Guest editorial

Coping with the complexity of safety, health, and well-being in construction

1. Introduction

The construction industry has been perceived as increasingly complex, due to factors such as larger projects, larger supply chains, the growing use of information and communication technologies, as well as a changing political, social, economic and legal external environment (Bakhshi *et al.*, 2016). Furthermore, the complexity of construction projects is due to the inherent features of the industry, such as the dependency on environmental conditions (e.g. weather and soil conditions) and the long duration of projects, which makes them more exposed to uncertainty from the environment, including changes in client requirements. However, a portion of this complexity may be unnecessary (Axelrod and Cohen, 2000) as a result of the ineffective control of wastes.

Thus, complexity theory (CT) arises as a natural framework for the analysis of existing construction management practices. In line with others (e.g. Morel and Ramanujam, 1999), the term "complexity theory" is adopted as a perspective for the modelling and understanding of systems, rather than as a unified theory. The use of CT as a lens for project management has been a topic of academic interest over recent decades (e.g. Gidado, 1996; Ballard and Tommelein, 2012). These efforts have been motivated by the perception that complexity tends to increase the time and cost of projects, and thus requiring more sophisticated planning, coordination and control (Baccarini, 1996). Less explored in construction has been the upside of complexity, which is known as a potential source of innovation, efficiency and resilience (Hollnagel, 2017).

As an integral part of project management, construction health, safety and well-being (CHSW) influence and are influenced by the overall project complexity. On the one hand, for instance, CHSW tends to increase project complexity by adding layers of protective structure, both physically (e.g. safeguards) and managerially (e.g. standardised operating procedures and inspections). On the other hand, characteristics of the overall project complexity, such as the dynamic working conditions and the diversity of stakeholders, may not be compatible with the bureaucratisation of safety management (Dekker, 2014) and overly prescriptive regulations. The nature and implications of this mutual relationship between CHSW and project complexity are not yet well understood, which is unsurprising given that both constructs are multi-dimensional and therefore, mixed influences should be expected.

This Special Issue aims at contributing to advancing the knowledge of the relationship between CHSW and the complexity of construction projects, by presenting 11 papers that can be associated with this theme. In total, 8 out of the 11 papers in this Special Issue are extended and refined versions of papers originally published in the proceedings of the Joint CIB W099 and TG59 International Safety, Health, and People in Construction Conference, which occurred in Salvador, Brazil, on August 2018. To make it explicit the links between the papers and CT, in this Editorial these are analysed regarding how they accounted for five guidelines for coping with complexity.

2. Guidelines for coping with complexity

Guidelines for coping with complexity are available from several sources, both in construction management and other disciplines. The term "coping with complexity" is

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intended to convey the notion that complexity cannot be completely controlled, but only influenced by design. To a considerable extent, complexity arises from the self-organisation of agents that act according to what makes sense to them from a local perspective (Cilliers, 1998). In construction, four exemplar guidelines for coping with complexity have been proposed by Bertelsen and Koskela (2005). These include creating slack, reducing complexity through modularisation and standardisation, codification through the implementation of the Last Planner System of production control, and improving improvisation skills. In healthcare, Braithwaite *et al.* (2018) compiled 20 complexity-oriented enablers and insights. More generally, Clegg (2000) proposes core principles of socio-technical systems design, which have an underlying complexity thinking.

In this Editorial, five guidelines for coping with complexity devised by Saurin, Rooke and Koskela (2013) are adopted as a basis (Table I). A sixth guideline, referred to as

Guidelines	Dimensions of the guidelines
Provide slack	Slack is a mechanism for reducing interdependencies and slowing down or eliminating the propagation of variability (Safayeni and Purdy, 1991). Slack is usually operationalised through some human (e.g. cross-trained professionals), technical (e.g. spare pieces of equipment) or organisational resource (e.g. double-check of quality specifications). Slack can be either designed into the system or arise opportunistically as a result of self-organisation (Saurin and Werle, 2017)
Give visibility to processes and outcomes	Systems should be intuitive (Clegg, 2000), to reduce imaginary complexity Visibility should be given to informal work practices, which may encompass either useful innovations or latent hazards that overtime may be taken for granted as part of regular work Visibility should allow for real-time performance monitoring and the free sharing of information (Galsworth, 2017)
Encourage diversity of perspectives when making decisions	Diversity of perspectives may help to tackle uncertainty Agents involved in decision-making should hold complementary skills Some requirements for the implementation of this guideline are high levels of trust, reduction of power differentials and identification of apt decision-makers (Page, 2010)
Monitor and understand the gap between work-as-done (WAD) and work-as-imagined (WAI)	Standardised operating procedures cannot cover all situations. Complexity theory regards procedures as dynamic, local and situated constructions, which need adaptation in the face of variability. This is in contrast with the traditional view of procedures as "devised by experts (management) to guard against the errors and mistakes of fallible human operators at the sharp end, who are more limited than the experts in their competence" (Hale and Borys, 2013). Procedures may be of different types (e.g. goal oriented, action oriented) and, for all types, the gap between them and practice should be monitored
Monitor unintended consequences of improvements and small changes	The impacts of small changes and improvements may be significant in complex systems due to non-linear interactions (Perrow, 1984). Improvements and small changes interact between themselves, and this poses opportunities for unintended consequences. Small changes and improvements may be either non-intentional or intentionally self-initiated by the organisation (e.g. through kaizen) as well as originated from external sources (e.g. a client changes its order)

Source: Adapted from Saurin, Rooke and Koskela (2013)

Table I.
Guidelines for coping with complexity

"create conditions that support resilience", is not explicitly discussed given that it is interpreted mostly as a consequence of following the other guidelines. These guidelines have been identified from a literature review that covered a wide variety of sources (e.g. theoretical discussions and reports of practical experiences of applying complexity thinking). Besides, their small number makes it practical their use for this Editorial. Piece of evidence of the construct validity of these guidelines in construction is available from Saurin, Rooke, Koskela and Kemmer (2013), who presented a description of what these guidelines look like in a refurbishment project. In healthcare, Bueno *et al.* (2019) discussed how improvement interventions in intensive care units accounted for these same guidelines.

It is worth noting that contingency is a core characteristic of socio-technical system design (Clegg, 2000) and, as such, the mentioned guidelines are context dependent, and their use can trigger undesired interactions. For example, privacy may sometimes take priority over visual control (Bernstein, 2012), and slack may introduce more parts and interactions into the system, thus creating new error possibilities (Perrow, 1984).

3. Overview of the papers included in this Special Issue

An overview of the 11 papers that form this Special Issue is presented in this section. Sherratt and Ivory unpack the shared understanding of safety held by workers on five large construction sites in the UK using a complexity lens. Results provide empirical support for the inclusion of situational self-organising as part of construction safety management systems.

Both the papers by Regis *et al.* and Aboagye-Nimo *et al.* address the role played by women in the construction industry. Regis *et al.* identify the main difficulties faced by female front-line workers at Brazilian construction sites, as well as good practices that might provide a better environment for them. In turn, Aboagye-Nimo *et al.* take a complementary perspective, focussing on difficulties faced by women in managerial roles in six large construction companies in the UK. Both studies point out several problems, such as prejudice in the hiring process, division of labour based on gender instead of competence and a struggle to re-enter the industry after maternity leave.

Hampton *et al.* investigate how stress develops and manifests in three UK construction projects, highlighting contributing factors to stress, consequences and tools to cope with stress based on an ethnographic study. Also, in the UK, Oswald *et al.* discuss the informal management activities and financial incentives that occur when projects are under production pressure. Both studies point out that coping with uncertainty about limited time is an essential source of stress and pressure to construction workers. Safety tends to be hindered by these pressures, according to Oswald *et al.*

MD and Gangadhar introduce a knowledge-based safety culture measurement tool and examine its validity and reliability in the Indian context. The tool is comprised of a questionnaire based on 69 factors that influence knowledge-based safety culture. Results of applying the questionnaire indicate the importance of accounting for the knowledge dimension when developing a safety culture in the construction industry.

Manu *et al.* develop a tool for assessing the Design for Occupational, Safety and Health (DfOSH) organisational capability of construction firms. The tool is organised around 18 capability attributes nested within 6 categories, namely, competence, strategy, corporate experience, systems, infrastructure and collaboration. The attributes related to competence are highlighted as the most important.

Jin *et al.* use the Prevention through Design (PtD) concept and 4D BIM as a basis to develop a tool for assessing construction risks – at the activity level and daily – during early phases of multistore building projects. A case study in the USA illustrates the application of the tool.

Nnaji *et al.* identify 26 factors that predict successful adoption of safety technologies in construction, in the context of the USA. Statistical analysis indicates that 12 out of the

26 predictors are the most influential – technology reliability, effectiveness and durability were ranked as the most influential predictors.

Mzyece *et al.* explore the interoperability between the Construction Design Management (CDM) regulations and BIM, based on a systematic literature review and theoretical testing. Results indicate that BIM provides a systematic approach for the discharge of CDM obligations.

Finally, Melo and Costa propose a framework to integrate resilience engineering concepts and unmanned aerial systems technology in order to support the safety planning and control process. A case study of applying the framework, in Brazil, demonstrates the benefits and barriers associated with the proposal.

Overall, these studies offer a mix of perspectives addressing: the description of what complexity looks like, such as the investigations of production pressures, stress and women's role; tools for measuring proxies of complexity, such as the safety culture survey and the list of attributes for assessing design for safety organisational capability; and tools for influencing complexity, such as the use of BIM and unmanned aerial systems for risk assessment and monitoring. These three perspectives have a parallel with the three emphases of resilience engineering studies identified by Nemeth and Herrera (2015), namely, finding resilience, assessing resilience and influencing resilience through design.

4. How the adoption of the guidelines was analysed

A content analysis of the papers above (Bryman, 2016) was carried out in order to assess whether and how the previously mentioned guidelines were accounted for by the papers that form this Special Issue. As such, we looked for excerpts of text that could point out examples of either adopting or neglecting the guidelines. An excerpt could consist of several lines of text, and be associated with more than one guideline. Data interpretation encompassed possible applications of the guidelines, even if these have not been explicitly discussed in the papers.

5. How the guidelines were accounted for

Table II presents the results of the analysis, illustrating how the papers accounted or could have accounted, for the five guidelines for coping with complexity. Examples of applying all guidelines were identified. This suggests that the complexity of construction projects can be intuitively acknowledged both in the research design and in the development of strategies for coping with complexity in practice.

Regarding the guideline "provide slack", Ziyu *et al.* describe an excellent example of applying a slack strategy known as the margin of manoeuvre. According to Stephens *et al.* (2011), this strategy means the creation of margin (i.e. slack in terms of time in this case) via local reorganisation or expansion of a unit's ability to regulate its margin – i.e. through early risk assessment based on 4D BIM. By contrast, insufficient slack (e.g. overtime work) seemed to be an underlying contributing factor to unsafe practices, workers' fatigue and stress, as pointed out by Hampton *et al.* and Oswald *et al.*

The use of information technology also supported innovative applications of the guideline "give visibility to processes and outcomes". Melo and Costa illustrate how this could occur through the use of unmanned aerial systems for safety inspections, while Ziyu *et al.* show how the benefits of 4D BIM visualisation for risk assessment.

The guideline "encourage diversity of perspectives when making decisions" was adopted in the research design of some studies – e.g. interviews with several stakeholders. Hampton *et al.* demonstrate how the neglect of the said guideline may be underlying the stress of construction workers and managers. Similarly, the use of the guideline "monitor and understand the gap between work-as-imagined and work-as-done" was intrinsic to some research designs that privileged qualitative data and understanding of the tacit and hidden social relationships in construction sites. This is illustrated by Sherratt and Ivory, who

Table II. Association between the guidelines for coping with complexity and the papers that form this Special Issue

Authors	Title	Guidelines: Provide slack	Give visibility to processes and outcomes	Encourage diversity of perspectives	Monitor and understand the gap between WAD and WAI	Monitor unintended consequences
Sherratt and Ivory	Managing "a little bit unsafe": complexity, construction safety and situational self-organising	This study lends empirical support to self-organising as an element of safety management. This accounts for control slack (Schulman, 1993), which means some range of individual action unconstrained by formal structures	A culture of enforcing compliance with safety signage may be at odds with a self-organising model	Evidence supporting the self-organising model was obtained from operatives, site foremen/supervisors and managers	The notion of self-organising acknowledges that WAD is different from WAI. Besides, workers' understanding of safety was explored in depth	Examples of unintended consequences arising from trade-offs between efficiency and safety were discussed
Emmanuel *et al.*	The complexity of women's modern-day challenges in construction	The skill shortage in the UK construction industry may be framed as a problem of insufficient slack. This is aggravated by the industry's lack of attractiveness to women	There is a need for giving visibility to discriminatory practices against women in the construction industry. Many women are afraid of speaking up about this	Lack of gender-diverse teams may hinder the exploration of innovative viewpoints and solutions	The study is based on in-depth interviews with six women in managerial positions. It sheds light on these women's perspectives of WAD	Employees' frustration, dissatisfaction and difficulty of hiring qualified employees may be unintended consequences of current approaches for gender in the construction industry
Regis *et al.*	Women in construction: shortcomings, difficulties and good practices	This guideline is not addressed in this study	Discriminatory practices against women are not widely recognised as such by men. Management gives visibility to procedures related to how women should behave at the site and interact with men,	Perceptions from both men and women were gathered from interviews. In conflict with this guideline, results indicated that women are encouraged not to talk too much to	The interviews provided empirical evidence of how discriminatory practices against women are normalised in the studied construction sites. Thus, work-as-done by women did not seem to be much	The study points out unintended consequences of discrimination against women, such as difficulties for balancing work and private life demands, and sexual harassment. Other

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Table II.

Authors	Title	Guidelines: Provide slack	Give visibility to processes and outcomes	Encourage diversity of perspectives	Monitor and understand the gap between WAD and WAI	Monitor unintended consequences
			instead of the other way around	men during work to prevent harassment	different from work-as-imagined by men, who took for granted some discriminatory practices	consequences, while undesired, could not be framed as unintended – e.g. division of labour based on gender rather than skills
Hampton *et al.*	Framing stress and associated behaviours at work: an ethnography study in the United Kingdom	The findings of this study suggest that insufficient slack (e.g. limited resources, need to work extra hours or during weekends) can be an underlying source of workers and managers stress	The study did not address this guideline	The neglect of this guideline (e.g. lack of communication, absence of feedback, difficult communication around negotiations and concessions) in construction sites may be a source of workers and managers stress	An ethnographic approach was adopted to understand how stress develops and manifests in ten construction sites of three construction companies. This is a proper approach to understand WAD	The study illustrates how several taken for granted work organisation practices in the construction industry generate stress as an unintended consequence
Oswald *et al.*	Managing production pressures through dangerous informality: a case study	In order to keep production schedule demands, workers are incentivised to accept overtime work. Fatigue and greater vulnerability to accidents result from this lack of slack, both at the individual and project levels	The informal incentive schemes are covert and unofficial – i.e. they, and their possible causes and consequences, are not widely visible to the relevant stakeholders	The adopted ethnographic research approach, over a 3-year study, allowed for capturing the perceptions of a wide diversity of agents. Production pressures were acknowledged across all hierarchical levels	The ethnographic approach offered insight into work-as-done, revealing several informal practices not anticipated by work-as-imagined	The discussion of the unintended consequences of production pressures and informal pay structures are a central aspect of this study
MD and Gangadhar	Developing a knowledge-based	The different stakeholders who	There is no discussion on how to give visibility	The survey was answered by clients/	The survey includes questions related to tacit	The study did not address this guideline.

(*continued*)

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	safety culture instrument for the construction industry: reliability and validity assessment in the Indian context	answered the survey may offer complementary perspectives. This accounts for cognitive slack (Schulman, 1993)	to the survey results. On the other hand, some of the survey items account for the visual management of safety	owners, contractors and consultants. As a drawback, there was a lack of participation from representatives of lower hierarchical ranks	knowledge, which plays a vital role in filling in the gaps in WAI	However, as it occurs with any measurement tool, it can have unintended consequences if associated with incentives for "right" or "desirable performance" (e.g. unreliable responses)
Manu *et al.*	Design for occupational safety and health: key attributes for organisational capability	Some attributes of the model of Design for Occupational Safety and Health (DfOSH) rely on a design review, which is a type of redundant inspection procedure	The study did not address this guideline	Intra and inter-organisational collaboration are some of the proposed attributes for assessing DfOSH capability	The need for advice from agents who are aware of WAD (in-house staff or external experts) is an attribute of the capability model	Although this is not explored in the paper, the DfOSH capability can be correlated with the capability to design cost-effective and high-quality buildings. This could be an unintended positive consequence of focussing on DfOSH
Chukwuma *et al.*	Influential safety technology adoption predictors in construction	The adoption of safety technologies is a means of designing slack into construction sites – e.g. redundant monitoring and warning systems	The use of explicit criteria for selecting safety technologies makes this process visible and traceable	Twenty-six predictors of technology adoption were identified, based on inputs from contractors, sub-contractors and consultants	As no specific safety technology is explored, details of WAD are not discussed. The list of predictors can be a framework for this investigation	The breadth of the list of predictors indicates issues that could give rise to unintended consequences (e.g. resistance from employees) when

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Table II.

			Guidelines			
Authors	Title	Provide slack	Give visibility to processes and outcomes	Encourage diversity of perspectives	Monitor and understand the gap between WAD and WAI	Monitor unintended consequences
						adopting a safety technology
Ziyu *et al.*	Using 4D BIM to assess construction risks during the design phase	Risk identification in the early project phases allows more time for the setup of safety measures	The 4D visualisation and simulation resources reduce perceived complexity	The 4D model offers a platform for collaborative risk assessment involving designers, contractors and owners	Prevention through Design (PtD), by definition, develops models of WAI. However, these models can be more precise if based on the accumulated knowledge of WAD	The authors argue that the proposed PtD tool does not disrupt the typical design process. However, a more comprehensive set of outcome measures, not only related to safety (e.g. quality, productivity) could shed light on desired and undesired, unintended consequences
Mzyece *et al.*	Building information modelling (BIM) and the CDM regulations interoperability framework	BIM offers a complementary and alternative approach for the discharge of CDM obligations. Thus, BIM can be framed as a slack resource in this context	BIM contributes to the discharge of CDM obligations, particularly in the context of information – e.g. exchange, storage, update, and review. This information is available on a platform accessible to relevant agents	BIM is well-known as a platform for collaborative work, which can encourage the uptake of diverse perspectives when coping with CDM regulations	The proposed CDM and BIM interoperability framework are discussed on a theoretical level (i.e. work-as-imagined). An empirical test is necessary to assess how it performs in work-as-done	The study did not address this guideline in depth, though difficulties for the uptake of BIM are mentioned
Melo and Costa	Integrating resilience engineering and UAS technology into construction safety planning and control	Unmanned Aerial Systems (UAS) are not intended to replace direct inspection and observation fully. UAS offers an opportunity for redundant inspections	Visual assets from safety inspections can be made available in real-time to several agents	All visual assets were available to the project personnel to assist in their decision-making process	The inspection checklist had a broad coverage, in addition to photos and videos. There was also a weekly indicator comparing WAD and WAI	There was a concern with unintended consequences from the UAS – e.g. interference in the construction tasks during the flight; and b) the invasion of privacy

Table II.

uncovered workers self-organising strategies that contributed to maintaining safety in the face of complexity. The study by Oswald *et al.* also shed light on work-as-done by using an ethnographic approach for investigating production pressures.

Finally, the adoption of the guideline "monitor unintended consequences of improvements and small changes" was implicit in some papers when they discussed barriers to implement the proposed solutions and the drawbacks of refusing to cope with complexity. This point is exemplified by the two papers that addressed the role played by women in the construction industry (Regis *et al.*, Emmanuel *et al.*). Discriminatory practices and the sector's lack of attractiveness to women ultimately hinder the industry's performance, in terms of skill shortage and lack of cognitive diversity.

6. Conclusions

This Special Issue documents empirical and theoretical work that contribute to the understanding of construction safety, health and well-being from a complexity lens. The papers cover a wide range of social and technical topics, which need to be investigated from a holistic and integrated perspective. The contents are expected to encourage innovative thinking and action for coping with complexity in construction. In particular, there seems to be an opportunity for the investigation of how the five discussed guidelines for coping with complexity – along with other insights from CT and systems safety approaches – can give rise to new principles and practices to support resilience in construction projects.

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