REDUCING THE HUMAN COST IN CONSTRUCTION THROUGH DESIGN

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The construction industry is still one of the highest risk industries as far as Work-related Musculoskeletal Disorders are concerned. Literature reviews written on and observation of the health and safety management of construction projects show that there are windows of opportunities for professional designers to contribute to safety and health of workers in construction and maintenance processes. A model for a participatory design is proposed to show the paramount importance of partnerships between various stakeholders in the preparation of a construction project to result in a healthy and safe construction workplace over and above an enhanced productivity and quality.

Health and safety, design, construction, building planning

1 Introduction

The construction sector remains one of the highest risk sectors in Sweden in regard to Work-related Musculoskeletal Disorders (WMSDs). These disorders are a long-term discomfort caused by work that it is the result of acute or instantaneous trauma of soft tissues or their surrounding structures (Dimov et al, 2000). In the Swedish construction industry, more than one man in five, twice as many as for all men employed, has reported work-related musculoskeletal disorders (Lundholm and Swartz, 2006) and these disorders constitute about 69% of all reported work-related injuries in 2005 (Samuelsson and Lundholm, 2006). The cost of WMSDs associated with direct worker compensations is high. The direct costs from compensation of musculoskeletal disorders are appreciated far more than the indirect costs associated with disruptions in productivity and quality, worker replacement costs, training and work absence costs. It is believed however, that the direct costs due to compensated work related musculoskeletal disorders are only a relatively low proportion (30-50%) of the total costs (Hagberg et al., 1995). The construction industry health and safety image problem and today's booming economy make it difficult for this industry to draw more educated workers. The shortage of skilled workers threatens the quality of construction, as inexperienced apprentices tend to make more mistakes requiring correction (ICAF, 2000). Thus, it is really of paramount importance to improve the construction work environment in order to keep skilled workers as well as reducing the construction time and increasing quality. Some studies have shown that a fairly large percentage of construction accidents could have been eliminated, reduced, or avoided by making better choices in the design and planning stages of a project (Hecker et al, 2005). Therefore, paying attention to health and safety issues in the design phase could have a significant impact in reducing the risk of injuries and the cost associated with health and safety related project delays.

2 Preventing WMSDs at the pre-build phase

Prevention through design, the concept that significant reductions in injuries can occur when safety is designed into a product, service or process, has been established within the general occupational health and safety field for many decades (Manuele, 1997). The basic philosophy of successful ergonomic design seems to be the anticipatory thinking in terms of design processes and their consequences. Thus, anticipation means that the designer is aware of the consequences of his actions (Luczak et al., 2006).

According to OSHA (2004), architects and quantity surveyors should be made aware of the potential improvements that can be introduced if manual handling methods were reviewed during the design phases of projects. Contractors, clients, and suppliers can encourage good practice standards to be fully implemented. Employers have legal duties to protect workers from WMSDs, based on European Directives. Where the risk of musculoskeletal disorders cannot be designed out at the pre-build phase, then employers should carry out a risk assessment to identify the hazards, assess the risks, and take action to prevent ill health or injury (OSHA, 2004).

3 Design for construction workers and end-users

Designer decisions made during the schematic and design development phases of a construction project directly impact health and safety of construction workers on the worksite. Many decisions also impact the safety of end-users, maintenance and repair workers, and construction crews during renovation or deconstruction cycles (Haas, 1999). In the design of buildings and other structures designers consider health and safety of end users in the design of the permanent structure, but similar concerns for construction workers during the building process are traditionally ignored (Rwamamara, 2005; Hecker et al., 2006). The hierarchy of controls and elimination of hazards in occupational health and safety recognizes that engineering controls and the elimination of hazards through design are preferable to administrative controls and personal protective equipment in limiting worker exposure (Manuele, 1997; Hecker et al., 2006). Health and safety concerns addressed by architects and engineers apply almost exclusively to the end-user of a building, rather than the workers who construct it. For example, in a Swedish study where a number of architects were interviewed on whether or not they take into consideration health issues into their design, to this question they responded that their design considers the health and safety of the end-user and not the construction worker (Rwamamara, 2005). Traditionally a boundary has been created between design and construction by defining expected scopes of work and standards of practice, however new safety knowledge exposes the design professional’s significant influence on worker safety (Gambatese, 1998). There are however many instances in which design improvements have been shown to affect both workers and end-users. To mention just a few examples; designing scaffolding tie-off points into exterior walls of buildings for construction and renovation purposes, and design of high parapet walls to protect workers on the roof and end-users during the life of the building. These walls will provide immediate guardrail protection and eliminate the need to construct a guardrail during construction or future roof maintenance (Behm, 2006). Further examples on impact of addressing worker’s health and safety in design are reported in Weinstein et al. (2005), whereby providing more space and height for a variety of trade workers, design changes reduced ergonomic risks, and likely alleviated problems related to congestion, access, and material handling.

4 Where design can make a difference

Design has the potential to reduce health and safety risk through materials and equipment design. A UK research project that studied about 100 accidents, using an ergonomics systems approach, to identify where safety is compromised and why; an analysis of design factors in the 100 accidents suggests that approximately half of these incidents could have been prevented by design alteration (Gibb et al., 2004).

The following were the type of designers considered in the UK study and their potential in risk reduction:

- Permanent works designers (architects, civil and structural engineers, mechanical and electrical engineers, etc.) could have reduced the risk in almost half of the accidents.
- Materials designers (design of materials themselves and their packaging, delivery method, etc.) could have reduced the risk in more than a third of the accidents.
- Equipment designers (tools, plant, and equipment) could have reduced the risk in 60 of the 100 accidents through improved design of the equipment being used.
- Temporary works designers (scaffolding, formwork, etc.) could have reduced the risk of more than a third of the accidents.

In regard to WMSDs reduction, studies on ergonomic risk factors (Schneider et al., 1995) and ergonomic interventions in construction (Schneider, 1999) point us in the direction where to focus our design improvements efforts; thus it makes sense that professional designers could make a difference in the following areas identified from a study review on best practices conducive to the reduction of WMSDs (Rwamamara, 2005): the access for material and equipment; worker's anthropometry and access; the size and the weight of materials; prefabricated buildings; temporary works

These suggested areas are in line with what Toole and Gambatese (2006) have identified as the trajectories that designing for construction safety is likely to follow.

Design for material and equipment access

With the growing industrialization of construction and the gradual shift to offsite prefabrication of structural and finishing elements that are then assembled on site, production equipment and support structures are increasingly making room for transportation equipment (Shapira, 2007). Thus, material handling and lifting equipment dominates construction sites. Consequently, designing for material and equipment should take account that equipment and material need to be delivered and removed during and after construction work; this could be done through designing vertical wall hatches on all floors which can provide access for machine stocking and mechanized lifting which could greatly reduce the risk of injury. When designing for material and equipment, it is extremely important to produce realistic methods statements. These method statements should indicate type of materials, type of machinery, the type of tools and the actual process of working to be undertaken. By devising a comprehensive method statement for all elements of construction work, it is possible both to enhance safety and to improve productivity. When these method statements are dealt with during the design process, then one has an opportunity to value-manage the construction project (Lingard and Rowlinson, 2005).

Design for Worker's anthropometry and access

To have a safe work environment, designers should account for the variations in the anthropometrics of the workforce (Gnaneswaran and Bishu, 2006). People come in a great variety of sizes and the proportions of their body parts are not the same. In reality, hardly a person exists who is average in most or all respects, consequently products or processes "designed for the average" fit nobody well (Kroemer et al., 2001). Thus, devising tools, gear, and workstations to fit their bodies require careful consideration; design for the statistical "average" will not work. Instead, for each body segment to be fitted, the designer must determine what dimensions are critical: this may be a minimal or a maximal value, or a range. Often, a series of such decisions is necessary to accommodate body segments or whole body by workspace and equipment. To achieve ease, efficiency, and safety, it is mandatory to consider the ranges of, the variations in, and the combinations of physiologic and psychological traits to accommodate anthropometric variability (Kroemer, 2006). General criteria for workspace layout relate to human strength, speed, effort, accuracy, importance, frequency, function, and sequence of use. Achieving the task while assuring safety for humans, avoiding overuse and unnecessary effort, and assuring ease and efficiency, are the primary design goals (Kroemer, 2006). Architects can draw an assembly or arrange space to promote a safer access during work and after completion, for example by minimizing the number of confined spaces and thus minimizing awkward postures for workers. In addition to designing for worker's anthropometry and his workplace for easy access; it is important to design for access and placement by crane or other lifting equipment such as worker-lifts.

Size and weight of materials

Size and weight of building materials directly impact construction workers, therefore material choice and dimension can be used to protect workers and reduce the cost (Rwamamara, 2007). Design that considers the size and weight of the building materials to be used will reduce the risk of WMSDS by diminishing the likelihood of heavy manual material handling. In addition to this benefit, the cost of material waste (due to resizing) and extra work repetitive work tasks related to resizing of materials on the construction site will be eliminated.

Design for prefabrication

Prefabrication involves the assembly of pieces in a factory, followed by the transportation of the assembled component to its permanent location and the final fit up. According to Toole and Gambatese (2006), prefabrication does reduce the hazard level of a task in two ways: First, it allows the work location to be shifted to a lower hazard environment where risks associated with working at height or in confined spaces are reduced; secondly, prefabrication allows the work to be shifted from the construction site to a factory, which allows the use of safer, automated equipment which reduces the incidence of WMSDs. The use of prefabricated components eliminates or reduces many traditional construction work tasks that are associated with WMSDs risk factors (Simonsson and Rwamamara, 2007). Furthermore, Gibb et al. (2004) suggest that permanent works designers could reduce the risk by reducing the amount of work done on the construction site, mainly through increased use of some form of pre-assembly. Among the most important benefits attributed to the use of prefabrication or off-site production are; minimization of on-site operations, reduction of site congestion, reduction of on-site duration and improved health and safety (Gibb and Isack, 2003). These benefits which are all directly or indirectly lead to health and safety of the construction worker should be considered in their designs.

Design for temporary works

As argued by Lingard and Rowlinson (2005) the contractor is expected to design temporary works, however in case of particularly complex elements, it is essential that the designer consider temporary works in the design process. Temporary works are often needed either because there is a risk that a structure might otherwise collapse or because it is necessary to remove some vital supporting member for renovation or alteration. All temporary works should be designed before the start of the construction phase and the level of design and drawings of temporary works such as scaffolding, cranes and telescopic props must commensurate with the scale of the works. For example the design of scaffolding should not, unless it is very straightforward, be left to the scaffold erector; it is important that prior thought be given to the location of scaffold foundations, where standards can and cannot go and where boarded out decks are required to enable the work to proceed with as little difficulty and risk as possible.

5 Design means and methods

Design is a problem solving process, and in this paper, this process is concerned with the designer's ability to adopt the construction work environment to suit workers health and safety needs. The design process could emulate the Construction Design and Management (CDM) regulations in UK and EU which clearly define the designer's duties in respect of reducing health and safety risks during construction to avoid hazards, combat risks and provide information. According to the CDM regulations in the UK, the best form of protection against a hazard is to eliminate the hazard at source. Where elimination and /or reduction of the impact of the hazard are not possible, the information about the hazard should be provided so that it can be dealt with as safely as possible (Wright et al., 2003). To evaluate WMSDs risk implications in construction design, the design process needs a multidisciplinary team, involving all stakeholders involved in the design, construction and use of the facility. Participants might include design professionals, the client, the principal contractor, sub-contractors, the suppliers and service consultants or maintenance contractors. A Participatory health and safety Design (figure1) which takes into account of inputs from all stakeholders in design and construction processes at the conceptual design level is proposed and presented as a conceptual model to improve the construction workplace in regard to health and safety risks in general and WMSDs risks in particular.

The participatory design model in fig.1 shows those important relationships that design professionals should have in order to reach an optimal design that reduces the human and the financial cost. Designers are to get inputs from other stakeholders in a construction project in order to produce a participatory health and safety design that is not detrimental to the workers' health and safety both during the construction phase as well as during the maintenance phase for the end-users; thus the participatory design saves construction projects not only human cost by reducing or eliminating injuries, but it does save on financial costs related to productivity and quality.

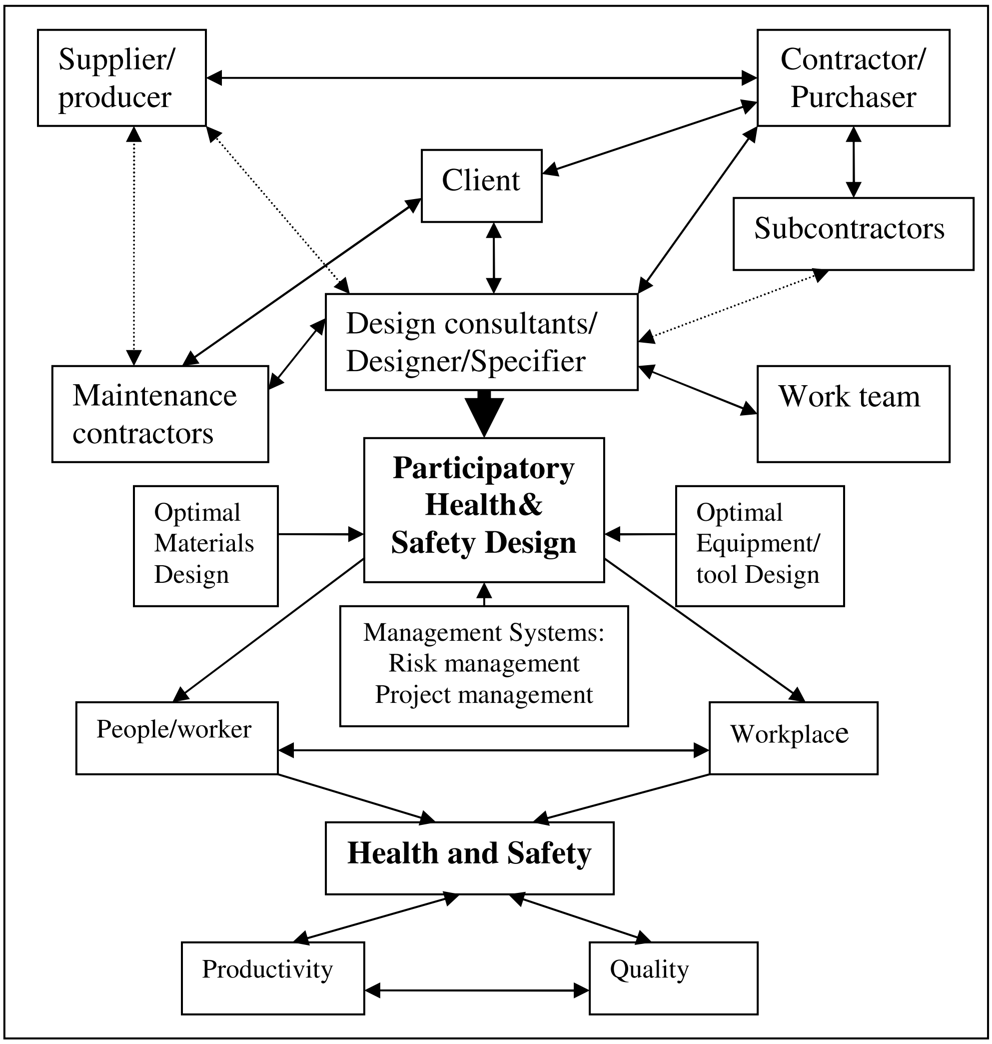

Figure 1. Model for minimizing the Health and Safety risks through a participatory design process

6 Conclusion

There is an opportunity to both protect workers and reduce construction costs through paying attention to human costs during design. This paper showed specific areas where professional designers should consider in their designs in order to reduce or eliminate construction work injuries such as WMSDs. The conceptual model for a participatory design proposed in this paper, shows the vital importance of partnerships between various stakeholders at the project preparation stage. The result of such partnerships is of course the intelligent design itself and its benefits namely health and safety for construction workers and end-users, and enhanced productivity and quality which will benefit many stakeholders especially the client in terms of reduced financial loss.

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