Mapping the processes and developing the rule sets for automated compliance checking of health and safety regulations in UK's infrastructure projects

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Introduction

The construction industry faces adverse health and safety (H&S) performance challenges. It is well-known that construction fatalities are three times higher than the all-industry rate in the UK. These H&S performance issues are further manifested in infrastructure projects that are typically large and complex, and involve many workers and onsite machinery [1]. To ensure desirable H&S outcomes in the UK, the design and construction processes must comply with the H&S regulations, especially the Construction (Design and Management) Regulations 2015 [8]. However, such compliance checking is traditionally conducted manually, which can be inefficient, laborious, and error-prone [5, 7, 14].

Automated compliance checking (ACC) is a tool for assessing compliance. In ACC, the design is checked against the regulations and requirements, with the results including "pass", "fail" or "unknown" [5]. ACC has the potential to significantly improve the quality and efficiency of the traditional compliance checking process [16]. In the past 50 years, extensive research efforts have been devoted to the ACC field, where several studies have looked at compliance with the H&S regulations. For example, Zhang, Teizer [12] and Zhang, Teizer [13] developed rule sets for ACC against Occupational Safety and Health Administration (OSHA) regulations [11] based on existing safety in design best practices. They focused on workways and egress rule sets, and geometrical attributes such as the dimensions of holes in slabs and openings in walls, respectively. Moreover, Getuli, Ventura [6] used parametric rule sets to represent Italian Construction H&S normative texts, which were executed in Solibri Model Checker to check compliance automatically.

Problem statement

Although there have been some existing ACC studies on the H&S aspect, they focused on product-related regulations and clauses (i.e., looking at the objects and properties to check compliance), and little research has focused on the ACC of process-orientated regulations. This research thus selected the Construction (Design and Management) Regulations 2015 (CDM 15) in the UK as an example to look at its compliance checking during the design stage. For the design stage, the CDM 15 regulations specify the principal designer's duties (regulation 11) and the designer's duties (regulations 9 and 10) [8]. These regulations are outcome-based, objective-driven, and process-focused. There is no provision of detailed prescriptive guidance regarding how compliance can be achieved. Previous ACC research has mainly focused on prescriptive, product-focused regulations, whilst compliance with such process-focused and outcome-based regulations has not yet been checked automatically[2, 15]. Based on the current situation in the UK's infrastructure sector, two general research gaps are identified: 1) The implementation of ACC against the CDM 15 regulations will require clear and operable rule sets that are not currently

available; 2) there needs to be improved processes in the H&S management in UK's design organisations in the construction industry to achieve better efficiency and assurance in CDM compliance.

Research questions and gap

Given the current situation in this research domain and the gaps identified, this research aims to support the development of ACC for the CDM 15 regulations in the UK by developing processes and rule sets for H&S by design in infrastructure projects. Note that this is an ongoing research effort, and the proof-of-concept prototype development is out of the scope of this paper. Developing clear processes and rule sets is important because in the typical compliance-checking scenario, the rules are readily available in the regulatory documents, and the ACC process starts with interpreting the rules. However, in the case of H&S by design, due to the process-based and outcome-driven nature of the CDM 15 regulations, outlining clear H&S by design processes that comply with the CDM 15 regulations and developing related metrics will be a starting point for ACC development.

To achieve the research aim, the following research questions need to be answered:

What would be a good H&S by design process in UK's infrastructure projects that supports greater compliance with the CDM 15 regulations?

In UK's infrastructure projects, what metrics and/or rule sets would ensure that H&S by design processes have improved compliance with the CDM 15 regulations?

Methods

Design Science Research (DSR) is used to develop processes and rule sets for automated compliance checking of the CDM 15 regulations. DSR is a research methodology where researchers try to solve real-life problems by creating innovative artefacts (the processes and rule sets in this case) and thereby contributing to the body of knowledge [9]. DSR is suitable because this research aims to address the compliance checking problem by developing artefacts for ACC of the CDM 15 regulations.

In DSR, artefact development is an iterative process. In this paper, there are several iterations required in developing the artefact, as follows:

Questionnaires and semi-structured interviews are conducted to gather opinions and ideas from H&S by design experts in a UK infrastructure design organisation. Questionnaires are distributed to project managers working on infrastructure projects. Whilst questionnaires help to understand how H&S by design is conducted in a large number of projects, their weakness lies in that they cannot provide sufficient depth for developing detailed and standard H&S by design processes. After analysing the questionnaire responses that reflect the current practice of H&S management in the design and engineering of different infrastructure projects, semi-structured interviews are conducted to help gain a more in-depth understanding and develop detailed process maps.

Based on the input data in 1), two draft H&S by design process maps are produced concerning the design and the design change scenarios of the H&S by design processes.

The produced H&S by design process maps are reviewed by experts using focus group interviews. The focus group method is used as it facilitates discussions and idea exchanges, and generates collective views on a topic [4]. It is also a time-efficient way to generate substantial content [3].

Based on the comments from Stage 3, the process maps are revised and finalised.

Based on the process maps developed in Stage 4, semi-structured interviews are conducted to gather metrics to check compliance.

The proposed metrics developed in Stage 5 are then reviewed by experts in another focus group interview and adjustments are made.

Results and Discussion

Health and safety by design process maps

Fig 1 and Fig 2 show the H&S by design process maps that are produced as a result of the interviews, questionnaires and focus groups with experts in H&S by design in the UK's infrastructure sector. The first process map shows the process of H&S by design in the design stage, which includes project stakeholders and CDM duty holders. The second process map shows the process of H&S by design in the construction stage (design change).

Checking compliance with the CDM 15 regulations is essentially checking whether the H&S by design process follows the standard process in the produced process map. As such, the process maps provide a good starting point towards automated compliance checking of the CDM 15 regulations.

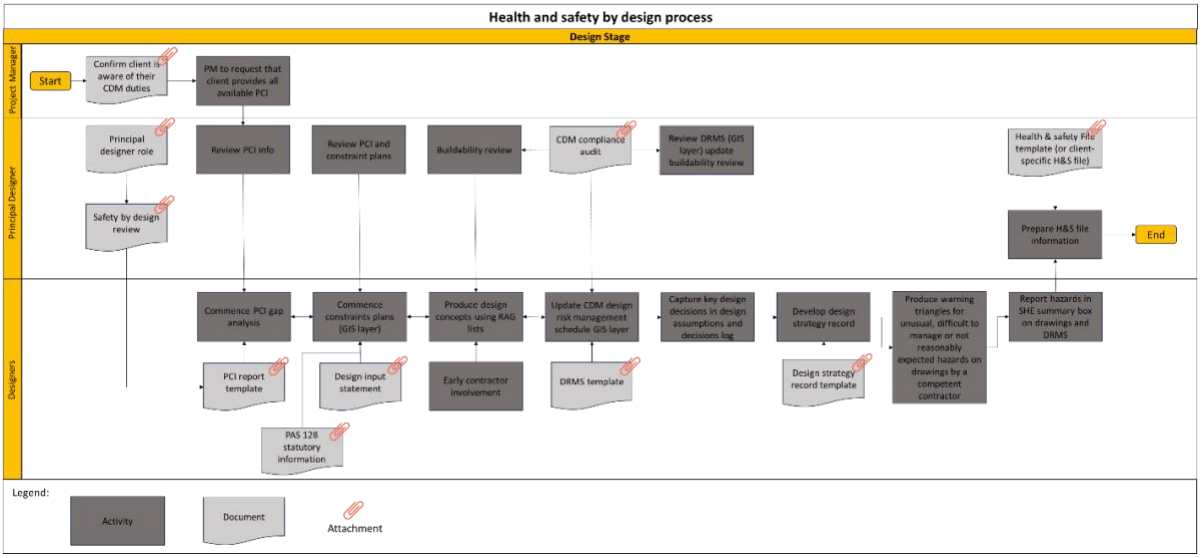

Fig. 1: H&S by design process map (design stage).

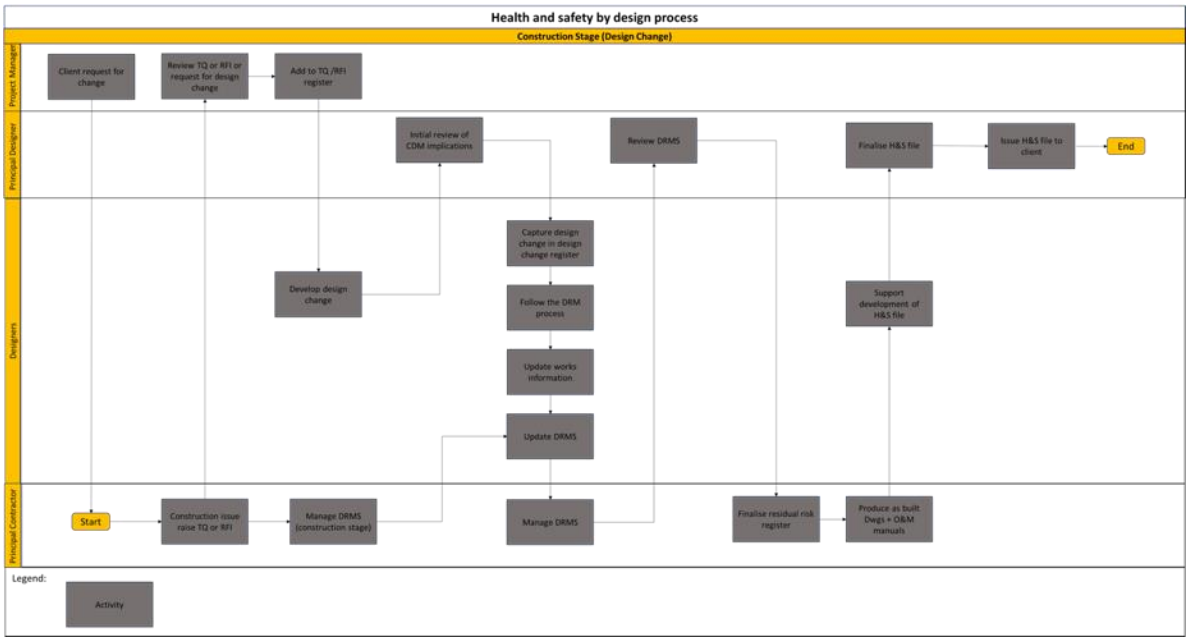

Fig. 2: H&S by design process map (construction stage).

Rulesets/metrics to measure compliance

The rule sets and/or metrics are developed following the steps outlined in the methods section. These rule sets/metrics are developed to support the compliance checking process and are complementary to the process maps. As there are too many metrics, here in the extended abstract we will only present the structure of the metrics spreadsheet and some examples instead of the full list of metrics.

The metrics structure resulted from a thorough analysis of the CDM regulations. Eight common components that construct (or result from) the CDM clauses have been found by the authors, the components and some examples are presented in Table 1.

Table 1: Components of the CDM regulations and examples.

Components	Types of each component	Example(s)
Clause original texts	Not applicable	If the client fails to appoint a principal designer, the client must fulfil the duties of the principal designer as set out in regulations 11 and 12.
Number	Not applicable	Regulation 4 (1); Regulation 5 (3)
Compliance impact (trailing outcome)	Not applicable	Not accepting the post unless they have the skill, knowledge,

		experience to fulfil the role or have the organisational capability.
Subject	Type of actor; Named actor; evidence	Client; principal designer; contractor; the Health and Safety Executive; evidence (e.g., contracts, emails, meetings, documents)
Verb	Interact; report; specify; or verbs related to factors	Interact; report; specify; coordinate
Object	Type of actor; type of report; type of specification; type of factors; named actor/clause/entity/entry; evidence	Pre-construction information; principal contractor; designer;
Exception	Not applicable	As soon as is practicable; so far as is reasonably practicable; except any exempt information as mentioned by the CDM regulations
Time element	Explicit time element (mentioned directly in the clause); implicit time element (not directly mentioned in the clause)	At the start of the shift in which the work is to be carried out; after any event likely to have affected the strength or stability of the excavation; client to provide pre-construction information (which is related to the award of the contract)

As shown in Table 1, in each clause there is a clause number and clause original texts, as shown in the "examples" column. Each clause has a compliance impact (trailing outcome), which explains what impact the clause has regarding CDM compliance. The texts in each clause are related to five components, namely subject, verb, object, exception and time element, where exception and time element are optional (these do not exist in all clauses). The subject, verb and object refer to the constructs of the clause. Subjects in CDM clauses can be classified into two main types, namely type of actor (the instance of which is called "named actor") and evidence, with examples shown in Table 1. Verbs are usually "interact", "report", "specify", or "verbs related to factors (e.g., coordinate with stakeholders)". Objects in CDM clauses also have several types, including type of actor, type of report, type of specification, type of factors and evidence. And similarly, their instance can be "named actor/clause/entity/entry". The examples are shown in Table 1. A common expression in the CDM clauses is "so far as is reasonably practicable",

which sets out the exception to the duty specified in the rest of a clause. It is essentially to say that it is acceptable that not all measures are taken as it may not be financially practicable. In addition, it is important to consider the time element of CDM clauses as in some cases, CDM compliance relies on timely actions.

Discussion

This research presents H&S by design process maps, compared with previous ACC research about H&S regulations such as Hossain and Ahmed [10], this research makes a distinct contribution as it is concerned with process compliance rather than product compliance (i.e., focusing on objects and attributes). The findings of this research can make an impact through its implementation in practice. In practice, the processes in the process maps are expected to be followed as standard procedures. Metrics are developed to measure how well the processes are followed automatically. When checking against the metrics, the process maps need to be considered as the time element as compliance with the CDM regulations is time sensitive.

This research also highlights that ACC has a broader meaning: not only as a tool to check compliance and provide a one-off report but also as a decision support tool during the design process to achieve better business value. This resonates with the design organisation's aspirations. The CDM 15 regulations and internal company processes can be checked in this ACC workflow.

Conclusion

This paper presents the processes and rule sets (metrics) for the automated compliance checking of the UK's H&S regulations (CDM 15 regulations) in infrastructure projects focusing on the design stage. With the results of this paper, ACC systems could be developed to check compliance with the CDM 15 regulations.

This study is one of the first to focus on developing rule sets and processes to check compliance in design risk management from a health and safety perspective. Based on this research, researchers could conduct future studies to develop an ACC system to check compliance in the H&S aspects against the CDM 15 regulations, similar H&S regulations in other countries and other outcome-based, objective-driven and process-focused requirements. For practitioners, the process maps produced in this research can serve as a guideline to improve their H&S management processes in design and construction (design change) stages and achieve better compliance outcomes with the CDM 15 regulations.

This study has limitations. The process maps and metrics are developed based on experts' input. Future research could collect more data from experts to improve and refine them further.

Acknowledgements

Appreciation is expressed to the company and all participants for their support in this study. The authors would also like to thank UKRI, as this investigation was developed through a Knowledge Transfer Partnership (KTP) project supported by Innovate UK. The authors would also like to thank Nicholas Nisbet for his suggestions on this study.

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