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BARRIERS TO DIGITALISATION OF CONSTRUCTION HEALTH, SAFETY, AND WELL-BEING REGULATIONS ENFORCEMENT AND COMPLIANCE CHECKING

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Abstract

To improve health, safety, and well-being (HSW) in construction, enforcement and compliance with regulations are fundamental. While the attention to digital technology in the industry is gradually improving, practitioners have been using digital aids in form of wearable and connected devices (e.g., tablet computer linked to web-based software platform dedicated to safety management) for checking and auditing construction site safety performance, research into the area in terms of human-assisted compliance and enforcement of HSW regulations in the design and planning phase remains low. Using the systemic literature review methodology, the barriers to implementing such digital technologies in the enforcement and compliance with HSW regulations have been examined. The findings indicate that research into this area is still in the embryonic stage. However, the main barriers to compliance checking include typical technological factors (including its readiness and reliable use on construction sites), people (e.g., their acceptance, phobia for digital technology, and scepticism), organisational (e.g., exceeding or meeting contractual obligations), economical (e.g., the high investment both in the purchase and maintenance of the digitalization effort), and lack of relevant skills and knowledge. Further, regulatory authorities still struggle with integrating digital technologies into the existing enforcement approaches, and the nature of HSW data and types of risks are also barriers to them. This study is a desktop review hence empirical validation is required.

Keywords: Building and Engineering, Digital compliance, Health and safety regulations, Successful innovation, Regulatory compliance

1 BACKGROUND AND RATIONALE

While the health, safety and wellbeing (HSW) record of the construction industry is poor [1], attention to it is increasing, resulting in some improvement. While the extent of improvement is arguably disproportionate to the level of risks in the industry and its performance when compared to other industries, law and regulations, standards, activities, equipment and tools including the digital ones require more attention for optimum results. While there are many ways of improving HSW, two of them are adoption of digital technologies [2-5] and compliance with HSW regulations and standards [6]. There are two levels of enforcement and compliance with HSW regulations and standards.

The first level, HSW standards, statutory regulations, and guidelines are enforced by a national, regional, or industry regulator (an external actor) [7]. Commonly, the regulated (for example, construction contractors) can play a row in its development and enforcement (ibid). However, the enforcement of HSW regulations can be time-consuming, resource-intensive (capital and human), and in some countries - such as the developing ones - the dysfunctional legal systems mean that the regulator is unable to prosecute the regulated for any breach of legislation [8]. Additionally, some of these regulations do not keep up with technological innovations [9]. Barriers to the enforcement of HSW regulations are covered in detail in Umeokafor et al. [8].

Nevertheless, technological innovations, such as the application of big data analytics and associated technologies to HSW enforcement activities can contribute to addressing some of these challenges [10]. For example, HSW inspectors adopt a risk-based approach. Zhu [11] reports how the Norwegian Labour Inspection Authority has adopted big data and machine learning technologies for it. They developed and tested the Risk Group Prediction Tool (RGPT) which identified the risk levels of organisations, enabling them to focus their resources where required. This is beneficial to inspectorates with limited resources available for regulatory activities. Further, a study on the historical data on fire and buildings in Suzhou, China, has been analysed using neural networks and data machine learning algorithms, enabling the Suzhou fire brigade to establish fire risk prediction systems that increased the efficiency of fire prevention by six to eight times [10].

In contrast, digital technology applications by HSW regulators or in activities are still in the infancy stage, hence require further development and testing. Despite the plethora of research into the enforcement of HSW regulations in construction, there are still knowledge gaps in the literature in terms of digitalising it. This search by the authors shows that no studies focus on the barriers to digitalising HSW regulations enforcement from the regulators' perspectives.

The second level is the internal compliance/safety rule checking/HSW monitoring where organisations ensure their workers comply with regulations/policies/standards. These include in-house policies and standards or those adopted externally to meet the HSW guidelines and statutory regulations set at the first level above. Site inspection is one of the tools for this where safety officers/site managers/ fore persons walk around the site to detect unsafe working conditions and behaviours towards complying with HSW regulations [5, 12]. However, the effectiveness of this is limited, especially where there are many workers [12]. Traditional methods of performing safety checks including inspections often require labour-intensive manual input, which can be prone to errors and puts workers at further risk if hazard identification fails [12, 13]. This may happen, for example, to engineers in the project design or planning phase, who have limited or inadequate safety knowledge (aka. part of professional negligence). Further, conventional techniques, although carried out with high empathy can be time-consuming thus costly [5]. The ability of tools available to users in the field to predict the future, irrespective of the level of data that is available is also limited [3].

One of the solutions to the challenges is the implementation of digital technologies [2, 13]. For example, private block chain technologies can be adopted for HSW regulations, standards, and practice compliance and for audit when third parties such as insurance companies are involved [2]. Further, according to Khan et al. [14] there are two primary technologies for monitoring unsafe behaviours on construction sites, computer-vision, and sensor-based monitoring. For example, for sensor technologies, wearable technologies for monitoring compliance with HSW regulations and standards, resulting in real-time and valuable data is also possible [2]. In terms of computer vision-based monitoring systems, CCTVs (closed-circuit television) capture hazards including the persons involved, and machine learning or neural networks analyse the data captured [4, 15]. Furthermore, BIM-based automated safety checking also occurs. 'Rule-based Code Checking’ validates the design phase by comparing Building Information Models against current codes and regulations translated into parametric rules' [16]. Also, Zhang et al. [5] report BIM-based automated safety where there is an automatic safety inspection which is reported to the safety or site manager demonstrating possible hazardous scenarios, the rationale, where and when that may occur, and the possible solutions. In this system, BIM models and projects' real-time progress information are combined with existing H&S regulations, guidelines, and best practices, and any activities that contravene the limits of the latter are automatically identified and relevant workable solutions are provided [5].

Despite the plethora of studies on digital technology for compliance checking (for example, [5, 12, 17, 18]), there are still limitations. For example, following a review of, at least 37 papers, Barata and da Cunha [2] found no studies that focus on integrating 'important sources of data for compliance (for example wearable and sensors technologies, augmented reality, internet-of-things), as it happens in audits required by OHSAS 18001 safety standards and legal regulations (p. 527). According to them, the extant studies mainly address the application of digital technologies to accident prevention and the reduction of its consequence, safety training, and fall hazard detection. Further, there are limited studies on the interaction between humans and technologies on compliance applications, and environmental conditions in construction health and safety (ibid). Few studies, e.g. Awolusi et al. [17], have covered this sparsely. Our review shows that no study focuses on identifying the barriers to digital technologies for safety compliance checking in a high level of detail.

Given the background established so far, the overarching aim of the current study is to investigate the barriers to the digitalisation of construction HSW regulations and standards enforcement and compliance checking. Hence, the following questions are set to guide the study:

What are the barriers in constriction to implementing digital technologies in the HSW:

(1) compliance checking?
(2) enforcement of regulations and standards from an external regulators' perspective?

A rather broad definition of ‘digital technology’ is adopted, in other words, the reviews’ focus is intentionally not a specific one.

2 METHODOLOGY

The barriers to implementing digital technologies in the enforcement and compliance with SHW regulations/standards were examined. A hybrid approach for the literature review, consisting of both a systemic literature review (SLR) methodology and the citation approach, was adopted in the study. The Scopus database was searched in March 2023, covering the year 2000 to 2023 with relevant keywords such as digital compliance, digital compliance checking, and health and safety. Figure 1 presents the overall six-stage research process including the systematic search while Table 1 details the second stage, identification, including keywords used. After the question was framed (Stage 1), the relevant literature was identified through a systematic search for the appearance of the keywords in Table 1 on the documents' titles, keywords, and abstract (TITLE-ABS-KEY) (Stage 2). In Stage 3, the abstract and title were read for relevance before the analysis and extraction of data in Stage 4. The findings were interpreted (Stage 5) and reported (Stage 6).

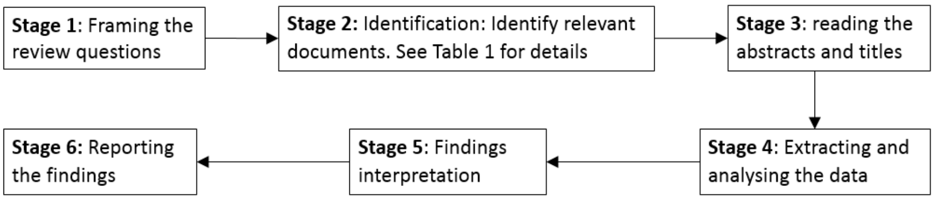

Figure 1: Overall research process

Table 1: Details of the identification section of Figure 1

Date of search	Keywords, Publication year, and location of search on documents	No of docs before limits	Limits: Sources type; Sources type; Language	No of docs after limits
21 March 2023	(TITLE-ABS-KEY *(technology)* AND TITLE-ABS-KEY (*enforcement*) OR TITLE-ABS-KEY (*compliance*) AND TITLE-ABS-KEY (*health* AND *safety*) OR TITLE-ABS-KEY (*wellbeing*) AND TITLE-ABS-KEY (*regulations*) AND TITLE-ABS-KEY (*construction*) OR TITLE-ABS-KEY (*digital* AND *technology*) OR TITLE-ABS-KEY (*digitalisation*)) AND PUBYEAR > *1999* AND PUBYEAR > *1999*	24	Sources type: Conference proceedings, Journal, Trade Journal, book series, book Document type: Conference papers, reviews, articles, book chapter, conference reviews, and short survey Subject areas: Business, Management and Accounting; Computer Science; Energy; Engineering; Environmental Sciences and Decision Sciences Language: English	18
22 March 2023	(TITLE-ABS-KEY (*technology*) AND TITLE-ABS-KEY (*enforcement*) OR TITLE-ABS-KEY (*compliance*) AND TITLE-ABS-KEY (*health* AND *safety*) OR TITLE-ABS-KEY (*wellbeing*) AND TITLE-ABS-KEY (*regulations*) AND TITLE-ABS-KEY (*construction*) OR TITLE-ABS-KEY (*digital* AND *technology*) OR TITLE-ABS-KEY (*digitalisation*)) AND PUBYEAR > *1999* AND PUBYEAR > *1999*	209	Subject areas: Business, Management and Accounting; Computer Science; Energy; Social Science; Engineering; Environmental Sciences; Sources type: Conference proceedings, Journal, book series, book Language: English	24
23 March 2023	(TITLE-ABS-KEY (*emerging* AND *technology*) AND TITLE-ABS-KEY (*enforcement*) OR TITLE-ABS-KEY (*compliance*) AND TITLE-ABS-KEY (*health* AND *safety*) OR TITLE-ABS-KEY (*wellbeing*) AND TITLE-ABS-KEY (*regulations*) AND TITLE-ABS-KEY (*construction*) OR TITLE-ABS-KEY (*emerging* AND *technologies*)) AND PUBYEAR > *1999* AND PUBYEAR > *1999*	20	Subject areas: Computer Science; Energy; Social Science; Engineering Sources type: Conference proceedings, Journal, book series, book Language: English	7
Total		253		49

Table 1, following the keyword search where 253 documents were found, 49 documents were screened for relevance by reading the title and abstract after which 10 (five from the first and second searches each, zero from the third one) were used for the analysis. This was complemented with 20 in the citation approach where the references of materials, e.g. books and journal articles, are searched towards finding relevant materials that can be used [19]. A total of 30 documents were used for the analysis. Umeokafor [1] and Umeokafor and Okoro [19] adopted this approach in the review of literature. The qualitative content analysis was conducted aided by a synthesis matrix [20] which commenced by exploring the preconceptions and experiences of the lead author based on the broad parent themes. The matrix was later expanded by the new ideas from the content analysis.

3 FINDINGS, ANALYSIS AND DISCUSSION

3.1 Description of documents

The 10 documents found in the systematic search consist of 2 journal and 7 conference papers and one book series. Of the 20 analysed from the citation approach, 17 were journal papers, one conference proceeding output, and two reports. Using 30 studies for analysis in a literature review methodology can afford opportunities for reliable findings and conclusions. For example, studies such as Swallow and Zulu [21] have used less 18 for their review and Umeokafor and Okoro [19] is based on 7.

3.2 Barriers to digital technologies implementation in safety, health and well-being compliance checking

The study found 7 themes and 18 subthemes under which the barriers can be categorised, and the summary is presented in Table 2. The themes and selected subthemes are presented and discussed below. There are inter and intra-theme connections between the factors.

3.2.1 Value and cost

This theme consists of three sub-themes, high cost, the perceived value of digital technologies, and the limited understanding of the cost-benefit of the relevant digital technologies (Table 2). The high investment associated with digital technologies for HSW monitoring is covered in studies [4, 9, 14, 22]. For example, Seo et al [23] report the large capital investment for acquiring and maintaining unmanned aircraft systems (UAS). Similarly, installing CCTV cameras on construction sites can be expensive to cover the wide, constantly changing and frequently obstructed work environments [24]. However, when wearable technologies are used, the investment and maintenance of technology can be lower compared to the vision-based ones [17]. Yet, computing is still required to analyse the raw data and generate meaning from HSW information for decision making. The implication of this includes that those small and medium-sized enterprise (SME) contractors who are financially disadvantaged lag behind, and the application is skewed to larger projects. This is consistent with the findings of Andriescu et al. [9] and Gheisari and Esmaeili [22] in the sub-theme titled internal organisational challenges.

In terms of the value of digital technology for HSW compliance, organisations may not find the adoption of the relevant technologies useful for compliance efficiency. Hence, they find little value in taking them on and are sceptical to invest in it (Table 2). For example, Barata and da Cunha [2] found that some companies view that while the current technologies are not ready yet for compliance checking and improvement, they enable the monitoring and alerting of hazards. In one of the interviews, a respondent stated, “sometimes the problem is not in the existence of solutions for OHS; it is in convincing the users of the need to use it, daily”. One of the HSW experts also stated that “we can monitor all the parameters in the world but for regulatory compliance, it is also crucial to proving that the data is reliable and not easily manipulated. It is essential to demonstrate our commitment to safety when dealing with insurance companies and assessors” [2].

3.2.2 Legislation and standards

As noted in Table 2, this study found inadequate standards as a barrier [2, 9, 16]. For example, writing about the lack of certification for standards, Andriescu et al. [9] report how, despite the efforts by the European Committee for Standardisation (CEN-CENELEC), they found smart Personal Protective Equipment (PPE) without certification standards. Further, the reports states that there should be a balance in the certification of standards for OSH monitoring to avoid significant cost increases (ibid). Likewise, inadequate HSW standard issues are consistent with non-technological barriers to H&S in [8]. Another reason is seen when organisations face interoperability challenges. While this belongs in the technological factor theme, the high number of different manufacturers of the technologies results in disconnected solutions rather than following a standard that allows easy integration among the existing systems [9]. The authors also report how the European Union (EU) legislation so far failed in addressing the constant changes in technology for HSW compliance checking. HSW legislation being outdated is consistent with the findings of Umeokafor at al. [8]. However, this challenge might be explained by the fast changing pace of technological advancement which makes it difficult to consolidate isolated efforts. Also, market reach or domination can influence technology adoption, as recently seen in an EU mandate, which requires that all mobile phones must be equipped with a USB Type-C charging port by end of 2024.

3.2.3 Characteristics of construction industry and process

The complex construction environment (Table 2), unlike manufacturing where the product and process may not change as frequently, is unique, the supply chain is fragmented, and the outputs/product and the work environment in which they are constructed are seldom the same. The findings of this study show that they have negative implications for the adoption of digital technologies for compliance checking in HSW (Table 2).

Table 2: Barriers of digital technologies implementation in SHW compliance checking

Theme	Subtheme	Supporting evidence
Value and cost	Cost Value Cost benefit	• High cost of design and adoption of digital technologies [9, 14, 22-25]. • Usefulness: ability of technology, for example, the smart ones to be fit for purpose [2] • A limited understanding of the cost benefit of using technology in OSH compliance [2, 25] • Lack of information for conduction cost benefit analysis of adopting digital technology for H&S monitoring [9]
Legislation and standards	Regulatory limitations	• Limited regulation, for example, on safety distance of UAV to crew, machinery and building during operation [22] • Local regulation limits UAV usage at night [22] • No dynamic legislation – fail to keep up with technological changes [9]
	Inadequate standards	• lack of manufacturing practice/standards or poor quality of technologies [2] • Lack of certification standards [9] • Lack of minimum level of requirements and mandatory informative content [16] • Complex standardisation of smart PPE [9] • Testing and certification by external bodies is complex and lengthy [9]
Charateristics of construction industry and process	Complex construction environment	• Dynamic nature of construction [5, 14, 22] • Non-digitalised construction sites [16] • Complexity and unpredictability of workers movement on sites [14, 15, 23]
	Weather and noise	• Weather challenges e.g. UASs are susceptible to wind [22] • High level of noise [12,15]
	Internal organisational challenges	• Size of organization e.g. SMEs [9] • Complexities in integration of technology [9] • Size of project [22]
People	Collaboration	• Lack of collaboration between H&S coordinators & building designers [16] • Project organization and roles [16] • Exceeding or meeting contractual obligations
	Resistance	• Lack of reliability and acceptability [9] • Dependence on manual methods of monitoring [14] • Oppositions from trade unions against H&S monitoring using technology [9]
Skills, competence, and knowledge	Limited skills competence &experience	• Lack of competence and experience in digital technology for H&S [13,18] • Limited skills and knowledge of usage [22] • Extensive training requirement [22]
	Lack of info. & awareness	• Limited awareness of digital technological in health & safety [26]. • Lack of information on effectiveness of digital technology in compliance checking [9]
	Poor market knowledge	• Poor understanding of market demand for technology [27] • End-user needs not informing the design and development of technology [9]
Technological factors	Technological requirements Inefficient technologies e.g limited algorithm	• Limitations in translating H&S regulations, guidelines, and best practices (normative text) into parametric rule-set which are computable parameters [16] • Errors in outputs as the algorithm and/or types of cameras or other technologies result in inaccuracy [15, 28] • Inaccurate or poor detection [4, 12, 15, 27] • Aspects of technology processes are not automated [5] • High false alarm rate from vision-based ones [14] • Prone to occlusion [14, 28, 29] • Interoperability challenges [9]
	Quality of technology	• Limited durability of sensors [2] • Battery life issues, e.g., from sensor-based ones [4] • Safety concern from usage, e.g., piloting [22] • Heavy monitoring equipment [24]
Liability and legal concerns and damages	Data management	• High data drift with the sensor-based ones [4] • Ethics, data protection, security and privacy [9, 17, 22] • Complex data processing and transmission [17] • Lack of comprehensive dataset [29]
	Personal privacy	• Personal information privacy issues [2, 29, 30-32]

For example, according to Zhang at al. [5], the risk dynamics and real-time representation of unsafe conditions on construction sites may be limited and challenging because of the constantly changing construction environment. Khan et al. [14] and Gheisari and Esmaeili [22] are in support. Further, the study also found that complexity and unpredictability of workers movement on sites is a major barrier [14, 15, 29]. For example, in Anjum et al. [15], see evidence that digital technologies such as vision sensors (cameras) using deep learning to assess the work at height activities for compliance with HSW regulations on site present a risk of less accurate information on unsafe worker behaviours because of the complexity and unpredictability of their movements on site.

Equally important are the internal organisational challenges. Implementing digital technologies can be costly, requiring a higher level of skills to which the larger organisations have more access than the smaller ones. The current study found that some peculiar challenges encountered by small and medium enterprises unlike the larger ones e.g. limited funds and information is a limitation to HSW standards, regulations, and best practices compliance checking [9]. Further, Andriescu et al. [9] demonstrate that employers may be willing to integrate digital technology in HSW compliance due to the associated complexities from the cost, duration of implementation, and non-bespoke solutions or organisational needs. The point here is that every organisation would have an existing HSW management system/procedure, but integrating the digital technology into the system, for example, site inspection systems may be challenging incompatible with some of the activities/procedures of other technologies in use. The technology must be designed and implemented in line. Gheisari et al. [22] also observe that UAS are mainly applied to large and tall projects, putting the smaller ones at disadvantage.

The findings in this theme are consistent with extant studies. For example, Koeleman et al. [30] demonstrate that the characteristics of the construction industry e.g., its fragmented supply chain; the lack of repetitions, e.g., uniqueness of projects; and transience, e.g. inconsistent project teams and constant personnel changes, is the main reason why the construction industry is stuck in the analogue era. Further, Boadu et al. [33] support this argument and offer insight into the negative influence of construction industry (using Ghana as a case study) on health and safety management developing countries, enabling some comparison with the developed ones. According to their findings [33], while the regulatory complexities (for example, the lack of single regulatory authority for HSW in the industry), labour-intensive construction methods, and lack of skilled and educated workforce are the highest-ranking characteristics, the colonial influence and the fragmented practices in the industry are the lowest. Furthermore, the finding of a positive correlation between lack of single regulatory authority and colonial influence (($r = 0.427$, $p \leq 0.01$), means that as one of these increases, the other decreases and vice versa. By implication, there is evidence (based on the view of the respondents) of the colonial influence and absence of a single regulatory authority on health and safety performance of the industry. While some other developed countries experience similar colonial influence, it is unclear the extent to which this applied to HSW compliance checking with digital technology. However, in developed countries such as Nigeria and Ghana, there is an overreliance on colonial influence. Umeokafor [7], Umeokafor et al. [8] and Boadu et al. [33] report how most of the current HSW regulations and standards are adopted from the British ones. Most times, there is little consideration of the intended context of operation hence in most cases, they are not fit for the purpose [7, 8].

In terms of no single regulatory authority, this means that there are distributed occupational safety and health (DOSH) as opposed to the consolidated occupational safety and health (COSH) in developed countries such as Britain [34, 35]. This makes the integration of digital technologies more challenging because of differences in interest and value, skills level, the scope of operations and availability of funds [35]. Umeokafor [35] offer a treatise on the differences between HSW regulatory frameworks of developed and developing countries and why many adopted or transposed regulations or standards from developed countries do not work in developing ones like Nigeria.

3.2.4 People

This theme is made up of two sub-themes, collaboration, and resistance (Table 2). The construction industry has been resistant to technological changes; hence, it is not surprising that there is limited acceptance of HSW compliance technologies in construction as found in our study (Table 2). Equally important is the impact of changes in HSW management systems on the employees and other stakeholders which results in external resistance. Evidence of external resistance was found in the study. For example, in Andriescu et al. [9], trade unions have expressed concerns about the digitalisation of HSW enforcement and compliance checking because the technology-based HSW monitoring systems may result in productivity pressures for workers which will have negative implications for mental health and wellbeing. This finding is consistent with studies such as Watterson [36] where influence of external pressure in the regulation of HSW is well documented. Admitted that there are possible negative mental health and wellbeing implications due to digital technological advancement in HSW regulation enforcement and compliance checking, this is consistent when other changes in organisations. Consequently, should be factored into the risk management of organisational change. It should stimulate innovative ways of organisational change which consider building on external and internal resistance to advance a collaborative environment for HSW management including compliance checking.

3.2.5 Skills, competence and knowledge

Three subthemes are here, limited skills, competence and experience, lack of awareness and information and the poor market knowledge (Table 2). Table 2 shows that poor knowledge of the market, lack of awareness and information, and limited competence and experience were also barriers. For example, [27] found that there is a limited understanding of market demand for digital technologies used in HSW. This is supported by [9] who found that designing and developing digital technologies without understanding the needs of the end-user results in a lack of acceptability. This is consistent with the findings of Boadu et al. [33] in 3.2.3 where the lack of skills and an educated workforce impacts health and safety performance. Our findings show that digital technologies in HSW regulation enforcement and compliance checking are no exception.

In terms of lack of awareness and information, the construction industry is known for its resistance to the adoption and implementation of digital technologies; HSW compliance checking is no exception. The current research found that one of the explanations is the lack of research on the effectiveness of the systems hence adoption is demotivated, according to the findings of extant studies such as Umeokafor et al. [9]. However, the dearth in HSW (including compliance) research is worse in developing countries when compared to the developed one. This also results in the inability to conduct a cost-benefit analysis to justify adoption. This has more negative implications for SMEs than the large contractors (ibid), especially those in developing countries, like Nigeria. All these are possible explanations for the worse compliance with HSW regulations records in developing countries.

3.2.6 Technological factors

Despite the potential of digital technologies to improve HSW, the study found that barriers resulting from them are made up of three subthemes, technological requirements, quality of technology, and inefficient technologies. For inefficient technologies, while the technologies may be effective, evidence shows limitations and inefficiency. The findings of Anjum et al. [15] show that algorithms can be limited, for example, when 2D images from 2D CCTV are used, they identify the workers standing beside ladders as working on them rather than only those working on them. However, stereo-vision cameras can address this. Khan et al. [4] support this finding, reporting the inability of the technology in their study to detect unsafe behaviour, perhaps because of a limited dataset and captured angle of the 2D images. Similar inaccuracy is reported by Ding et al. [28] who also found very long durations of computation, occlusion, and high levels of illumination impact the learning capacity and ability of the technologies to be used in real-life settings. In Habbal et al. [27] inaccurate detections are also found where, for example, there is only 56 percent of shoe or feet detection. Missed or inappropriate detection of hats, e.g., those on the floor not worn by anyone is also found in [12]. Another barrier is that the normative texts of regulations/guidelines/standards/best practices are not translated into a parametric rule set to enable the software to interpret them [16]. The quality of the process of doing this for compliance-checking purposes using digital technologies may be limited and costly (ibid).

3.2.7 Liability and legal concerns and damages

Made up of the two subthemes, data management and personal privacy, the barriers cover the negative implications of data breach or loss. In terms of personal privacy, according to Barata [2] one of the ways that this is a concern is through the level of data that the technologies obtain. For example, wireless and wearable technologies for PPE compliance monitor the performance, heart rate, and even the number of steps of the workers. The personal information here is at a high risk of being breached by fellow employees especially, when medical-related.

Another barrier is ethics, data protection, security, and privacy (Table 2). For example, wearable devices present a high-security threat such as malicious attacks resulting in data theft or corruption [17]. While legislation or trade unions can protect workers, e.g. in Europe [9], this case may not be the same in many developing countries as even when there are legal provisions, the enforcement and ability to protect the workers may be limited. Consequently, Awolusi et al. [17] argue for strong security measures such as proprietary algorithms and secure authentication to protect the data and intellectual property. However, underpinning this with statute in developing countries where regulatory regimes including the instruments are limited may be challenging and take a long time. Even when in place, enforcement is likely to be an issue given the poor legal system in countries like Nigeria with length court cases [7,8].

3.3 Challenges and barriers to implementing digital technologies in the enforcement of construction HSW regulations and standards from the external regulators perspective

The five main barriers found are: multiple types of risk; nature of data analytics; cost; skills, knowledge and experience; and data privacy and security.

3.3.1 Multiple types of risk

While regulators may have more than one Machine Learning (ML) tool, European Agency for Safety and Health at Work [11] found that their dimensions of targeting risks may not match the multiple facets of risks. There are different types of risks so for regulators to develop risk models to capture the varieties is challenging. When possible, it is at a higher cost. Further, when there are political risks and a risk-based approach to enforcement is used, ML algorithms are unable to consider political views [11], a core aspect of this regulatory approach [7].

3.3.2 Nature of data analytics

From the big data perspective, the types of HSW data can be a limitation here [37]. HSW regulators (inspectorates) usually analyse inspection objective data from construction sites and companies. However, they may not be automatically identifiable with unique identifiers as machine learning algorithms depend on unique identifiers to assign predictive values to companies [11]. By implication, this is a prerequisite for application on construction sites but when unavailable using the technology is impossible.

3.3.3 Cost, skills knowledge and experience, and data privacy and security

The high-cost requirement of digital technologies that regulators can use, for example, big data and analytics are covered in literature, by Bilal et al. [38] and Madanayake and Egbu [39] where it is the highest barrier to implementing this technology. This can be a barrier to HSW regulators, especially as the technology is still in its embryonic stage. In many countries, they are constrained by finance [8]. For skills knowledge and experience, and data privacy and security, the same challenges in Table 2 that organisations encounter in compliance checking apply here. The only difference is that regulators may have access to money to tackle the challenges. While some of the challenges and barriers in this Section (3.3) are not unique to HWS regulators, some are. Addressing them is fundamental to integrating digital technologies into the enforcement of construction HSW regulations and standards in multiple project phases, and among other applications, Prevention through Design and Planning (PtD/P) [40-42], proactive safety [43-44], and personalized learning and feedback [45-46]. One consistent implication of the findings in this section is the need for regulators to drive change. Although industry leaders advance their practices regardless, if overlooked, the general industry may not follow swiftly. This happens to be, however, the industry sector that contributes most to the devastating numbers of accidents in the construction industry.

4 CONCLUSIONS

In this study, the barriers to implementing digital technologies in the enforcement and compliance with SHW regulations have been examined using the literature review methodology. The study found that the barriers to HSW compliance checking which aims to meet regulatory requirements can be categorised under 18 subthemes in 7 themes, including technological (e.g., its readiness and reliable use on construction sites), people (e.g., their acceptance, phobia for digital technology, and scepticism), and lack of relevant skills and knowledge. In terms of digital technologies in the enforcement of construction HSW regulations and standards from the external regulators' perspective, while the HSW (or labour) inspectorates also encounter economic, skills, and knowledge shortage barriers, like the regulated, the multiple nature of risks and nature of data analytics are also main barriers.

Digital technology adoption in construction is gradually improving. Its ability to improve the activities of the industry and associated productivity levels is without question. However, it has become evident in the current study that its efficiency in addressing the needs and challenges of HSW regulation enforcement and compliance checking is still a long way away. Hence, this mission continues to encounter challenges that threaten the foundations of HSW improvement, especially in developing countries where the regulatory regime and characteristics of the industry face unique challenges. While overall, the identified barriers seem familiar for any technology adoption in the construction industry, the strategic position of regulation and compliance in HSW make it fundamental to HSW improvement with implications for the performance of the industry. Consequently, practitioners in the role of end user, researchers and developers who initiate or create technology may wish to set a specific focus and clarity in what technologies will aid or transform the state of the practice. As the findings of the study are subject to empirical validation, further study is recommended.

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