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OPERATIONALISING HEALTH AND SAFETY REGULATIONS THROUGH DESIGN SCIENCE RESEARCH

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Abstract

Investigations into compliance checking have paid little attention to how process-oriented regulations can be made accessible and operable. This paper explores ways that these expectations can be met. The study considers the macro level requirements enforced by a government agency, as exemplified by the UK Construction (Design and Management) Regulations (CDM 2015) which assigns responsibilities and duties clients, designers, and contractors, many of whom lack confidence in fulfilling these obligations or in evidencing their discharge. The findings highlight an opportunity for guidance that is firmly grounded in regulatory requirements yet tailored to the distinct roles of industry participants.

Introduction

Compliance checking has usually been associated with the systematic comparison of regulations against a building proposal, typically structured building models (BIM) (Eastman et al., 2009; Nawari, 2012). Previous work has shown how the semantic mark-up of Requirements, Applicability, Selection and Exceptions (RASE) can support compliance checking, whether applied to design models (BIM) (Nisbet et al., 2023) or to site monitoring information (Nisbet et al., 2024). However, regulatory obligations that prescribe required behaviours, rather than physical or spatial performance, are qualitatively different. While the built-environment literature has devoted substantial attention to product-based regulation, far less attention has been paid to the regulation of processes, even though process-based duties are often invoked when product information is incomplete or unavailable. Health and safety regulation exemplifies this challenge: although trailing indicators such as incidents and near-misses are well understood, there are few leading indicators that can be assessed in advance (Zhang et al., 2024a). This paper therefore examines a situation in which evidence of compliance is unlikely to exist in either structured or unstructured form, and where the discharge of continuing obligations depends on duty holders who are often uncertain about what those obligations entail.

Highlighting the logical semantics of a regulation (its hierarchy of objectives, associated duties and specific metrics) offers a way to investigate the structures and behavioural patterns implied by the text (Nisbet et al., 2023). By systematically seeking hypernyms for the objects and properties named in the regulation, patterns of expected behaviour emerge, illuminating the intent and making the structures in the regulation explicit. These insights extend beyond checklists or decision trees and point toward the possibility of generating interactive teaching and learning materials that help embed compliant behaviour. In the current example, the outcome of the systematic analysis can be compared to the informal 'manage, maintain and improve, document' model used by UK Health and Safety Exective (HSE) HSE Inspectors.

Context and literature review

Regulatory context and application of CDM 2015

The Construction (Design and Management) Regulations 2015 (CDM 2015) represent the third iteration of the UK's CDM regulations (HSE, 2015a), introduced to align with the EU Directive on Temporary or Mobile Construction Sites (EU, 1992). Although construction fatalities have decreased since the first CDM regulations were introduced, the construction sector continues to experience the highest number of work-related deaths (HSE, 2025). These persistent health and safety (H&S) challenges prompted the revisions of the CDM regulations in 2007 and 2015, aiming to address shortcomings in coordination, clarity of duties, with the intention of improving H&S outcomes.

CDM 2015 places strong emphasis on accountability. The regulations are structured around five key duty holders: client, principal designer (PD), principal contractor (PC), designer and contractor. A key idea of the 2015 revision was to highlight the influence of design decisions on construction H&S, placing greater responsibility on designers and PDs to identify and manage risks early in the project lifecycle. This reflects a broader shift toward improving H&S performance through more effective design risk management, also referred to as Construction Hazards prevention through design (CHPtD) (Toole & Gambatese, 2008). However, despite this improved clarity of responsibility, the CDM 2015 regulations remain process focused and outcome oriented, offering limited detail on the specific procedures required to achieve compliance (Zhang et al., 2024a). As a result, practitioners often struggle to interpret what compliance looks like in practice, particularly during the design stage.

To address these gaps, significant effort has been made to interpret and operationalise CDM 2015. The HSE's official guidance (L153) provides definitions, clarifications and examples of what constitutes compliance, including expectations for key documents such as the health and safety file and the construction phase plan (HSE, 2015b). The HSE has also been delivering the "Discovering Safety" programme, which includes a range of projects focused on improving health and safety in construction. This has involved several 'SafetyTech' regulatory sandbox initiatives that bring in industry start-ups to trial innovative solutions and develop case studies supporting CDM compliance and enhanced H&S outcomes and construction risk library which mapped out risk scenarios and mitigation measures.

A range of industry and standards bodies have also produced supplementary guidance to support practitioners. For example, the Institution of Civil Engineers (ICE) has published guidance on Design Risk Management (DRM), a core requirement under the CDM regulations (ICE, 2020). The document provides clear explanations of risk concepts, the fundamentals of DRM, and the respective responsibilities of different stakeholders throughout the process. The Construction Industry Training Board (CITB) has published six guides, five for duty holders and one for workers. The duty-holder guides outline the key tasks, the information required or to be provided, practical suggestions of how responsibilities can be carried out, and guidance on applying these duties when working with domestic clients. The worker guide explains what the regulations mean on site, emphasises consultation and communication, sets out the information workers should give and receive, highlights the need for cooperation and coordination, clarifies expectations around competence and training, and illustrates what good health and safety practice looks like in construction. Despite the comprehensive list of actions, the guides do not always distinguish between what is essential and what is desirable; applying CDM requires judging what is reasonably practicable in context, and not all of the listed measures are proportionate or necessary on every project. In addition, without some example case studies from real life projects, the list can feel theoretical. In addition, national and international standards such as BSI PAS 1192-6 (BSI, 2018) and ISO 19650-6 (ISO, 2025)focus specifically on health and safety information management, offering guidance on how hazard and risk information can be structured, shared, and maintained throughout a project. Both standards promote treating risk information and mitigation measures as shared project resources that can later be generalised into organisational learning. These two standards have inspired the development of a Construction Risk Library (CRL) (Osorio-Sandoval et al, 2023), as an open resource to guide the identification of design risks and the selection of appropriate treatments.

Along from these general guidelines, there are also efforts to clarify key concepts such as "so far as is reasonably practicable" (SFARP). The ICE published a commentary for SFARP, which outlines the legal summary and guidance and a compliant design approach (ICE, 2010). However, it lacks concrete examples and only touched on high-level evidence for a compliant design approach. In addition, the Construction Industry Research and Information Association (CIRIA) attempted to unpack SFARP for designers by explaining how to balance risk, proportionality and practicability in design decisions, emphasising cautious, team-based judgement and the need to eliminate or reduce foreseeable risks through the design process (CIRIA, 2015).

CDM in practice

More recent research has moved beyond interpreting the CDM regulations themselves to examining how they shape practice. Mzyece et al. (2019) approached CDM regulatory compliance from a BIM-integrated perspective, proposing a BIM–CDM interoperability framework to support the discharge of CDM duties. Their framework focused on three key CDM documents (pre-construction information, construction phase plan and H&S file) and explored how BIM and common data environment could support managing these documents. An ICE review conducted three years after the regulations came into force found that, although the industry had broadly adapted to the new framework, many practitioners continued to struggle with ambiguous clauses and terminology (ICE, 2019). The report highlighted persistent uncertainty around how to interpret certain duties, particularly at the design stage. This is where misunderstanding is most evident: many designers still under apply design risk management principles, especially the requirement to eliminate, reduce and control risks through design. Responding to the outcome-oriented nature of CDM 2015, Zhang et al. (2024b) developed a process map of the H&S by design process based on interview results with practitioners, providing a practical and detailed workflow to support designers and PD to fulfil their duties. Also focusing on the design stage, Hare et al. (2020) developed a multimedia digital tool to help designers identify and mitigate common design-related hazards, offering practical support for design-stage CDM compliance. Adaku et al. (2021) focused on clients, identifying seven key practices they use to achieve CDM compliance. The findings highlighted that some these practices depend on the PD's arrangements, underscoring the importance of understanding the PD's role in coordinating pre-construction H&S. Shifting the focus to the construction stage, Nisbet et al. (2024) used a semantic annotation approach (RASE mark-ups) to support live CDM compliance checking on construction sites, integrating site diary entries and site-monitoring data to evaluate compliance in real time.

Industry working groups have also played a significant role in supporting CDM compliance on projects through collective knowledge sharing. Workshops that bring multiple duty holders (e.g., clients, PDs) were organised and lessons learned documents and best practice guidance were published addressing specific aspects of CDM

compliance. Notable examples include the BIM for Health and Safety (BIM 4 H&S) group, chaired by the HSE, and the Highways Safety Hub, underpinned by the National Highways' Principal Designer Working Group (Highways Safety Hub, 2023). Together, these initiatives provide a forum for cross-organisational learning and help translate regulatory requirements into practical approaches for improving design risk management.

The principal designer role

The studies above highlight both the importance of the Principal Designer role and the persistent uncertainty surrounding its practical interpretation. Introduced in CDM 2015 to replace the CDM Coordinator, the PD was intended to lead and coordinate pre-construction H&S matters. This shift reflected the HSE's aim to embed H&S considerations at the centre of the design process by placing responsibility with the lead designer rather than peripheral H&S consultants (Jolly, 2023). However, architects and lead designers have often been reluctant to take on the PD role, with findings indicating that many still view H&S as a contractor responsibility, resulting in the role being frequently undertaken by H&S consultants, client advisors and project managers (MPW R&R Ltd, 2023).

In addition, a key requirement of CDM 2015 is that PDs must be competent, yet the regulations offer little clarity on what this competence entails in practice. Addressing this gap, Adaku et al. (2022) developed conceptual models for assessing PDs' skills, knowledge and experience, expanding CDM competence across multiple levels, such as occupational and task-specific dimensions. Ndekugri et al. (2022) investigated the coordination role of the PD during the pre-construction stage. They found that while CDM 2015 has improved early PD appointment, significant challenges remain around assessing PD competence, ensuring adequate resourcing, and overcoming barriers such as limited awareness, misunderstandings of duties and intentional non-compliance. These issues have direct implications for how design risks are identified, coordinated and managed, which is the focus of the next section.

Design risk management

Design risk management is a core process undertaken by designers and the PD. It is an iterative process focused on identifying and managing risks during the design stage and forms an integral component of both overall project risk management and routine design practice (ICE, 2020). The central principle is that an inherently healthier and safer design can improve H&S performance across the entire project lifecycle, benefiting both construction workers and end users. Design risk management is guided by the principles of prevention, most commonly expressed through the "ERIC" hierarchy: eliminate, reduce, inform and control (HSE, 2015b). This hierarchy prioritises eliminating risks through design or design changes wherever reasonably practicable, with control measures such as reliance on personal protective equipment (e.g., using earplugs or protective gloves) considered only as a last resort. Although construction projects may involve hundreds or even thousands of potential hazards and risks, design risk management puts more emphasis on a smaller subset of significant, unusual or difficult-to-manage risks (CIRIA, 2015; ICE, 2019). This focus highlights the need for designers to address these risks proactively and early in the design process to achieve effective H&S outcomes. Design risk management, despite its focus on the design stage, also emphasises the need for residual risks to be appropriately managed and handed over to those who will control the subsequent stages of the project, typically the PC (or the contractor where no PC is appointed) (ICE, 2019).

However, despite the aspirations set out in CDM 2015, studies consistently show that designers and PDs often struggle to apply these principles consistently in practice, particularly when interpreting what constitutes a 'significant' risk or determining how far mitigations are reasonably practicable (ICE, 2019). This persistent challenge reflects a broader pattern identified across the literature, where understanding and operationalising CDM duties remains inconsistent, especially during the design stage.

Research gap

Despite extensive guidance and a decade of implementation, the literature consistently shows the varied levels of understanding and ongoing challenges in fulfilling CDM duties, particularly in relation to design risk management. Practitioners in industry still lack operable, practice-ready knowledge on how to fulfil CDM duties at the design stage. In particular, the PD role and design risk management processes remain poorly understood. This requires an iterative investigation framed to answer whether the absence of an operable target (analogous to BIM or site logs) invalidates the use of semantic annotation and whether gap between legislative text and operable knowledge can be closed by other means.

This paper addresses this gap by using semantic annotation (mark-up) to expose the logical intent of the clauses relating to the PD and then classifying those actions by examining the operative verbs. This ensures that the outcome of four classes of action is learnable and teachable whilst remaining evidently grounded in the legislation.

Research methodology

This paper is presenting a case study based on the existing UK regulations around health and safety, examined from the point of view of one of the nominated 'duty holders', namely the 'Principal Designer' (PD). Design Science Research (DSR) (Hevner et al., 2004; Peffers et al., 2007) allows a progressive sequence of iterative steps to be taken to move from the regulation to a concise summary of the duties, meeting the criteria of arriving at a learnable and teachable understanding. Figure 1 shows a DSR dashboard based on Takeda et al (1990). The knowledge base is UK legislation and regulations, and the practice context is the uncertainty around CDM 2015 duties. The problem is to produce accessible guidance with quality

around learnability and teachability, as a grounded presentation of CDM 2015. The iterative research process needs to test for clarity and simplicity.

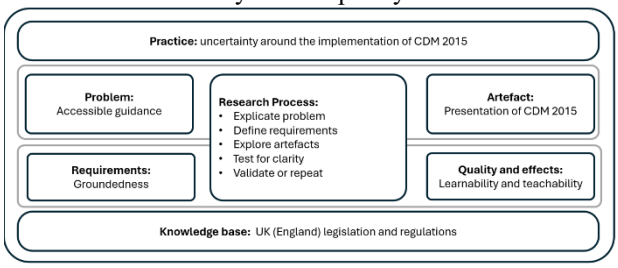

Figure 1: DSR approach (based on Takeda et al 1990)

Investigation

The investigation began with applying the RASE annotation (mark-up) methodology to the regulation. This involves identifying the hierarchy of objectives as boxing which in this case is mostly identical with the sectional hierarchy of clauses and sub-clauses. In one case a clause '8(1)' acts as a sub-clause of another '8(2)'. Mark-up is also applied to the terms that identify any testable proposition, such as the 'role' being taken, using underlining. These metrics can be annotated with their implied property and target. Some propositions may require further discussion such as 'reasonably practical' but in principle these can be answered. All the objectives and metrics are then assigned a logical role, chosen from 'Requirement' (blue), 'Application' (green), 'Selection' (purple) or 'Exception' (orange), indicating how they contribute to the evaluation of their immediate containing section. This mark-up is sufficient to make the document machine operable. For example, by specifying that the actor of interest for this case study is the 'Principal Designer', the document is immediately shortened to reflect only the clauses that refer to that actor. Figure 2 shows the mark-up following this choice.

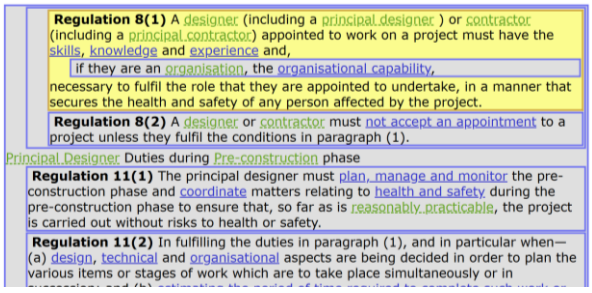

Figure 2: CDM 2015 with RASE mark-up (extract)

However, this still contained a wide variety of tests. Whilst these can be answered individually, given our aim of making the regulation more comprehensible, we can apply a systematic approach to identify not just the test such as '(has) skills' but to group this test with others such as '(has) knowledge' and '(has relevant) experience'. By consulting an online dictionary service (such as Wordnet or WordHippo) and or informally, the concept of 'skill' can be found to have the hypernym 'capability'. Capability is also a good hypernym for 'knowledge' and 'experience'. The metric '(has relevant) skills' can be revised to be 'property=capability comparator=includes target=skills'. Table 1 shows five examples.

Table 1: Regulation terms and hypernyms (extract)

Terms	Hypernym
accept, manage, monitor, coordinate	consider
plan, comply	specify
inform, liaise, ensure, cooperate, assist, provide to	communicate with
report, review	share
reasonably practical, relevant, foreseeable, appropriate	scoping

Having performed this substitution, the number of different properties mentioned in the metrics is considerably reduced. Some comments relating to their evidencing in practice are given in Table 2.

Table 2: Hypernyms with possible evidence (extract)

Hypernym	Possible evidence
consider	memos, design file notes or other records
specify	changes affecting the design and specification of the works
communicate with	confirmation of both sending and receipt.
share	information exchange records

The selection of hypernyms allows us to see a pattern in the kinds of properties involved in the metrics present in the text. Some properties remain categoric, such as whether the PD is an organization (as opposed to an individual). Functional properties tend to be numerical, but there are none in the current example. Lastly, many properties are tests for membership of classes and sets, which may require background knowledge of any hierarchy and synonyms.

Having created a rationalised mark-up for the regulation, a number of presentations can be generated automatically. For example, a conceptual graph can represent the logical operability of the Regulation. Other decision-based presentations are possible including decision trees and flow diagrams. However, these are not shown here because the regulations are not applied at a single point but are intended to be applied continuously.

A presentation derived from the marked-up regulation (Figure 3) summarizes the selected hypernyms as a form allowing the input of values for the properties involved. The text of the regulation is repeated below offering the alternative of the input of values in context. Where the range of possible answers is known, the form offers a drop-down selection. Selecting or providing a value fills in all synonymous slots.

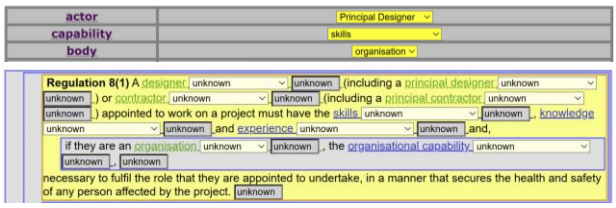

Figure 3: CDM 2015 as linked form and text (extract)

Results

An alternative presentation offers a matrix of the clauses (vertically) and the property hypernyms (horizontally), with each cell including all the target values. Figure 4 shows selected cells from the matrix. This simplifies the PD duties once appointed into a set of four manageable activities: consider/specify/communicate-with/share.

clause	consider	specify	communicate with	share	measure
R11-01	• health and safety	• plan, manage and monitor • coordinate			• reasonably practicable
R11-02	• general principles of prevention • construction phase plan • health and safety file	• design • technical • organisational • estimating the period of time required to complete such work or work stages			• relevant
R11-03	• carrying out or liable to be affected by construction work • maintaining or cleaning a structure • using a structure designed as a workplace	• risks to the health or safety			• reasonably practicable • foreseeable
R11-04	• duties in regulation 9		• designers		
R11-05		• cooperate	• client • each other		
R11-06a			• assist the client	• pre-construction information	
R11-06b			• every designer and contractor appointed, or being considered for appointment	• pre-construction information	• control
R11-07			• liaise with the principal contractor	• planning, management and monitoring of the construction phase • coordination of health and safety matters during the construction phase	

Figure 4: CDM 2015 as a matrix (extract)

This allows us to highlight the lists of key targets the PD has duties around (see Table 3). Under the duty to 'consider', we can note the inclusion of 'health and safety' and the risk register. The PD is required to 'communicate with' all of the other roles identified in the regulation. The PD is required to 'specify' (by affecting the drawings, specifications and risk registers) design, technical and organizational matters. 'Sharing' of the risk register(s) in the form of the 'pre-construction information', 'construction phase plan' and the 'health and safety file' is required.

Table 3: Hypernyms with topics (extract)

Hypernym	Topics
consider	Health and safety
	General principles of prevention
	Construction phase plan
	Health and safety file
specify	Planning
	Coordination
	Design
	Technical (matters)
	Organizational (matters)
	Time for work (estimate)
	Risks to health and safety
	Cooperation
communicate with	Designers
	Client
	Principal contractor
	All
share	Pre-construction information
	Construction phase plan
	Health and safety file
scoping	Reasonably practical
	Relevant
	Appropriate
	Foreseeable

Since these duties are open-ended in terms of their scope and in terms of their duration, it is important to note the qualifications offered for several of these duties. Table 3 summarizes some scoping filters applied to these duties. These apparently ambiguous filters are the subject of specific legal and regulatory guidance. Phrases such as 'reasonably practical' have specific meanings. These frame compliance in terms of normal practice, best practice and other considerations of proportionality. The recently developed Uniclass 'RK' risk classification table (NBS, 2026) and the publication of a 'Construction Risk Library' (CRL) may inform this judgement. The Uniclass table creates a reference list of many types of risk with RK_40 focused on risks to health and safety. This CRL library provides lists of common construction risks and possible treatments and mitigations. These two resources may help judge relevance and appropriateness. The publication of BSI PAS1192 Part 6 and its subsequent development into ISO 19650-6 has explored how the risk register can be treated as a single shared resource, through all three versions in the UK regulations 'Pre-construction information', Construction Phase Plan' and 'Health and safety file' (in-use). The forthcoming guidance to Part 6 in the Information Management Initiative (IMI, 2026) will suggest the filters (views) applicable to a risk register to obtain each of these documents.

Discussion

Regulatory compliance can be effected through changes to the physical and spatial aspects of the built environment

or through governance over the actors and information involved. Regulating actors can focus on requiring levels of competence including skill, knowledge, and experience. Alternatively it can prescribe programmes of actions that must be carried out. In either case there is unlikely to be direct evidence that can be checked systematically in real time. Instead, it becomes important that the expectations are embedded in the level of understanding of the actors so as to inform their behaviour continuously. A simple but justifiable model can be trained and learnt. The technique will be presented to a focus group later this year which may lead to the deployment of the learning/teaching materials. This should produce the evidence to support the validation of the approach.

UK CDM regulations are an example of secondary legislation that imposes expectations on process, not product, in the expectation that the desired outcomes will be achieved. The requirements are open-ended in the sense of not specify the timing of actions and in the sense of no limitation to the amount of effort and output required but for the limiting phrases. This makes the legislation daunting for practitioners and hard for third parties such as insurers to evaluate.

RASE mark-up has been used to expose the objectives and metrics used in defining one actors duties. A repeatable process has then been used to extract the verb-noun predicates. The verbs have been rationalised through the use of hypernyms and the nouns (and scoping adverbs) have been rationalised by reference to emerging classification and information management principles. The same process can be applied to any regulatory document in any language. Exceptionally, if no dictionary of hypernyms is available for a particular language, then manual intervention will be required. Filtering for any particular role, stage or duty or any other attribute is non-specific and is a feature of the generic generation of the presentations.

Conclusion and future work

This paper illustrates that benefits from RASE mark-up can exist even when there is not likely to be a target database for systematic compliance checking. It has addressed a knowledge gap by using RASE mark-up to expose the logical intent of the clauses relating to the PD and then classifying those actions by examining the operative verbs to generate a concise conceptual model of the duties imposed by the regulation. This conceptual model can inform teaching and learning material and act as a simple tacit framework to guide practitioners in their work, without having to refer to the legislation repeatedly and without the potential for scope creep induced by anxiety about under-performing the satisfaction of the obligations. This is significant for bringing ‘process’ based regulations into the realm of operable knowledge.

Future work can look at how online dictionaries and Natural Language Processing (NLP) tools can support Large Language Models (LLM) in automating the addition of RASE mark-up. With this in place learning/teaching material could be rapidly generated from source documents.

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