Guest editorial

Innovation in construction health, safety and environmental research

Technical and behavioural innovation in construction health, safety and environmental management is promising to transform the construction industry's reputation from a relatively dangerous and unhealthy working environment to one where risk-related issues are more effectively "managed". Recognising this, *Construction Innovation* has dedicated a special issue to this movement.

The reputation for poor safety, health and environmental conditions is historically well grounded in the construction industry. A century ago, it was accepted that deaths would occur at a rate related to the dollar value of a project or the number of floors of a skyscraper. For example, 5 men died during the construction of the Empire State Building (completed 1931), and 27 workers died during the construction of the Brooklyn Bridge (completed 1883) in New York City. However, exceptions existed. For example, a shortage of skilled workers after an outbreak of the plague resulted in outstanding safety engineering and performance of the construction of Brunelleschi's Dome for Florence's Santa Maria del Fiore in the early fifteenth century, according to King's book "*Brunelleschi's Dome: How a Renaissance Genius Reinvented Architecture*". Similarly, the Golden Gate Bridge in San Francisco is often cited for its exceptional safety performance. However, until the early 1980s, in North America at least, the economic and moral costs of a human life were not typically sufficient to merit special attention to good health and safety and environmental practices. Later in the 1980s, workers' compensation insurance costs were increased by 50 per cent to the labour costs for iron workers in cities such as Chicago. Given this, the economic and moral arguments for addressing the industry's poor safety record became overwhelming, and pressure to examine the problem to improve the situation consequently increased.

Studies published in the 1990s, such as those funded by the Center to Protect Workers' Rights (CPWR) in Silver Spring, Maryland, and the Construction Industry Institute (CII) in Austin, Texas, began to empirically identify best safety practices. These were built on "the Three E's": engineering, enforcement and education. The identified best practices included:

- tool box meetings at the beginning of every shift to discuss safe methods for the planned work;
- structured hazard analysis processes;
- drug testing;
- corporate leadership commitment; and
- cultural changes to encourage mutual vigilance.

Implementation of best practices correlated over time, with improvements in measured rates of safety. For example, the industry's Lost Workday Case Incident Rate (LWCIR) declined from 6.8 in 1989 to 2.5 in 2008, and the rates for CII's members declined from 1.9 in 1989 to 0.20 in 2008. The construction industry's Total Recordable Incidence Rates (TRIR) in the same period declined from 14.30 to 4.70, while the TRIR for CII members declined from 7.19 to 0.57. While these results are encouraging, Karimi *et al.*'s article in

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this special issue points out that, "the fatality rate in construction declined from 14.24 to 9.4 per 100,000 full-time equivalent workers from 1992 to 2010, which accounted for a 34 per cent drop (CPWR, 2013)". This was less impressive. However, in the past five years, the rate of accidents has essentially flat-lined. In 2013, the TRIR for the industry was 3.8 and that for the CII companies was 0.37, while the LWCIR in 2013 was 2.2 for the industry and 0.15 for the CII members (www.construction-institute.org/scriptcontent/ac2015slides/ac15-crew-opener.pdf). Clearly, further innovations are required beyond "best practices".

Some of these innovations are presented in this special issue. They combine several key facets, including:

- behavioural modification;
- automation and robotics;
- real-time sensing and monitoring;
- education, training and feedback;
- design for safety;
- leading indicators,
- virtual and augmented reality; and
- plant and equipment multi-disciplinary engineering innovations.

For example, in "Right-time vs Real-time Pro-active Construction Safety and Health System Architecture" (Teizer), the concepts and tools from automation, robotics, real-time sensing, design for safety and training are integrated in a framework for the support of future research, development and deployment. Here, the focus is primarily on safety.

In, "Physiological cost of concrete construction activities" (Migliaccio and Lee), health is the primary focus. Concrete construction workers are studied in controlled situations, and the data are analysed from several perspectives. Perhaps, the key finding is that widely deployed heart rate monitoring is now technically and economically feasible. It is a good indicator of workload, and can be used to control excess loading that can lead to health problems.

Overloading is one of the possible mechanisms for the relationship discovered and validated empirically in "Quantitative Analysis of the Impact of Craft Worker Availability on Construction Project Safety Performance" (Karimi *et al.*). This paper presents a strong statistical argument for a relationship between labour shortages and the substantially worsening safety performance on projects. Why is this true? Labour shortages on a project may lead to schedule pressures and lower than average skill levels, which may lead to more overtime, which may lead to fatigue and more accidents. Implications are sobering. If labour shortages continue, risk of accidents will inevitably increase.

A complementary empirical framework is presented in, "Information technology and safety: Integrating empirical safety risk data with building information modelling (BIM), sensing, and visualisation technologies" (Hallowell *et al.*). A vision is presented for an innovative, empirical combination of technologies and data to reduce accident risk. It is suggested that accident risk patterns can be recognised automatically based on attributes of a task and its situation, and that such patterns can also be related to potential impacts. Attributes are collected from a number of information sources, including sensors.

Sensors, and machine vision in particular, play a lead role in, "Tracking-Based 3D Human Skeleton Extraction from Stereo Video Camera for an On-site Safety and Ergonomic Analysis" (SangHyun *et al.*), and in "Classifying Construction Site Photos for Roof Detection: A Machine-Learning Method towards Automated Measurement of Safety Performance on Roof Sites" (Dai *et al.*). Skeleton extraction using machine vision can be used to track body motion for posture analysis, biomechanical analysis and activity recognition. This is useful information for safety monitoring and analysis, as well as for ergonomic analysis. Limitations due to occlusions, illumination and site deployment provide good material for future research. Machine vision is also demonstrated to detect violations of safety procedures in roofing. Falls from roofs are a major cause of accidents and fatalities in North America; while these violations are easily recognised, the subsequent enforcement is often lax, and it is likely that many of us have walked past such violations at least once in our lives without intervening. Anything that can be done to improve safe roofing behaviour would be a significant contribution.

Finally, in "Opposing Influences on Construction Plant and Machinery Health and Safety Innovations" (Holt), this paper acts as fervent reminder that despite constant engineering innovations in plant and equipment such as vibration isolation, field of view improvement and safety locks, that "behaviour" remains possibly the key challenge. Undesirable behaviour and lack of training tends to limit the positive influence of engineering innovations, and actions are proposed to mitigate the conflict between such influences.

As a whole, the articles presented in this special issue on "Innovations in Construction Health, Safety and Environmental Research", represent a high-quality sampling of the broader body of related research in this arena. Their impact is compelling, significant and thought-provoking.

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