Journal of Safety Research 41 (2010) 107–122

Contents lists available at ScienceDirect

Journal of Safety Research

journal homepage: www.elsevier.com/locate/jsr

Mitigating construction safety risks using prevention through design

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ARTICLE INFO

Available online 2 April 2010

Keywords:
Construction Hazards Prevention through Design
Risk assessment
Health and safety management
Building
Construction process

ABSTRACT

Introduction: Research and practice have demonstrated that decisions made prior to work at construction sites can influence construction worker safety. However, it has also been argued that most architects and design engineers possess neither the knowledge of construction safety nor the knowledge of construction processes necessary to effectively perform Construction Hazards Prevention through Design (CHPtD). *Method:* This paper introduces a quantitative methodology that supports designers by providing a way to evaluate the safety-related performance of residential construction designs using a risk analysis–based approach. The methodology compares the overall safety risk level of various construction designs and ranks the significance of the various safety risks of each of these designs. The methodology also compares the absolute importance of a particular safety risk in various construction designs. *Results:* Because the methodology identifies the relevance of each safety risk at a particular site prior to the construction stage, significant risks are highlighted in advance. Thus, a range of measures for mitigating safety risks can then be implemented during on-site construction. *Impact on industry:* The methodology is specially worthwhile for designers, who can compare construction techniques and systems during the design phase and determine the corresponding level of safety risk without their creative talents being restricted. By using this methodology, construction companies can improve their on-site safety performance.

1. Introduction

The construction industry is statistically one of the most hazardous industries in many countries (Carter & Smith, 2006; Wang, Liu, & Chou, 2006; Camino, Ritzel, Fontaneda, & González, 2008). For example, in Spain, approximately 30% of fatal accidents in all industries between 2000 and 2006 occurred in the construction industry, killing approximately 350 employees per year (Ministerio de Trabajo e Inmigración, Subsecretaría de Trabajo y Asuntos Sociales, 2006). Besides causing human tragedy, construction accidents also delay project progress, increase costs, and damage the reputation of the contractors (Wang et al., 2006).

Formal identification of hazards in the workplace is one of the foundations of successful safety management (Trethewy, Atkinson, & Falls, 2003; Carter & Smith, 2006) and an essential component of occupational health and safety (OHS) legislation (Trethewy et al., 2003). However, the findings of Carter and Smith (2006) indicate that current hazard identification levels in construction projects are far from ideal. These authors identified several significant barriers to improving hazard identification: knowledge and information barriers (i.e., failure to share information across projects, lack of resources in smaller projects, subjective hazard identification and risk assessment, and reliance upon tacit knowledge), and process and procedure barriers (i.e., lack of a standardized approach, and undefined structures for tasks and hazards).

Most contractors see their health and safety plans, which must include full risk assessment, as merely a burdensome requirement that they must fulfill in order to avoid government fines. As a result, they often neglect the proper implementation of these plans (Wang et al., 2006; Saurin, Formoso, & Cambraia, 2008). Since the adoption of Royal Decree 1627/1997 (transposition of Directive 92/57/EEC), Spanish building designers are legally required to consider working conditions in their designs. However, studies have shown that designers in general—not just in the construction industry—fall short of satisfying this obligation (Behm, 2005; Fadier & De la Garza, 2006; Frijters & Swuste, 2008). Some earlier studies have indicated that safety planning and control methods need to be improved even beyond what is required by regulations and standards (Saurin, Formoso, & Guimaraes, 2004).

Not only contractors, but also designers, architects, and structural engineers have an influence on the health and safety of building site employees (Gambatese & Hinze, 1999; Behm, 2005; Frijters & Swuste, 2008; Gambatese, Behm, & Rajendran, 2008; Toole & Gambatese, 2008). Research conducted by Behm (2005) and Gambatese et al. (2008) demonstrated that 42.0% of construction fatalities were linked to the design of the construction safety concept.

In recent years, academics and professionals have focused on the concept of Construction Hazards Prevention through Design

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doi:10.1016/j.jsr.2009.10.007

(CHPtD), in which engineers and architects explicitly consider, during the design process, the safety of construction workers (Toole & Gambatese, 2008). As noted by Toole and Gambatese, even though articles on CHPtD have appeared in top construction journals, the literature has not yet addressed the technical principles underlying CHPtD in order to help designers better perform CHPtD and to facilitate the development of additional CHPtD tools. Additional tools and processes are needed in order to assist architects and design engineers with hazard recognition and design optimization (Gambatese, 2008).

Up until now, most publications on this subject have offered solutions that can be directly implemented and checklists for the subsequent monitoring of the design. Precise advice of this sort inhibits the designer's creative process and hampers the usual design process (Frijters & Swuste, 2008). Other authors, such as Gambatese and Hinze (1999), have developed a repository with design suggestions for improving construction worker safety while in the design phase.

Even so, there has been little research on how health and safety aspects can be interactively integrated during the design and preparation phase. Of the papers that have provided such methods, the approaches of Carter and Smith (2006), Cheung, Cheung, and Suen (2004), Cheung, Tam, Tam, Cheung and Suen (2004), Imriyas (2009), and Seo and Choi (2008) are among the most noteworthy; however, subjective judgments often influence their accuracy. Especially worthwhile is the method developed by Frijters and Swuste (2008), which has proved to be an objective, albeit labor-intensive, way of integrating safety aspects into the design process.

This study aims to establish the necessary basis and criteria to quantitatively measure the safety performance of construction projects. Its objectives are, first, to provide designers with a risk-analysis-based way of evaluating the safety-related performance of their residential construction designs, and second, to help construction companies improve their on-site safety performance.

Therefore, we have developed a quantitative methodology for dealing with potential safety risks at the pre-construction stage (in the design, planning and preparation phases), thereby contributing to the customization of the Safety Decision Hierarchy proposed by Manuele (2006) for construction projects. This hierarchy supports the idea that it is better to eliminate safety hazards through design than to later try to protect workers from hazards. In short, proactive hazard identification and elimination is safer and more cost-effective than reactive hazard management (Toole & Gambatese, 2008). This proactive elimination of hazards must be done by designers during the conceptual and detailed design of a facility (Toole & Gambatese, 2008). Hazards remaining after successive redesigns must be addressed by the contractor during the execution phase.

2. Methods

This paper presents a systematic approach for dealing with potential safety risks at the pre-construction stage (in the design, planning, and preparation stages). The proposed methodology serves as an assessment tool for measuring the safety risk level of construction projects. It also provides a consistent basis for comparisons, future labeling, and CHPtD benchmarking between different construction companies and construction sites.

Fig. 1 summarizes the methodology for predicting and assessing the safety risks related to the construction of residential buildings.

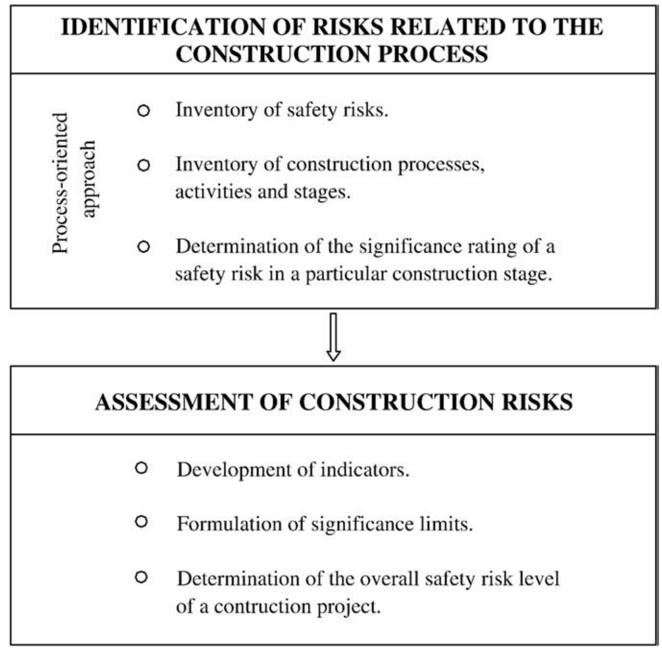

Fig. 1. Research methodology.

The first step is to identify specific safety risks related to the construction process. The process-oriented approach requires an inventory of construction processes, activities, and stages, as well as common safety risks. Decisions regarding significant risks in each construction process must be made based on the establishment of a significance rating. The second step is to assess construction safety risks. This involves developing corresponding indicators, formulating significance limits, and determining the overall safety risk level of a construction project.

2.1. Identification of safety risks related to the construction process

The first step of this methodology is to identify construction risks. For this purpose, an exhaustive, process-oriented preliminary analysis, similar to that of Gangolells et al. (2009), is carried out (Fig. 2).

2.1.1. Inventory of construction processes, activities and stages

In any process-oriented approach, the first step is to identify the main processes. As in Gangolells et al. (2009), the construction processes considered as main processes were (1) earthworks, (2) foundations, (3) structures, (4) roofs, (5) partitions and closures, (6) impermeable membranes, (7) insulations, (8) coatings, (9) pavements, and (10) door and window closures. Each of these main processes was separated into smaller process steps. A total of 219 stages and activities were ultimately considered in this initial safety review (Fig. 2).

2.1.2. Inventory of safety risks

As suggested by OHSAS 18001:2007 and OHSAS 18002:2000, this initial review uses reports of incidents (including ill health) and accidents that have occurred in other organizations (Fig. 2). The Occupational Accident Report Form of the Spanish National Institute of Safety and Hygiene at Work was used as a guide in order to initially identify general safety risks (Fig. 2).

2.1.3. Determination of the significance rating of a safety risk in a particular construction stage

OHSAS 18001:2007 defines a risk as the combination of the likelihood of occurrence of a hazardous event and the severity of the injury or ill health that can be caused by the event. Consideration of risks in terms of the probability of their occurrence and the severity of their consequences provides the general rationale behind safety risk assessments (Carter & Smith, 2006). Probability (P) is defined as the likelihood of a hazard's potential being realized and initiating an incident or series of incidents that could result in harm or damage. Severity of consequences (C) is defined as the extent of harm or