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Knowledge and opinions of designers of industrialized wall panels regarding incorporating ergonomics in design

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Abstract

As residential construction moves towards industrialized construction methods, ergonomic exposures of construction workers may increase due to heavier components and changes in construction activities. Ergonomic considerations early in the design stages are expected to have the most impact, provided that designers are aware of ergonomic risks and are willing to incorporate ergonomic principles into designs. To determine current knowledge and opinions regarding ergonomics in the context of one commonly used industrialized construction method (prefabricated wall panels), 12 panel designers completed a questionnaire, and seven of those designers participated in a semi-structured interview. Results showed that panel designers generally have little knowledge about the influence of panel designs on workers' ergonomic risks. Panel designers were neutral or slightly resistant to incorporating ergonomics into designs, due to perceptions of lack of responsibility and influence over workers' long-term health. Though the participants acknowledged the necessity of ergonomics in panel design, they were concerned with the possibilities of increased workload, costs, and decreased design flexibility. To advance the incorporation of ergonomics in panel design, panel designers need to recognize the potential ergonomic impact of their panel wall system designs. Current research represents an initial step in creating support tools for use in designing wall panel plans that decrease the risk of work-related injuries and illnesses in construction workers.

Relevance to industry

Understanding the background knowledge and opinions of panel designers regarding ergonomics in construction is necessary to develop successful design support tools that incorporate ergonomic principles into panel design.

Keywords: Residential construction; Construction safety; Design for safety; Panel wall construction

1. Introduction

Residential building construction is the seventh largest US industry representing approximately 4% of the nation's annual economic activity (NAHB Research Center, 2002), but it is also characterized by a high number of occupational injuries. Residential construction workers sustain disproportionately higher fatalities and non-fatal injuries compared to other employees. While residential construction workers make up 0.83% of the US workforce, they account for 2% of the total work-related fatalities and 0.97% of the total non-fatal work-related injuries (BLS, 2004a, b). In 2004, there were 38,900 non-fatal injuries reported, with an incidence rate of 5.0 (per 100 full-time workers) compared to 4.5 for all US employees (BLS, 2004b). The actual incidence rate and severity of occupational injuries in residential building construction may be higher due to under-reporting of minor injuries or company-paid cases (Glazner et al., 1998; Morse et al., 2001, 2005), as well as the lack of injury data specific to residential building construction (Dement and Lipscomb, 1999; Methner et al., 2000). Occupational injuries may result from single events or prolonged exposure to ergonomic risks, which can lead to problems such as lower back injuries, tendonitis and other injuries. (Punnett and Wegman, 2004).

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A new trend in residential construction is the increasing use of industrialized-housing methods (O'Brien et al., 2000). In contrast to traditional stick-built framing, industrialized-housing methods involve more pre-assembled, factory-built components. These methods may increase exposure of residential construction workers to ergonomic risks through handling larger and heavier building components. A representative example of industrialized construction methods is the use of panelized walls, also known as panels or prefabricated walls (NAHB Research Center, 2002). These panels are constructed in a manufacturing facility and shipped to construction sites on pallets. Panels are transferred from the pallets and erected in a sequence of designated positions. Workers are required to handle this large and heavy panel, which increases the risk of incurring work-related injuries.

Mitigating ergonomic risks in residential construction can be addressed by using the concept of safety in design. Traditional safety and work design guidelines promote improvements to work systems at the design level through engineering controls before making changes at the administrative or personal level; i.e., employee training or personal protective equipment (Goetsch, 2002). Changes in the early stages of any process would be effective because they take a proactive approach to systems improvement. Safety in design specifically promotes safety considerations in early design phases (Gambatese et al., 1997). In residential construction, ergonomic hazards can be addressed by applying safety in design concepts to ergonomics (Gambatese, 1998; Hecker and Gambatese, 2003; Hinze and Wiegand, 1992). Although ergonomic interventions could be introduced at several levels of the system, ranging from the architect to the construction worker, implementing changes at the design level may be the most effective according to this concept. Provided that designers have the proper tools and training to increase worker safety, these early-stage considerations will have the largest influence in decreasing ergonomic risks of construction workers.

The construction community has gradually become interested in the safety in design concept. Gambatese and colleagues (2005) noted that designing for safety can be a viable tool to improve workers' safety and health because the concept is easy to implement. A study by Behm (2005) reported that a large number of fatalities and injuries in construction sites were linked to design, and those fatalities and injuries could have been eliminated by applying the concept of safety in design.

For this study, panel design was targeted for potential ergonomic interventions in the earlier stages of the construction process. Panel designers play a central role in designing panel wall systems by generating a "panel plan" based on floor plans. They also make decisions regarding panel size, materials, stacking order, and panel assembly layout. On site workers then passively use the designed panels. Designers' panel plans are directly linked to on site workers through design choices that influence workers' tasks and physical demands. The centralized control over panel design decisions suggests that panel designers have the potential to reduce the likelihood of work-related injuries by incorporating ergonomics early in the construction process at the panel design stage, thus following the guidelines of safety in design.

Despite the need to reduce the risk of injury and illness in this new trend of panelized wall systems, no ergonomic analysis has been formally completed for the panel erection process to the authors' knowledge. Further, the incorporation of ergonomics in panel design has not been advanced in the residential construction industry. To develop methods to facilitate ergonomic principles in panel design, the current study used survey and interview data to provide a summary of the current ergonomic awareness of panel designers, patterns of panel installation, and opinions toward the incorporation of ergonomic principles into designers' work.

2. Methods

A two-phase study was conducted to determine the current knowledge and opinions of panel designers regarding aspects of the panel design process and ergonomics. Panel designers completed a 56-item questionnaire, and a subset of the respondents completed an additional interview on these topics.

2.1. Participants

To assure breadth and depth of ideas acquired, 12 panel designers from 11 different companies completed a questionnaire (10 males and 2 females). Seven of these designers then participated in a semi-structured interview after completing an informed consent procedure approved by the local IRB. Designers were first contacted by phone to solicit their participation and to confirm that they had the desired qualifications to complete the questionnaire. All participants worked for companies in the mid-Atlantic region of the United States (Virginia, North Carolina, and Maryland) or Illinois that are panel suppliers to production home builders. They had 3–30 total years of experience in the construction industry (Mean = 15, SD = 10 years) and 1.5–30 years of experience in panel design (Mean = 13, SD = 12 years). Seven respondents had hands-on experience in installing panels at the job site as a part of job training or personal interest.

2.2. Survey and semi-structured interview development

A combination of a questionnaire and semi-structured interview was employed to assess panel designers' general knowledge, opinions, and experience regarding panel design, principles, and practices; ergonomics; perceptions of barriers to incorporating ergonomics into construction design; and promotion of the inclusion of ergonomics in design. The questionnaire was completed first, followed by the semi-structured interview at a later date.

A 56-item questionnaire was generated on the topics noted above through a collaborative process with seven graduate students from four areas of expertize: ergonomics, construction management, architecture, and data management. Questions were revised based on relevance to research goals and ease of comprehension for panel designers who may not have been familiar with ergonomic concepts. The group went through several iterations of questionnaire development with feedback from two of the principal investigators in the project. The final version included simple "yes/no" questions, Likert-type ratings, and open-ended questions. It was distributed to designers using an online survey tool (http://www.survey.vt.edu). Items in the questionnaire consisted of demographics (e.g., age, education and experience in panel design) and questions pertinent to the four categories listed above. Participants could complete the questionnaire in less than 1 h.

A semi-structured interview script was developed to incorporate: questions that were too time-consuming for the questionnaire, participant-specific clarifications based on individual responses to the questionnaire, and hypothetical scenarios allowing participants to describe their thought processes during panel design. A similar iterative process involving researchers from different areas of expertize was performed to develop the interview questions. The underlying interview script contained 33 questions with additional questions (probes) based on the participants' responses to the questionnaire. Interviews were conducted at the participants' places of employment and lasted 40–70 min. All interviews were voice recorded with permission. The interview recordings were reviewed by the authors along with the results of the questionnaire for clarification purposes.

3. Results

Questionnaire results, combined with the interview results, were organized into four categories: panel design, ergonomics in panel design, perception of incorporating ergonomics, and promotion of the inclusion of ergonomics in design.

3.1. Panel design, principles and practices

Panel designers indicated that decisions regarding panel design are most constrained by the required floor plans for a house and panel installation, followed closely by location of openings (for windows and doors), panel size, and transportation (Fig. 1). Panel designers ranked panel weight and crew size as having the lowest importance in panel design. Eight designers (67%) noted that they have to take into account specific requirements for a different floor (e.g., extra load carrying, the floor system of a house, etc.).

Three major concerns noted by designers in creating panel designs were: dividing a wall into multiple panels, shipping panels (cargo greater than 3.05 m [10 ft] wide requires special permits in most areas), and stacking panels on pallets. Floor plan information on opening locations, lengths, heights, materials, and stud spacing is input in computer software. The software output includes panelized wall patterns, materials lists, panel assembly plans, stacking orders, as well as other information required for panel erection depending on the software. Seven panel designers (58%) replied that they verify all output and make corrections as needed.

The most common standard panel length is 3.66 m (12 ft), regardless of panel type (sheathed or unsheathed). Sheathing, which is a covering nailed directly to a panel frame to distribute loads and strengthen the wall, is commonly available as 1.22 by 2.44 m (4 by 8 ft), and the lengths can increase in increments of 0.61 m (2 ft).

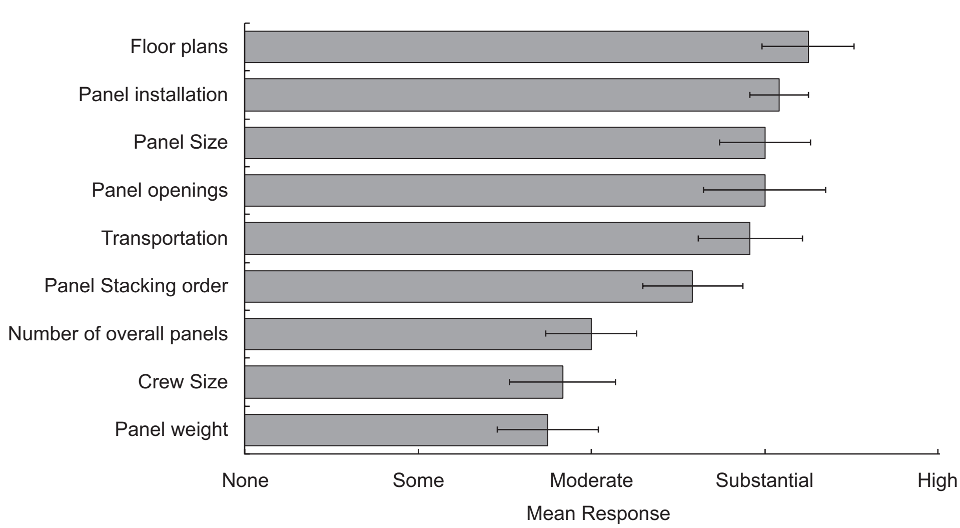

Fig. 1. Designers' perceptions of importance of specific factors in panel design. Error bars here and in other figures indicate standard errors.

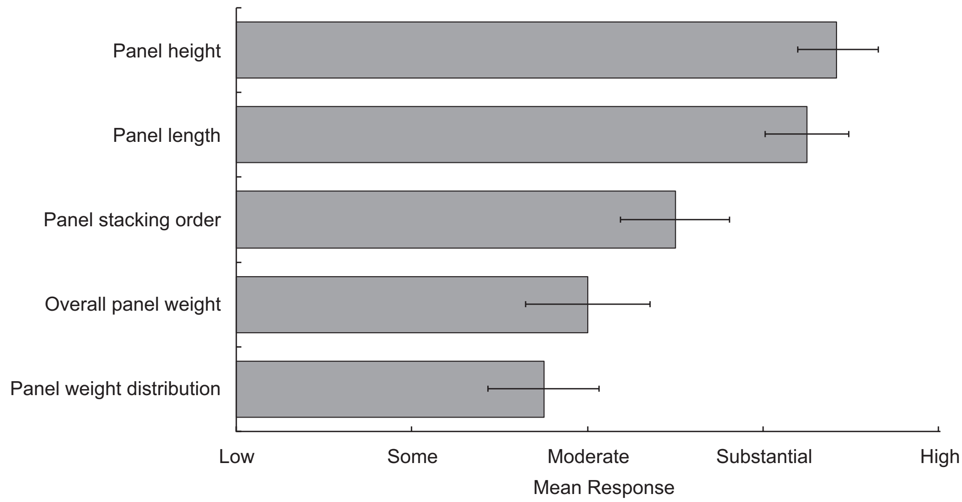

Fig. 2. Designers' perceptions of factors that influence efficiency of panel installation.

According to interview responses, the standard panel size is selected based on shipping costs, trailer load capacity, standard lumber lengths, and the designers' experience. The ideal panel sizes (from a materials waste perspective) start at 2.44 m (8 ft) and increase/decrease by 1.22 m (4 ft) increments; at these sizes no material waste is produced.

Designers responded that efficiency of panel installation on site is most influenced by panel size (both height and length), followed by stacking order (Fig. 2). Distribution of panel weight was the least influencing factor. Panel designers indicated during the interviews that panel stacking order could impact productivity on site.

3.2. Ergonomics in panel design

Most respondents (80%) were unaware of ergonomics in the context of construction. None of the respondents ranked their knowledge of ergonomics as "high," and the mode response was "moderate." Panel designers had difficulty providing specific examples of ergonomic principles. Some respondents mentioned that "workers should lift with the legs and not the back." One of the respondents mentioned proper working heights during the interview, and when further questioned, he said his company had just raised tables in the panel plant to improve work heights. Of the 12 respondents, only one had formal ergonomic training, but this regarded office environments. During the interview a few panel designers mentioned safety training for operations in the panel manufacturing plant, but no safety instruction was related to the on site panel installation process.

In the questionnaire participants were asked, "For a person who spends years as a construction worker, what body parts will most likely give them problems?" The panel designers responded that the lower back is most likely, followed by the knee and upper extremity. Designers said they selected these body regions because people complain about these areas as they age, and because these body regions are addressed during safety training for the plant. Designers ranked fatigue as the most possible cause of injuries, followed by over-exertion due to the weight of a panel (Fig. 3). They stated that workers would make more mistakes that could lead to injuries when fatigued.

3.3. Perceptions of incorporating ergonomics into construction design

Half of the respondents replied that designers should consider ergonomics in the design phase, and the other respondents replied that ergonomics was not their responsibility. Five respondents (42%) believed that ergonomic principles were already reflected in their panel designs because they divide a panel in two small panels if the panel is extremely long. One respondent noted that he considered the weight of a panel during design because the panel design software provides the weight associated with the design choices.

When asked to rank the level of responsibility for work-related injuries, panel designers gave themselves the least amount of responsibility and gave construction workers the highest amount of responsibility. Rankings were predicated by the fact that designers have little influence or control over workers because designers are not in direct supervision of workers. In addition, designers believed that on site workers would have a better idea of safety in their work environment.

When asked to rate the level of resistance or acceptance of assorted stakeholders to the concept of ergonomics in design, panel designers reported slight resistance on average. "Some" or "high" resistance was reported by 25% of the respondents while 50% were neutral (Fig. 4). From their comments, the participants were willing to incorporate ergonomics on the condition that workload, cost, and time did not increase. They believed that incorporating ergonomics would make designs less flexible. However, 75% of the designers expected that on site

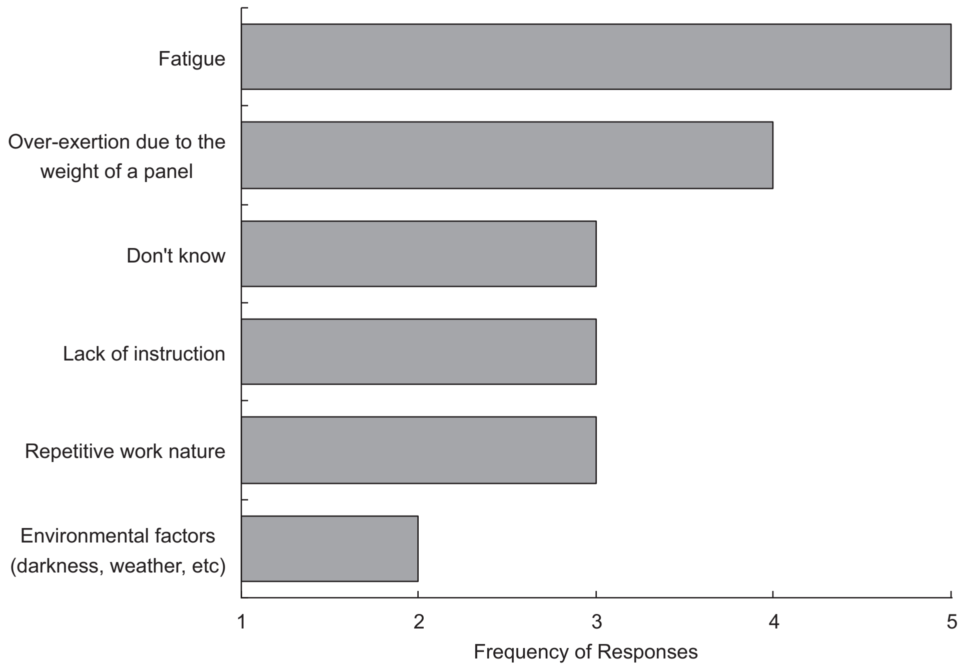

Fig. 3. Designers' perceptions of potential sources of injuries to on site workers.

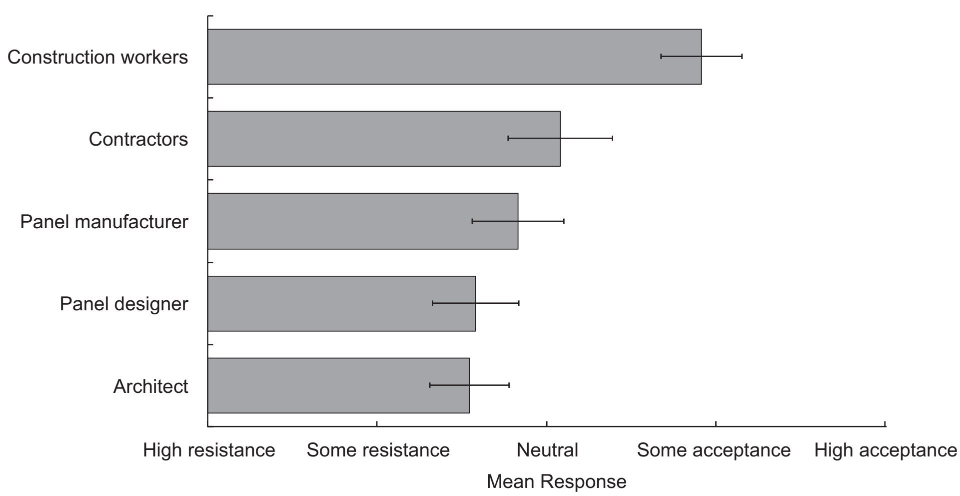

Fig. 4. Designers' perceptions of acceptance/resistance of each stakeholder to ergonomics in panel design.

workers would be the most accepting because they have the most to gain.

3.4. *Promotion of the inclusion of ergonomics in design*

Panel designers, in general, took a neutral stance (37%) or a slightly negative stance (27%) toward the feasibility of incorporating ergonomics in panel design. Although all respondents agreed on the necessity of ergonomics to reduce workers' risk of injury, they cited two main reasons for the slightly negative stance: ergonomics should be considered at job sites and ergonomics in panel design would increase their workload. The panel designers regarded ''decreasing injuries'' as the best reason to incorporate ergonomics when asked to rank reasons to incorporate ergonomics into design.

Panel designers responded that ''less injuries to workers'' would be the most expected outcome of incorporating ergonomics in their design while ''more regulations to follow'' and ''more time-consuming construction process at the site'' were tied as the next likely outcomes (Fig. 5). ''Lower workers' compensation costs'' was also rated as a major expected outcome. In addition, the panel designers expected that the inclusion of ergonomics in design would lead to an increase in the overall cost of panel wall systems due to additional training, equipment and software upgrades, extra materials to build panels, and a decrease in on site productivity.

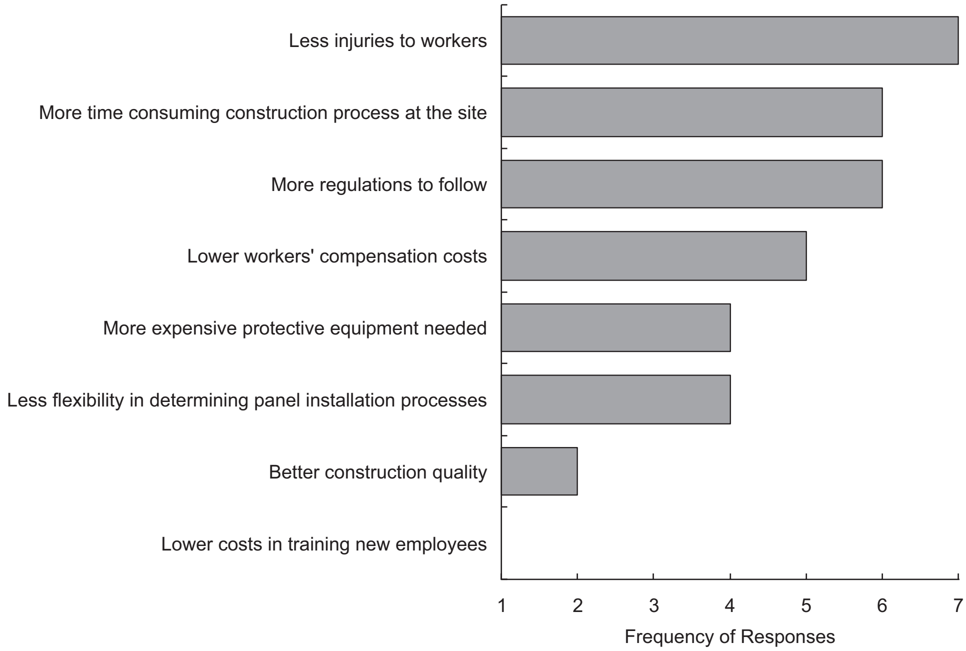

Fig. 5. Expected outcomes of incorporating ergonomics in panel design.

Panel designers mentioned one reason for the success of their product is the speed of installation compared to ''stick-built'' construction, as well as the easy compliance with construction codes. During the interviews, the designers emphasized that on site productivity and compliance with construction codes should not be compromised by the incorporation of ergonomics in design. Several designers indicated that they would be open to the incorporation of ergonomics in design if it required minimal change in their design process and did not compromise the merits of the existing panel wall system.

4. Discussion

The objective of this study was to understand panel designers' general knowledge, opinions, and experience regarding ergonomics with respect to designing panels. The results of the survey and interview indicated that panel design is largely influenced by floor plans and by the manufacturing and transportation aspects of panels. Panel designers make design decisions under these constraints, which in turn affect on site workers who handle panels. Nonetheless, the results of this study show that panel designers do have flexibility in design to incorporate ergonomics into panel wall systems.

Respondents expressed some resistance to the inclusion of ergonomics in their design process while accepting the need for ergonomics in design. Some designers thought ergonomic concerns were already reflected in their panel designs through dividing larger and heavier panels into multiple smaller panels. However, they transferred responsibility for ergonomic issues to the field and expected workers and supervisors to handle all situations. Panel designers considered the incorporation of ergonomics more feasible at the job site level rather than at the design level. As shown in Fig. 5, panel designers expected that the inclusion of ergonomics in panel design would lead to more regulations and more time-consuming construction processes. Moreover, they believed ergonomics in design would increase the current workload of panel designers due to added regulations and less design flexibility. This could account for resistance to ergonomics in the design process and a neutral or slightly negative stance toward the feasibility of ergonomics in design.

A similar gap was found between designers' self-stated knowledge of ergonomics and awareness of ergonomics in construction. They generally regarded their knowledge of ergonomics as moderate while reporting essentially no awareness of ergonomics in construction. This is consistent with previous studies which showed that lack of training, education, and guidelines are barriers to promoting designing for safety (Gambatese et al., 2005; Hinze and Wiegand, 1992; Toole, 2005). Interviews revealed that panel designers regard their panel wall system designs as being disconnected from the on site construction processes, and they were uncertain how their design choices could impact ergonomic exposures of workers. This implies that the designers may not have a thorough or sufficient understanding of on site construction activities.

Despite the general resistance to ergonomics in panel design and the lack of knowledge of ergonomics, panel designers have great influence over the design of panel wall system in all aspects such as material choices, panel size, stacking order, and panel assembly layout. For instance, designers stated that panel stacking order, which is an output of panel design software, can affect on site productivity by reducing double-handling of panels. Panel designers, however, failed to see how a reduction in double-handling of panels could be linked to ergonomic exposure of workers, which is comparable to how designers (or architects) in construction responded regarding the inclusion of safety in their design (Gambatese et al., 1997; Hinze and Wiegand, 1992). Designers' lack of understanding of the safety-in-design concept and construction processes have been identified as major barriers to its implementation and diffusion (Gambatese et al., 2005; Toole, 2005). To place issues such as double-handling in some context, the mass of the most common panel size (3.66×2.44 m) was conservatively estimated to be 118.7 kg when sheathed and 49.5 kg when unsheathed (from mass per dimension data reported by Wakefield and O'Brien, 2004). These relatively high masses indirectly support a potential increase in ergonomic exposures of workers. Previous evidence (Perttula et al., 2003) suggests that overexertion accounts for most minor injuries (3–30 days away from work) and can be minimized by reducing material handling.

During the interviews, several panel designers mentioned that home builders are paying a premium to use wall panels instead of stick framing. They provided four reasons: the installation of wall panels is substantially faster than traditional stick framing, there are rarely any framing/structural code violations when wall panels are used, the assembled wall panels are straighter and more level than traditional framing, and using wall panels reduces on site theft. Incorporating ergonomics in panel design could lead to an increase in productivity and better construction quality because improved panel design potentially reduces exposures (e.g. double-handling) without compromising the structural integrity or strength of a wall panel system.

In the safety-in-design concept, computerized safety tools (including graphics capabilities, guidelines, safety knowledge-based databases, etc.) are viewed as a viable solution to provide design suggestions for on site workers' safety, and such tools could compensate for designers' lack of understanding of the safety-in-design concept (Gambatese et al., 1997; Toole, 2005). Given the analogy between safety in design and ergonomics in design, ergonomic assessment tools can be developed in a similar manner to provide design alternatives that reduce ergonomic exposures of on site workers with little or no increase in panel designers' work. The development of ergonomic assessment tools is challenging because it requires comprehensive understanding of on site panel erection processes as well as how changes in panel design could affect ergonomic exposures of workers. Further, design changes intended to improve material handling may be particularly difficult to address in early design stages compared to design changes for safety (Weinstein et al., 2005). Still, workers' ergonomic exposures can be minimized by well-informed designers who use effective tools and supportive regulations.

In conclusion, panel designers had limited knowledge regarding ergonomics, and negative or neutral attitudes regarding ergonomics in panel design. Yet, panel designers have a crucial role to plan in terms of proactive control of worker injuries and illnesses, as their design choices have broad impacts on ergonomic exposures of construction workers. Such control, or 'ergonomics in design,' will require panel designers to recognize the ergonomic impacts of their design. This might best be achieved through a combination of appropriate education and effective tools. We envision that one such tool might be software that integrates with existing panel design software and facilitates a rapid and iterative evaluation of ergonomic exposures. The present results, which identify the knowledge and opinions of eventual users, are considered an initial step toward this goal.

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