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Modeling injury rates as a function of industrialized versus on-site construction techniques

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ABSTRACT

It is often predicted that the industrialization of building activities will lead to a reduction of accident rates in the construction sector, particularly as a result of switching activities from building sites to factories. However, to date no scientific research has provided objective quantitative results to back up this claim. The aim of this paper is to evaluate how industrialization affects the accident rate in different industrialized building systems in Spain. Our results revealed that the industrialized steel modular system presents the lowest accident rate, while the highest accident rate was recorded in the construction method with cast-in-place concrete. The lightweight construction system also presents a high accident rate. Accordingly, industrialized building systems cannot claim to be safer than traditional ones. The different types of "on-site work" seem to be the main variable which would explain the accident rates recorded in industrialized construction systems.

1. Introduction

The building industry had one of the highest accident rates in Spain in 2010 (Rubio Romero, 2005), with one of the highest rates of fatal work accidents (Ministerio de Trabajo e Inmigración, 2010). According to the International Labour Organization (ILO, 2003), at least 60,000 people die worldwide and many hundreds of thousands more suffer serious injuries and health problems on construction sites every year.

To reduce the accident rate in the sector one of the partial solutions proposed in the bibliography has been to replace traditional high risk tasks performed on building sites with lower risk tasks in factories. The idea is to increase the number of prefabricated elements such as facade panels, floor to ceiling walls, etc. A list of most of the prefabricated and modular building elements is shown in Table 1.

Traditional on-site production activities for building walls, floor slabs, ceilings, concrete or steel structures, or even heating, gas or electrical installation work, can be done, either partially or entirely, in a safer environment using industrialized building systems which can reduce risks and save time.

In this sense, Morse et al. (2009) came to the conclusion that "a significant proportion of the decline in injury and illness rates appears to be due to demographic shifts in industry composition", in other words, "a shift in employment from more hazardous to less hazardous industries" (Morse et al., 2009) means less workplace accidents. In this respect, new innovative elements and technologies, such as computerized systems (Aouad et al., 2012; Mahalingam et al., 2010), sophisticated machinery and tools, concrete additives (Martín Cosano, 2013; Uysal et al., 2012), etc., lead to greater efficiency on construction sites by using new industrialized building techniques. Industrialized building systems let us to transfer labour activities from the construction site to the factory, which will eventually contribute to a significant reduction in the accident rate in the building industry (Escrig Pérez, 2010).

In this sense, industrialization represents an increase in rationalization, the intensification of repetitive operations and greater specialization of workers. However, industrialization is usually also accompanied by a transfer of the traditional craftsmanship carried out on the building site to the factory (Escrig Pérez, 2010) or, in terms consistent with the above definitions, by a general increase in pre-fabrication.

Despite the transfer of work from the building site to the factory usually associated with industrialization, and the foreseeable impact on health and safety performance at work (Del Águila García, 2006; Morse et al., 2009), no studies on the impact of this change have been published and, consequently, empirical and quantitative estimations are not available. Research on the industrialization of building activities has so far concentrated on

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Table 1
Prefabricated and modular building elements (Barton et al., 2011).

Most commonly used prefabricated and modular building elements
Exterior walls
Mechanical, electrical and plumbing (MEP) building systems
Building superstructure
Roof construction
Floor construction
Interior room modules

Table 2
Classification and description of building systems considered.

1. Traditional building systems	Description	
1.1 Conventional construction methods	"Components of the building are pre-fabricated on site using timber or plywood formwork installation, steel reinforcement and cast in-situ". (Haron et al., 2005) This building system is considered much more costly and includes labor, raw material, transportation and low speed of construction time (Badir et al., 2002)	
2. Industrialized building systems (IBS)	Description	
2.1. Lightweight construction	Uses lightweight profiles, boards and laminated boards to provide flexibility and multiple configurations to build walls and ceilings with guarantees of complying with the thermal and acoustic insulation and mechanical and fire resistance established in construction standards.	
2.2. Concrete construction	2.2.1. Concrete structural panels	Uses precast concrete elements (i.e. walls, columns, etc.) that are built horizontally. After the concrete has cured, these elements are placed vertically and braced into position until the remaining structural components (roofs, intermediate floors and walls) are secured.
	2.2.2. Cast-in-place formwork	The concrete is poured where it is required to harden as part of the structure, as opposed to precast concrete. We consider it as IBS because careful planning of cast in situ work can improve productivity, speed, and total cost (Ismail, 2001; Haron et al., 2005).
2.3. Modular construction	2.3.1. Steel modular construction	Uses different kind of materials (steel, concrete, mixed, etc.). The modules are built in a remote manufacturing facility, transported to the site and assembled in situ.

environmental issues or work and production procedures. This is the case of the contributions made by Cooley (1980), McCutcheon (1989), Takada, (1990), Tam et al. (2007), etc.

Research on industrialized building and workplace health and safety have basically considered safety as a by-product of project design, the so-called Safety through Design (also known as Prevention through Design or PtD). In this sense, some of the authors who have studied safety through design are Behm (2005), Fadier and De la Garza (2006); Frijters and Swuste (2008), Gambatese et al. (1997, 2005, 2008), Gibb et al. (2004), Haslam et al. (2003), Tool (2005);, Tool and Gambatese (2008). Particularly important among these contributions is HASPREST, the pioneering research work carried out by Alistair Gibb of the University of Loughborough (UK) from 2002 to 2005. The main focus of this study was to analyze the benefits and implications for health and safety derived from the use of prefabricated elements in construction activities (Health, 2005).

This research aims at providing an estimation of the extent of the change of work from building site to factory and, at the same time, a tentative estimation of the accidents rate associated with industrialized systems. An exact estimation would allow us to assess the explanatory value of the variable total time on-site. In addition, these results would provide us with more objective information so that industrialized systems could be more accurately compared with traditional building systems.

2. Methodology

In order to estimate the how much work is moving from building site to factory due to industrialization, we first defined a reference building which could be constructed using different types of industrialized building systems or the traditional system (see Table 2). This approach would enable us to make a preliminary estimate, in objective terms, of the differential accident rate.

2.1. The reference project

Apart from the traditional building system, the different industrialized building systems needed to be clearly identified in order to define our model. For this purpose, we used the classification suggested by Del Águila García (2006), Gomez Muñoz (2008), which includes three basic categories (see Table 2): lightweight construction, concrete construction and modular construction.

Given the difficulty of finding companies specialized in the different types of industrialized building and also willing to take part in the research, we focused on identifying and involving at least one company for each of the basic building categories mentioned above. After a protracted web search of associations of specialized companies, 5 companies finally committed to the project, each corresponding to one of the basic categories defined by Del Águila García (2006) and Gomez Muñoz, 2008. One additional company was included to represent traditional building methods for comparison. In the end, we obtained the collaboration of the following companies:

- One company implementing traditional building methods. Concrete construction and interior partitions with ceramic brick.
- One company using lightweight construction with profiled metal sheets.
- Two construction companies employing concrete construction, one with structural panels and the other cast-in-place formwork.
- One company using steel modular construction.

The reference project chosen for comparative analyses had to meet the following characteristics so that all of the systems could be applied and be technically and economically viable:

(1) Height, span and open-plan spaces: lightweight construction systems are not suitable for high buildings, since profiles can only support the heavy loads involved with extremely complex underpinning.