplace fatalities were from the construction industry, and around 4000 construction workers die each year because of work-related illness (HSE, 2018). This is echoed across many developed countries. There have been a series of step change improvements regarding OHS since 1970s. But the progress in the construction industry has arguably been slower than other industries. One of the reasons is transactional (Smyth et al., 2019). The competitive bidding drives construction firms to keep investment and expenditure low in order to secure works. The large tier-one contractors had no internal incentive to make improvement, which requires investment. Instead, OHS improvements are externally driven by legislations and standards. Clients and contractors set safety management systems, procedures and behavioural programmes to comply with external requirements. The result is that OHS has been regarded as a "bureaucratic burden" (Swuste et al., 2012, p. 1333), which involves complicated documentation and box-ticking exercise rather than valid analysis and learning from experiences (Harvey et al., 2019).

Safety management research has been progressing through several ages, being informed by engineering, psychology, sociology and anthropology. Hale and Hovden (1998) proposed the age of technology, the age of human factors and the age of management systems. The first age focused on technical improvements to mitigate risks and hazards. People and management related issues emerged subsequently, leading to a focus on the human behaviour and the demand for a more systemic approach, hence the emergence of various safety management frameworks (e.g., Haslam et al., 2005). The systems age is followed by an increased concern for organisational culture and relationships. Yet studies point out that the current safety management measures in the construction industry such as safety inspections are ineffective in terms of proactive intervention to prevent accidents (Saurin, 2016). Safety culture is also found to be hard to sustain in construction firms, especially under major organisational changes (Smyth et al., 2019). Safety is bolt on as an extra in construction project business and can be compromised when emergent events bring shocks to organisational systems.

An adaptive age has recently emerged in other industries and incorporates theories and practices of high reliability organising, resilience engineering and organisational resilience (Borys et al., 2009). The age of adaption represents a move away from bureaucracy towards developing organisational and human adaptability to manage the increasing complexity and dynamics of organisations and their environment. Workers' knowledge and experiences are regarded as an asset to the organisation, which enable improvision and adaption (Hollnagel, 2008). In this vein, some violations of written rules, or 'work around' are perceived as inevitable and sometimes necessary adaptions to local circumstances (Hale & Borys, 2013). For construction organisations where project workers are physically and socially decoupled to the parent organisation and subcontracting is prevalent, human adaptability needs knowledge and relationship management supported by the firm in order to ensure both flexibility and consistency. Knowledge management system helps identify the gap between practice and procedure, capture and transfer the local knowledge across programmes and organisations, which increases the resourcefulness and resilience of the organisation. Relationship management fosters trust, openness and fairness across hierarchies, functions and organisations

(Smyth, 2015). Mutual trust between management and operatives is key to flexibility in decision making especially during crisis or unexpected changes (Xu et al., 2021). A culture of openness and fairness encourages raising concerns regarding OHS and wellbeing issues at workplace (Duryan et al., 2020).

The development and application of digital technologies is believed to offer opportunity for better OHS management as they can help the monitoring and reporting of OHS data between project and organisation levels and facilitate learning about OHS issues including errors and near misses. Table 1 summarised the digital technologies in relation to construction OHS management in the literature review (e.g., Ahn et al., 2019; Antwi-Afari et al., 2019; Niu et al., 2019).

Table 1: An overview of digital technologies for OHS management in construction

Function		Technology						
		BIM	Wearable sensors	RFID, UWB, GPS/GIS, GSM, Bluetooth, WLAN, IoT	VR/AR/Computer-generated simulation	Computer-/Tablet-/Mobile-aided	Camera /Drone	AI
Design	Prevention through design	X						
Planning	Safety plans	X		X				
Monitoring	Fatigue/Stress/Musculoskeletal disorders		X				X	X
	Wellbeing: e.g., sleeping patterns		X					
	Location of resources, equipment and/or workers			X				
	Safety behaviour & activities		X	X		X		X
	Working environment			X			X	
Reporting						X		
Training		X			X	X		

HIGH RELIABILITY ORGANISING IN CONSTRUCTION AND PROJECT MANAGEMENT

HRO theories emerged through the study of day-to-day operations in the nuclear power plant, air traffic control and US navy aircraft carriers. Those organisations are characterised as 'highly reliable' because they perform exceptionally and almost error-free, despite that "they all operate in an unforgiving social and political environment, an environment rich with the potential for error, where the scale of consequences precludes learning through experimentation, and where to avoid failures in the shifting sources of vulnerability, complex processes are used to manage complex technology" (Weick et al., 1999, p. 32). In this vein, safety is regarded as a dynamic non-event. Bureaucratic rules are seen as stifling whereas expert knowledge and adaptability supported by organisational systems and routines are needed to improvise and maintain performance, especially during the unexpected changes or crisis. The other common features include a high priority placed on safety, a learning

orientation, a just culture that fosters openness, fairness and psychological safety, decentralised decision making in emergencies and proactively anticipating and responding to potential threats (Saunders, 2015). Weick & Sutcliffe (2015) summarised five principles of HROs:

1. Preoccupation with failure: an ongoing attention to weak signals of failures through continuous monitoring, proactive reporting and pre-emptive analysis of possible vulnerabilities. It is also a preoccupation with learning from experiences including failures, errors and near misses, which are treated as an indicator of potentially larger problems.
2. Reluctance to simplify interpretations: analysing failures, errors and near misses beyond human errors and direct causes; valuing divergent viewpoints that question underlying assumptions, uncovering blind spots and identifying changes.
3. Sensitive to operations: obtaining and maintaining the big picture of current situations. On the one hand, bottom-up communication from operatives is encouraged. On the other hand, senior and middle management needs to be actively in close touch with what is happening here and now in operations. Such information and knowledge can inform decision making in crisis but also forestall the accumulating of small problems that might lead to systemic failure.
4. Commitment to resilience: ongoing development of capabilities and resources to absorb, adapt, recover and learn from the adversity. Organisational resilience involves greater skills at endurance, adaption, improvision and learning. This requires the support from organisational systems and routines but also individual competence and resilience, pointing to the importance of investing in both systems design and people.
5. Deference to experience: the tendency to shift decision-making to experts in the face of unexpected events. Subordinating written rules and hierarchies to expertise allows that emerging problems get quicker and better solution and capabilities are matched with the varying situations.

These principles demonstrate the organisation's capability to anticipate and contain unwanted situations and thus organisational mindfulness. Weick et al. (1999) defined organisational mindfulness as the "capability to induce a rich awareness of discriminatory detail and a capacity for action" (p. 37). Organisational mindfulness enables organisations and their employees to notice emerging threads, understand the interactions between actions within a system and act resiliently. Essentially, HRO theories promote a way of managing OHS and maintaining reliable performance through organisational and human adaptability enabled by good communication, learning, expert knowledge, trust and a strong organisational culture, rather than reducing it by increasing bureaucratic rules and control (Sutcliffe, 2011).

From the original contexts where safety is of prime importance and the consequences of incidents is far-reaching, the extent to which HRO theories can be translated to the construction industry has been debated in extant studies. Saunders (2015) compared the characteristics of the project environment and those of the operating environment that renders HRO. They pointed out some similarities between two environments, for example, high complexity, interdependencies between actions, multiple stakeholders with potentially divergent interests, uncertainties and information incompleteness. This is especially true for infrastructure projects or megaprojects that are undertaken in the public domain. A nuance in the debate is that in the original contexts safety and reliability are treated as equivalent concepts whereas in other industries such as construction they are not (Olde Scholtenhuis & Dorée, 2014). The concept of reliability is context-independent, "For some it [reliability] means the constancy of service; for others, the safety of core activities and processes" (Roe & Schulman, 2008, p. 5). Taking a pragmatic perspective, Olde Scholtenhuis and Dorée (2014) argue that reliability is important to all organisations in terms of improved performance and therefore HRO is applicable across a far broader range of industries. On the other hand, traits of the construction industry that impose barriers to applying HRO principles were identified (Harvey et al., 2019; Saunders, 2015), including the project-based organising, temporary work processes, financial pressures, prevalent outsourcing and transient workforce. Such traits hinder effective communication between hierarchies, learning and knowledge transfer at the firm-project interface and across projects,

investment in employees and leadership commitment. In particular OHS management, although construction is high-risk, the major concern is the frequency and rate of personal injury and fatal incidents. The safety-critical industries such as nuclear and aviation focus more on catastrophic events potentially causing societal impacts.

Despite the debates, HRO theories have been applied in the CPM to a wide range of topics (e.g., Brady & Davies, 2010; Saunders, 2015). This study focuses on OHS management and its digitalisation, using the five principles of HRO as the analytical lens. For the purpose of this study, reliability encompasses the consistency of service delivery, anticipation and resilience to shocks. It requires "the ability of organisations to plan for shocks as well as to absorb and rebound from them in order to provide services safely and continuously" (Roe & Schulman, 2008, p. 5). Safety refers to the way in which the organisation and project performs its mission without accidents, rather than an outcome of the project per se. Indeed, OHS incidents in the construction process can cause disruptions in the service delivery. HRO refers to systems, processes and procedures derived from the typical high reliability organisations that are critical to sustaining reliable organising and performance. Organisations, regardless of which industries they are in, can become highly reliable by creating the appropriate behaviour and attitudes supported by systems at multiple levels of organisation. In other words, they can be 'reliability-seeking organisations' that are enacted by mindful individuals and actions within the context of structure and routines.

RESEARCH METHODS

The research is explorative and uses qualitative methodology. 21 semi-structured interviews were carried out, discussing whether and how the digitalisation facilitates the organising of OHS in construction. As Table 1 shows that the range of technology available for assisting OHS in construction is considerable. This research is not to address the full range but to evaluate the range of issues emanating from the interviews. Data were collected from five types of organisation: institutions, professional bodies, client organisations, designers, and main contractors. Interviews were conducted with senior management, project directors, principal designers, health and safety managers, safety inspectors and site management. An interpretative approach is used to analyse data. The five principles of HRO (Weick & Sutcliffe, 2015) are used as an analytical lens to evaluate whether and how the current digitalisation facilitates the organising of OHS and enhances reliability.

FINDINGS

Overview of the digitalisation for OHS in construction

At the institutional level, OHS has not been embedded in the context of the industry. While the UK government has invested in digital innovation, OHS does not form an integral part. Most digital technologies are developed for productivity, and OHS is treated as an added value of such development. This is echoed by the organisation-level thinking that prioritises commercial considerations and treats safety management as something of a "bolt-on extra" (Smyth et al., 2019). It was commonly agreed that the main reason for minimal investment in digitalisation and OHS is cost. Contractors hold back on investment in order to appear more competitive in the bid stage. At senior and middle management levels, knowledge of OHS-related digitalisation is generally low and the competence to use and understand digital technology is problematic at all levels. In addition, the fragmented nature of the industry and the lack of systems integration between organisations impede industry-wide innovation and the collective capability to influence the institutional context including the government and public policy. Therefore, both the institutional environment and the strategic leadership at industry level are not intentionally addressing OHS through digitalisation.

In terms of the current digital technologies implemented in the field of OHS management, they are contributing to one of the five categories:

1. Replacing people or at least complementing human capability for high-risk activities, such as drones, self-driving vehicles and sensors that detect and warn OHS hazards and risks in the working environment
2. Monitoring human activities and working conditions including locations, behaviour and working hours, such as cameras and wearables
3. Visualising risks and hazards in design, planning and training, such as BIM, VR and AR technology
4. Improving safety management systems through digitising the paperwork, enhancing data storage and visualising data, such as reporting applications on smartphones and tablets, online information sharing systems, cloud storage and performance dashboard
5. Removing work off site into controlled factory conditions where digital technology can be more easily applied.

Digital technologies were seen as individual solutions that do not contribute to overall performance in a number of ways. Nor data from different sources are linked with each other to build up a better understanding of OHS conditions. There is a lack of strategic and systematic thinking in the adoption of new technologies and the tendency to pursue 'quick fixes' in response to external forces such as safety inspection and client requirement.

Analysis of the digitalisation for OHS from the HRO perspective

Preoccupation with failure

An ongoing attention to possible failures requires continuous monitoring OHS leading indicators, detecting weak signals, analysing and learning from errors and near misses and sharing knowledge within and across projects and organisations. The need to apply BIM to aid OHS management in construction phase was stressed by regulators, designers and main contractors. The concept of prevention through design (PtD) has been promoted by Health and Safety Executive (HSE) under Construction and Design Management Regulations 2015 (CDM 2015). Designers are encouraged to identify and resolve OHS risks and hazards through design, or to highlight and communicate them with main contractors. BIM can be applied to facilitate this process. Yet two barriers to PtD were identified. First, designers generally have poor knowledge about the construction process and thus lack the ability to identify OHS risks. In fact, some designs are not buildable and might cause accidents on site. Second, the level of collaboration between designers and main contractors is low particularly after the design handover. There is minimal investment and commitment to project planning. The knowledge about how design is realised and influences construction OHS is not fed back to designers and clients to improve future works. The role of principal designer is set up to coordinate OHS issues in the project lifecycle but not necessarily the process of transferring knowledge across different parties. BIM has been grafted onto existing ways of working. Therefore, it is not surprising to learn from the findings that BIM is seen primarily as a tool for design and technical information processing and not a potential forum for improving OHS operationally.

Cameras and wearables offer opportunities for detecting weak signals of failures as workers' activities and site conditions can be monitored and analysed post incidents. But this is a reactive approach to managing OHS. To prevent injuries, fatalities and work-related illness requires active prediction and intervention in real time. This not only calls for advancement in data transmission technology but also the competence of people who observe the activities, which is built upon continuous education and learning from experiences including failures, errors and near misses. The adoption of VR and AR in safety training in some large infrastructure projects was mentioned as an example of raising workforce awareness. One specialist consultant mentioned the high levels of dyslexia within the industry, and this may be a reason that visual technology resonates with practitioners. However, the positive impacts in the long term depend on the continuity of training that is updated as projects change.

More importantly, there is a lack of knowledge management system to support learning at individual and organisational levels, capture knowledge generated at individual and project level, generate and transfer generic knowledge for reuse at firm level and across projects. As one interviewee stated:

I'm going to be controversial. In construction, we're not interested in learning lessons, we're not interested in improving. What we're interested in is protecting our own reputation. So we're covered by lawyers. (Programme Manager of a megaproject)

Data that is collected is not done so systematically and the sector does not analyse it. The absence of systems causes difficulties to prioritise data that is useful for improvement and transformation and develop new capabilities to continuously improve performance. It was pointed out that the industry is repeating the same kind of accidents and incurring the same injuries due to the "unhealth culture about sharing information" (Head of Construction Sector and Policy of an institutional body). When it comes to information sharing inter-organisationally, the endeavour is focused upon successful stories. There is resistance to sharing experiences and learning from failures, errors and near misses. There are organisational reasons to enhance corporate image but also institutional factors that induce fear, distrust and blame cultures.

Reluctance to simplify interpretations

There was expressed concern that digital technology can be used as a 'black box' of which the output is taken for granted and hinders dialogues between people and at the human-technology interface. For what is inside the black box and how the output is produced is technologically complex to comprehend by users. This can further lead to rigid practice (act as the technology says) or inconsistent implementation of technology. To resist the tendency to simplify interpretations requires actively engaging with the workforce and using technology as a facilitator of communication.

When you do that [wearing wristband] you end up having a more detailed dialogue. Rather than being prescriptive and saying, "You're going to work X shifts and that's what the contract says." We engaged with the supply chain. Part of that engagement was to add this technology onto it to have a look after them. Eventually we changed the shift patterns to more benefit those individual groups. (Former Programme Manager of an infrastructure project)

In other words, data has to be managed in relation to understanding gaps between written rules and practices and recreating new practices to manage improvement.

It was recognised that digitising paperwork and cloud sharing enhance the ability to trace causes of safety incidents. Nevertheless, the digitised records tend to be used to find the 'culprit' to be blamed rather than to be systematically analysed to create knowledge and to be learned from. There are two challenges to be addressed in order to conduct systematic analysis of accident causes in construction. First is that technologies do not communicate with each other and therefore data from different sources is not linked with each other, which was mentioned by a researcher as a problem of "semantic enrichment". There is a potential for improvement in this vein by using text mining and machine learning in the analysis of accident reports. The second challenge is the cost and time pressures in the construction industry. As mentioned, because of the transactional nature of the business, senior management in construction has a history of pursuing 'quick fixes' or grafting on new technologies to existing structures and processes. The underlying assumptions are rarely challenged. It helps to make the sectors and organisational actors look engaged and proactive in the short run, but in the longer term the net result is a set of rigidities that are laid down and hold back effective adoption and iterative refinement. The last challenge, which was more commonly recognised in the interviews, is the blame cultures and the low level of trust between operatives and management and between institutional bodies and organisations. The fear of being blamed inhibited openness in reporting and the willingness to learn. This is worsened by the prevalent use of temporary contracts that make workers more vulnerable.

Sensitive to operations

There are ample examples where digital technologies can help the senior and middle management better understand what is happening in operations. The bottom-up communication about OHS issues from operatives are facilitated by the development of reporting applications available via smartphones and tablets. Safety management systems collect and visualise performance indicators. Large construction companies also invested in the information sharing system and individuals are required to share case studies monthly. Case studies are categorised in a number of ways such as project types and impacts. Drones are used for site inspection that saves time and cost as well. Yet, the level of engagement on both leadership side and operations side was reported as insufficient to bring about step change in performance. Some digital technologies pose problems as intrusive interventions. They can be perceived, indeed used, as monitoring devices by management that are unwelcome by operatives and indeed lead to pressures to intensify work rates that induce stress and fatigue, hence also exacerbate OHS. This type of action erodes trust and feeds perceptions of suspicion as to the motivations of management. Also, there is resistance to logging OHS issues. Apart from the trust issues and blame cultures as mentioned before, this can be due to other reasons, such as insufficient cost being built into bid prices to afford the time, awareness that the information will not be analysed and acted on in some cases, nor fed into and effective knowledge management system for re-use.

Deference to expertise and commitment to resilience

The last two principles, deference to expertise and commitment to resilience, lays the foundation to the effective implementation of digital technologies for OHS improvement. Despite that most OHS-related technologies are used by frontline workers, or at least need their inputs, the decision making about which digital tools to be adopted is largely top down from the senior management. This leads to that some technologies were perceived by operatives as not useful or intrusive and thus not consistently used. One reason for the reluctance of engaging and empowering the workforce is the perceived low competence among frontline workers. It was argued that to improve the effectiveness of digitalisation needs investment in people to raise their competence and responsibility of employing digital technologies to improve OHS. Yet individual responsibility alone is insufficient to induce transformation. Another integral part is the investment in organisational capability development and systems design to support learning, knowledge management and also relationship and trust, aligning to the long-term strategy of the organisation.

DISCUSSION AND CONCLUSION

The aim of the study has been to examine the process and outcome of digitalisation for construction OHS, from the perspective of HRO. The five principles of HRO theories (Weick & Sutcliffe, 2015), which are preoccupation with failure, reluctance to simplify interpretations, sensitive to operations, commitment to resilience and deference to expertise, were applied in the analysis. It has been found that digital technologies offer a major opportunity to improve and potentially transform OHS in construction. Yet the current way of adopting and implementing digital technologies falls short to realise long-term benefits for OHS and high reliability performance in projects and business. The findings point to two complementary approaches to achieve reliable performance. The first is to improve systems design to facilitate the creation and recreation of routines and procedures. Preoccupation with failures, reluctance to simplify interpretations and sensitive to operations contribute to actively anticipating and identifying weak signals of failures and then intervening through a set of procedures (Olde Scholtenhuis & Dorée, 2014). In this vein, reliability depends on the development of processes, procedures and routines. Nevertheless, adherence to rules and procedures alone will not lead to continuous improvement. Reliability is the outcome of a continuous management of fluctuations in human interactions (Sutcliffe, 2011). The underlying assumptions need to be challenged and routines recreated as gaps between written rules and practices are continuously

monitored, understood and shared between individuals, teams and organisations. This process requires good knowledge management to support learning and knowledge transfer at firm-project interface and across projects. It also requires good relationship management to nurture trust, respectful interactions and the awareness of how one's own actions fit into the larger system and with other people's jobs. Knowledge and relationship management systems contribute to the relational and social infrastructure of a mindful organisation. The adoption of digital technologies needs to invoke the rethinking through how the existing business needs to be re-engineered to optimise the implementation. It is based on the solid relational and social infrastructure that interrelations and integration between different forms of information and software can be explored and established. In other words, the soft and hard systems should be better integrated to enhance reliability. The second approach is to engage and empower the workforce in OHS management supported by the knowledge and relationship management systems. Working at the frontline can give operatives a clearer view of what are standard practices that are detrimental to safety, for example long shifts and working unsocial hours on site that induce fatigue and stress, which can pose broader challenges to current practices. Having such information needs an approach that encourages actors to mine and understand the data, before it can be usefully acted upon. In addition, different perspectives need to be embraced in decision making to avoid simplifying interpretations. This is supported by behavioural norms of respect, openness and trust, hence nurturing psychological safety to speak up about issues of concern, share one's own perspectives and ask other questions about their perspectives. Adaption and improvision rely on individuals who have the competence to understand and employ the technologies for the benefits of their own OHS. Lastly, to achieve HRO requires the digitalisation process generating collective mindfulness and a sense of caring rather than socially intruding among office and site workers.

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