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Challenges and Opportunities for Automating Physical Compliance on Construction Sites

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Challenges and opportunities for automating physical compliance on construction sites

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Abstract—The construction project lifecycle includes several compliance requirements that need to be checked at multiple levels and at different phases of the project. Inability to comply with these regulations due to lack of time and resources or human oversight can affect the project throughout its service lifecycle with the potential for severe outcomes. Following a number of high-profile failings and owing to the high stakes nature of compliance, digitalisation has been introduced in this field of construction over the past few decades to reduce mistakes and neglect. Although the compliance checking process in the design phase has seen significant digital advancement with artificial intelligence, machine learning and natural language processing, the physical compliance checking process on construction sites still remains largely manual.

This paper will present academic research on the industry challenges faced in automating site compliance checking process based on literature studies done in the past. The study highlights the need to address the different challenges and barriers of physical compliance from a more structured construct. The opportunities for process improvement, behavioural change, and technological intervention to improve or in some cases replace manual oversight were also explored. A thematic analysis was performed on the qualitative data of barriers to chronicle the list of challenges that need to be addressed. Findings from this study will help highlight the pressure points faced while conducting compliance checks at sites. This research aims to reduce the knowledge gap between the ailment of checking compliance on construction sites and the tools that can help fix the issue.

Keywords—compliance, construction inspection, automation, digitalisation

I INTRODUCTION

The construction project lifecycle includes several compliance requirements that need to be checked at multiple levels and at different phases of the project. Depending on the phase of the project, these compliance matters can be design based, related to the implementation of an agreed design (i.e., building control, fire regulations, energy performance etc), or the functional requirements of the constructed process (i.e., safety laws, environmental regulations, quality of works).

In the construction phase, a project must adhere to extensive regulations encompassing various aspects of the building process, including insurance, building codes, worker agreements, union requirements, safety codes, and more [1]. Despite the presence of such comprehensive regulatory frameworks, achieving construction compliance has proven to be challenging. Ensuring compliance from all stakeholders with the multitude of regulations is a formidable task.

Non-compliance in construction has significant consequences, leading to increased project costs and posing substantial risks to life and property. Poor quality is observed in more than 80% of building projects, resulting in up to a 50% increase in building costs and potential project delays of the same magnitude [2]. [3] noted that the manual nature of construction compliance processes contributes to inefficiencies, leading to cost overruns in 66% of construction projects and schedule delays in 53% of projects. It has been estimated that effective quality management could save the UK construction industry up to £12 billion annually [4]. In the United States, the cost of rework due to construction deficiencies is estimated to range from 6% to 12% of the total construction cost [5].

Construction compliance presents a complex challenge with multiple variables. Although the onus is on the contractor to provide compliance, there is an urgent need to explore strategies for inspection and adherence to regulations. The paper addresses the challenges of construction compliance by

undertaking a literature review on the compliance failures and breaks it down into three categories or parameters – process, behaviour and technology. The study tries to answer the question 'Can the integration of digitalization, behavioural changes, and process improvement offer a viable solution to address non-compliance issues in the construction industry? It focuses on the role of each category in attributing to compliance failure and relies on literature to suggest ways to improve them. Further, the paper describes the barriers to effective compliance obtained in the literature review through the lens of the three parameters. Finally, the paper presents a holistic approach to effective compliance by improving each of the three parameters.

II Methodology

To understand the challenges to construction compliances, it is important to look at the literature studies done in the past. [6] identified design-related activities as influential factors contributing to poor quality. Independent Working Group to Examine Defects in Housing, Ireland [7] reported in 2021 that between 1991 and 2013, 50% - 80% of the apartments and duplexes constructed in Ireland may be affected by one or more defects (fire safety, structural safety, or water ingress defect). Further, according to [8], 40% of quality failures occur during the construction stage.

Compliance is a multivariate problem. Effective compliance is dependent on multiple factors which needs to work in harmony to achieve maximum compliance. From an initial survey of journal papers written about construction compliance, it was noted that compliance challenges can be broken down into three primary categories – process, behaviour, and technology. To do a literature review, each individual parameter was searched separately to find the best results. The keywords, 'automation', 'artificial intelligence', 'robotic', 'sensors' were used along with 'construction compliance' to select papers for the technology aspect. It was noted that using 'automated construction compliance' as a single keyword returned papers for automated design code checking which fell out of the purview of this study and was rejected.

In the process category, to understand the current process of compliance checking of residential buildings in Ireland, the Building Control (Amendment) Regulations, Code of Practice and other associated reports and documents ([9], [10], [11]) were consulted. Finally, for behavioural aspect of compliance, 'compliance behaviour', 'worker behaviour' and 'behaviour practices at construction sites' keywords were used. This initial search produced limited papers with a majority of them involving case-studies in corrupt or unethical construction practices in specific markets. To broaden the scope of literature, compliance behaviour in different industries and as a sociological theme was searched. Papers addressing patterns and theories of compliance behaviour were shortlisted.

III Literature review

a) Compliance Failures & Challenges

The Grenfell Tower fire exposed significant shortcomings in regulatory oversight and responsibility. The official inquiries following the incident revealed a lack of clarity regarding accountability among various stakeholders involved, including the local government, building owners, contractors, and regulatory bodies. This lack of accountability hindered effective compliance monitoring and enforcement, allowing non-compliant practices to persist.

The tower underwent a major refurbishment between 2012 and 2016, during which several modifications were made to the structure. An inquiries committee that was set up found several inadequacies in the fire systems that were in place. The absence of a comprehensive sprinkler system and effective fire-resistant compartmentation exacerbated the intensity of the fire. Firefighters had trouble getting water since there was no "wet riser," a conduit filled with water that ran up the building to be utilized in the case of a fire, and the building's smoke extraction system was not functioning. Additionally, the building's fire safety assessments failed to adequately identify and address potential risks, such as the absence of a centralized smoke extraction system and a deficient evacuation plan. Dr. Lane, who testified during the inquiry, stated that the 2016 installation of exposed gas pipes was another contributing factor, and that none of the flat doors complied with current fire protection regulations [12].

Similarly, the Priory Hall scandal, which unfolded in 2011 in Dublin, Ireland, shed light on the severe consequences that can result from a lack of compliance with building regulations and safety standards [13]. The complex's evacuation, prompted by fire hazards and numerous building defects, highlighted the failures of self-regulation, as well as the absence of post-construction inspections and oversight. The complex exhibited multiple issues that jeopardized the safety and well-being of its residents. The flooding of the underground car park shortly after completion revealed poor construction quality and inadequate waterproofing measures. Plumbing problems and faulty fire safety systems further compromised the integrity of the building. Additionally, unauthorized room constructions without proper planning permissions highlighted a disregard for regulatory compliance [14].

During the Celtic Tiger era, self-regulation was prevalent in the Irish construction industry. During

Ireland's building boom between 1997 and 2007, a staggering 685,988 houses and apartments were constructed, according to ESB connections data. Troublingly, in October 2015, it was reported to the Dáil's Public Accounts Committee that 150 out of 300 vacant properties under the agency's control were identified as fire hazards, resulting in an expenditure of €100 million to rectify structural defects [15]. Furthermore, in 2021, the National Oversight and Audit Commission's Local Authority Performance Indicator Report revealed that 23 local authorities found over 90% of inspected dwellings to be non-compliant with the Standards' Regulations. Compliance regulations were often signed off during the planning and drawing stages, without thorough post-construction inspections [13]. Local authorities did not require an onsite representative for inspections, leading to oversight and a lack of accountability.

As per the Code of Practice for Inspecting and Certifying Buildings and Works, 2016 [10] local authorities are only required to carry out inspections for 12% to 15% of new buildings for which valid Commencement Notices have been received. Even recently, the National Oversight and Audit Commission's [16], shows that the inspection rate is abysmally low even with the effects of pandemic in mind. Although, the causes of compliance challenges seems varied, they can be sorted into three broad categories as described below.

b) Classifying Compliance Issues: A Categorical Analysis

Compliance Process

The process of compliance checking in the Republic of Ireland follows the Building Control (Amendment) Regulations 2014 (BCAR) [9]. The Code of Practice for Inspecting and Certifying Building and Works 2016 [10] provides a guidance manual to associated parties in order to comply with the BCAR. The process of compliance prior to BCAR was heavily self-regulatory. There would have been no checks done from local authorities or independent bodies to verify the viability of the building.

This self-regulatory approach, in general, creates several challenges. [17] highlighted the inconsistency among inspectors in interpreting compliance regulations to actual practice. [18] conducted a survey on identifying building defect where it was found that inspections by multiple inspectors lack consistency. This issue stems, not from an individual cognition bias, but rather from a broader perspective of process chain establishment.

After the implementation of BCAR [9], positive steps has been taken to upend the self-regulatory process with a more strict and independent compliance process. [10] provided guidance to tasks and functions that need to be carried out by each individual party. Further, necessary documents and checklists that need to be submitted to the local authority at each stage were clearly defined. This constitutes a pivotal stride towards attaining higher levels of compliance. However, it is necessary to engage in a meticulous deconstruction of construction compliance processes at the most foundational levels of construction activities, in order to realize enhanced degrees of regulatory conformance.

[19] stated that the compliance process and monitoring for construction is very weakly defined and understood by people implementing it at all levels. There is a clear lack of understanding in the tasks and sequence of activities that need to be carried out for compliance [3]. [20] noted that field inspection is subjected to uncertainty and inconsistency because the level of education and training of the inspector varies. The education and training of inspectors, site supervisors and labours need to be made uniform, systemic and comprehensively straightforward.

Furthermore, with proper systems in place, data collection and analysis through those systems depend highly on the inspector's experience and the fragmentation of data [21]. [11] stated that the regulatory regime of Ireland remains dispersed across multiple authorities and the liability of defects are heavily skewed towards the inspectors/certifiers. Conflict of interests among certifiers possess yet another problem in maximising compliance [22].

Compliance Behaviour

Compliance behaviour, specifically to construction, is a rarely reviewed research area. A significant number of studies dives into corrupt and unethical construction practices in specific regions or countries. Although human behaviour, is a culturally dependent concept, compliance behaviour can be interpreted in wider domains. To explore this area of study, certain studies from social sciences and psychology have been integrated in this review as listed below in Table 1.

Table 1: Papers reviewed to understand the behavioural aspect of construction compliance.

Author	Year	Key Findings	Implications for Construction Compliance
Olanrewaju & Lee [2]	2021	Most research about the poor quality of buildings are not conducted at the construction level but at design and handover level.	Competencies of the workers on the construction sites are very important determinants of the quality of the buildings.
Weaver [23]	2013	• Non-compliance is not only an incentivization problem. • The paper presents 'resource' and 'autonomy' as two other factors responsible for lack of compliance. • The rate of compliance depends on the perceived consequences of noncompliance and the importance of the issue to the general public. • Frequency of compliance checking has a positive relation to overall compliance. • Peer Effect - Compliance is likely to be higher when noncompliance is seen as socially unacceptable	• Compliance checking by independent investigators must be frequent for adhering to compliance. • Worker relations with their superior and colleagues plays an important role in enforcing compliance. • Stricter punishment may not be an obvious deterrent without resource availability and autonomy among labours.
Liu et al. [24]	2022	• Compliance can be portrayed from an incentive & opportunity framework. • Organizational Ethical Climate or "the consensus of organization members on ethical issues to support their ethical judgments and actions" plays a strong role in maintaining compliance standards. • Decision making under various pressure situations affect compliance significantly.	• Construction compliance will follow a top-down approach as organizational attitude is not a sum total of individual attitudes but skewed at the top. • Theory of planned behaviour suggests that construction compliance can be affected positively if perceived costs of violations outweigh the potential benefits
Luo et al. [25]	2022	• Compliance program in China lacked due to "lack of related laws and regulations", "insufficient support from the government", "lack of authorization to the compliance department", "shortage of compliance professionals", and "lack of case studies". • A total of 18 barriers were revealed categorised into social, resource, managerial, and psychosocial barriers.	• Solutions to these compliance challenges required proactive initiatives from top management in awareness, training and showing leadership and commitment to compliance. • Advanced technology integration was found to have potential in helping maximising compliance.

[23] studied the challenges and barriers to compliance when it comes to behaviour. The study found that non-compliant behaviour is not just an incentivisation problem which means that just by providing incentives to target people (people who implement compliance) or sanctioning them bear no fruitful relation to increasing or decreasing overall compliance. Individual behaviour is guided by multiple aspects including information availability, compliance capacity and willingness, and even peer effect.

Also, when it comes to construction compliance, [24] outlines different types of organisational behaviour that affects compliance at a project level. The study breaks down organisational behaviour using the Ethical Climate Theory (ECT) which categorises organisations based on the ethical climate it provides to its employees. The ethical climate was described as the relationship between four factors that influence rule violations [26] - structural secrecy, enforceability, procedural emphasis, and power imbalance. [2] showed that behaviours of site workers, materials and component installations,

methods of construction, plant and equipment, and working environment all have a direct impact on the quality of the finished project.

e) Compliance Technology

Usage of technology is at a very nascent stage in the construction industry. There are several areas of research that have shown promise in relation to construction activities in general. For construction compliance specifically, technology implemented at sites cover several aspects – enforcing safety, visual monitoring, code checking sensors, and detecting defects. An important underlying philosophy in using advanced technology is to ensure proactive compliance enforcement approach rather than a reactive failure detection approach. The papers reviewed for this section are listed below in Table 2.

According to [3] the construction inspection and monitoring process is still largely manual. The study explored the automation of construction inspection by classifying the process into 4 categories based on the type of work done by the technologies: data collection, information retrieval, progress estimation, visualization. The paper finds immense potential for cost and time savings in compliance processes with robot assistance wherein robots capture 360 views, provides compliance assurances based on automated compliance checking algorithms and marks items that need to be checked by an inspector.

[28] developed a platform of intelligent agents that can observe, report and document defects passively on a construction site. The integration of VR along with GPS and IOT sensors can prove critical in certain compliance inspections. However, the role of these technologies are highly dependent on a good network connection and a certain level of BIM maturity. [27] explored technology such as basic cameras for video calls and photo capture as mediums of virtual inspection. This study highlighted the current scenario of remote inspections that has been carried out over the last few years. The study derived the advantages and disadvantages of virtual inspection based on time and financial implications, changes to the scope of the inspections, changing practices and technological innovation, and benefits to customers. Although this level of digitalisation can hardly be classified as automation, it is an important first step towards it.

According to [30], the vision for an automated regulatory compliance system is complete when the physical asset has been certified and relevant automated checks are put in place for the O&M phase of the project. The study maps the entire process and produces a roadmap to achieve automation. An important highlight of this study is that complete automation is undesirable for industry professionals. The concept of full automation still holds a significant level of uncertainty, making it challenging to clearly envision. As a result, the extent to which it is seen as undesirable might be indirectly connected to the importance of construction activities.

IV Discussion

a) Barriers To Efficient Compliance

[24] considered organisational ethical barriers including incentives and sanctions, corruption, ethical climate, and individual attitudes towards compliance as the chief barriers. [3] showed lack of automation, data collection and analysis accuracy, education, and training to professionals as major barriers to compliance. [25] suggested lack of related laws and regulations, insufficient support from the government, lack of authorization to the compliance department, shortage of compliance professionals, and lack of case studies as major barriers to ethical practice. In all the papers, these barriers are seen as independent variables.

Arguably, a better understanding of these barriers can be found while analysing them through the lens of process-behaviour-technology construct. Each of these barriers are caused due to a lack in either of the above three parameters. To improve compliance, these barriers need to be addressed in relation to the three key elements of compliance. According to the literature, thirteen barriers to compliance can be listed. These barriers can be grouped as shown in Fig. 1.

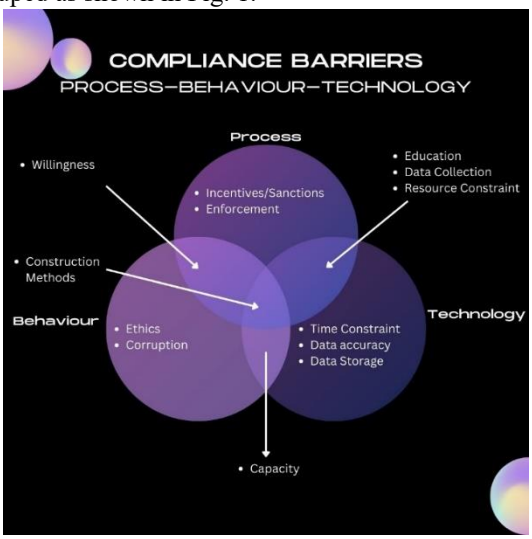

Fig. 1: Categorisation of Compliance Barriers

Table 2: Papers reviewed to understand the technological advancement in construction compliance.

Author	Year	Technology used	Findings	Limitations
Halder et al. [3]	2023	Managerial perspective of robotics	• The automation of construction inspection has been classified in 4 categories based on the type of work done by the technologies: data collection, information retrieval, progress estimation, and visualization. • Robots can capture 360 view and pinpoints items that need to be checked by inspector. • Frequency of manual inspection can be reduced as the robot can act as a first investigator of inspection.	• Extent of human-robot partnership remains doubtful as human interpretation of compliance is more than code checking. • Although the pre-inspection and post inspection administrative duties can be automated, the inspection stage poses a complex challenge. • Levels of non-compliance needs to be integrated in this human-robot environment to prevent excessive work stoppages.
Mott et al. [27]	2022	Basic cameras for video calls and photo capture. Market available products reviewed: ♦HoloBuilder ♦StructionSite ♦QuicaBot ♦H3Dynamics	• Virtual inspection of building codes for energy inspections - case studies on 5 countries: Australia, Canada, Singapore, UAE, US. • The quality of virtual inspections is dependent on the accuracy of the information received and the ability of the inspector to verify that information. • Virtual inspections can be more cost-effective by saving inspection, travel, and administrative costs.	• Follows basic video calling for remote monitoring and inspection. • Contractors being inspected can show only what they want to. • Compliance remains largely manual as inspectors can only check what they are shown through video calling.
Asgari & Rahimian [28]	2017	Intelligent cameras, RFID, sensors, VR Market available products reviewed: ♦Nimble VR ♦Prio VR ♦SmartRock2 ♦Daqri	• Virtual reality - provides spatial cognizance to professionals from BIM data. • Three main applications of the Internet of Things in off-site manufacturing - supply chains, factories, and products. • Cloud-based GPS working along with Radio Frequency Identification (RFID) chip technologies are going to enable the demanded visibility between the manufacturer, the suppliers, the distribution centre, the retailer, and the customer	• VR technology highly dependent on BIM maturity. • Use of IOT sensors and GPS under poor network conditions remains an integral problem.
Cheng et al. [29]	2022	ReID (re-identification machine learning model)	• Multiple camera tracking with non-overlapping field views can capture larger view fields and larger scope of works. • Worker identification can be done with a re-identification model that remembers each worker based on definitive features and reduces false positives.	• The cost mechanics of this multi-camera approach remains unstudied as it can have a serious impact on project cost. • The multi-camera approach needs to be tested in differing weather and low light conditions to check viability.
Beach et al. [30]	2020	Literature review on automated compliance	• Likely adoption of automated compliance remains partial among industry professionals surveyed. • Full automation is not desirable as per survey. • Twelve obstacles (in three categories – Technical, Political and Commercialisation) to automated compliance were generated based on academic literature and ranked by industry professionals.	• Levels of automation may not be a similar across all construction activities. • A bottom-up approach may work in some instances.

Incentives/Sanctions and Enforcement are process issues that need to be dealt with better regulations and further improvements in the compliance process. Ethics and corruption, both on an individual level and organisational level, are solely influenced by behaviours. Improvements in behaviour can change people mind-set on the need for compliance and negate rule violations. Technological investment can help improve the data accuracy and data storage issues of compliance. Also, a lot of time can be saved when specific digital solutions can be integrated into the compliance process.

Further, education and training to inspectors remain lacking because of weak processes and lack of technology investments. Similarly, data collection can be improved when the right processes are in place with the right kind of technology employed. All, these improvements result in better handling of resources and reduces wastage. Capacity, as defined in [23], is the control people have over their decisions to comply with regulations. This autonomy can be instilled by making changes in behaviour as well as implementing technological solutions that bring back control to individual inspectors. Willingness, or the information and cognition problem, attitude and belief problem and peer effects, can be improved by modifying both the processes in place as well as behaviours of individual people. Finally, construction methods employed depending on the type of project, region, materials, and resources available is a combination of all the three key aspects of compliance. While ensuring compliance, it is important to align the construction methods with the processes, behaviour, and technology available in that project.

b) Holistic Approach To Efficient Compliance

The three pillars essential for maximizing compliance are interdependent, requiring substantial enhancements in each area to achieve meaningful improvements in overall compliance. The impact of these improvements in one pillar on the other two pillars must be carefully analysed to understand their interconnected nature. Harnessing this knowledge of interdependence among the three pillars, the future research focus for automated compliance can be listed below in Table 3.

Table 3: Future research focus categorised under the three pillars of construction compliance.

Pillar	**Future Research Focus/Trends**
Process	Research on robust systems, protocols, and workflows at ground levels to guide construction activities.
	Advantages and disadvantages of independent third-party compliance authority and minimising conflicts of interest among parties.
	Research on more advanced digital platforms for streamlined documentation and permit acquisition.
	Potential of blockchain technology for secure and transparent record-keeping of compliance-related activities.
Behaviour	Development of comprehensive compliance training programs for all construction personnel.
	Research on the value of reward-based system to recognize and incentivize compliant behaviour.
	Requirement of industry-wide codes of ethics to guide ethical behaviour and decision-making.
Technology	Research on breakdown of individual construction activity and relevant technology that can check its compliance
	Utilization of BIM as a gateway to check compliant data and store reports
	Research on machine learning algorithms to analyse compliance patterns and predict potential violations.
	Utilization of virtual reality (VR) and augmented reality (AR) for immersive compliance training experiences.

These three pillars—process, behaviour, and technology—form an interdependent framework that collectively contributes to the maximization of compliance in construction projects. By addressing each pillar comprehensively, stakeholders can foster a culture of compliance, streamline construction processes, and harness the potential of technological advancements to achieve higher standards of compliance in the industry.

V CONCLUSIONS

In conclusion, the construction industry continues to face significant challenges in achieving compliance,

leading to substantial risks, cost overruns, and compromised safety. Despite the critical need for improved compliance practices, there is a lack of research and attention towards automation in construction compliance. Understanding compliance challenges and barriers through the framework of the three pillars—process, behaviour, and technology—provides a comprehensive perspective. There also exists a research gap in comprehensively understanding the barriers to automating compliance checks at sites. The discussion on digitalisation cannot be removed from the aspects of process and behaviour. By addressing these pillars conjunctively, including enhancing procedural frameworks, promoting responsible behaviour, and leveraging technological advancements, stakeholders can lay the foundation for making a positive impact on compliance in construction. Research needs to be done by carrying out surveys and interviews about the specific challenges to compliance and creating a comprehensive framework to address them. Further, digital technologies for compliance needs to be tested in simulated environments along with necessary process improvements and behaviour changes to effect change.

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