DEVELOPING A STRATEGY FOR INTEGRATION OF DESIGNING FOR CONSTRUCTION WORKER SAFETY AND BUILDING INFORMATION MODELING

Olbina, Svetlana, M.E. Rinker, Sr. School of Building Construction, University of Florida
Hinze, Jimmie, M.E. Rinker, Sr. School of Building Construction, University of Florida
Issa, Raymond, M.E. Rinker, Sr. School of Building Construction, University of Florida

ABSTRACT
Until recently, the responsibility for reducing construction injuries was placed solely on the contractors. At the same time, designers make many decisions about the facilities they design that directly impact worker safety. The implementation of designing for construction worker safety (DCWS) principles can have a positive impact on construction safety, cost, schedule, productivity and quality of construction, but the widespread implementation of DCWS (also referred to as construction hazard Prevention through Design (PtD)) by U.S. design firms has been lacking. The purpose of this research was to investigate how the use of Building Information Modeling (BIM) technology in conjunction with DCWS/PtD principles can reduce the potential for fatalities and injuries on construction projects. The objective was to develop a strategy that would help implement DCWS/PtD principles in the design phase of a project through the use of BIM. For example, the strategy can include: 1) a knowledgebase of the DCWS/PtD principles; 2) an interactive web site for adding suggestions; and 3) a BIM tool that checks for DCWS compliance. The ultimate beneficiaries of an integrated BIM and DCWS/PtD system include designers, contractors, facility owners, and construction workers. By integrating DCWS/PtD and BIM in a project, safety will no longer be an afterthought, but it is put on equal basis with the other design parameters. DCWS/PtD becomes an integral tool for use with BIM software, just like quality, cost, schedule information, structural analysis, HVAC load and building code compliance checking tools that are currently available for BIM. Introducing construction safety as a parameter at the design stage enhances its impact on construction workers in terms of human asset sustainability.

Key words: Design for construction safety, Building Information Modelling, Safety compliance checking.

INTRODUCTION
The U.S. Bureau of Labour Statistics reports that while over 6% of the nation’s workforce is employed in the construction industry, nearly 20% of all worker fatalities occur in the construction industry. Until recent years, the responsibility for reducing construction injuries was placed solely on the employing contractors. At the same time, designers make many decisions about the facilities they design that will directly impact worker safety. Designing for construction worker safety (DCWS) (also referred to as construction hazard Prevention through Design (PtD)) has received considerable attention in recent years. The implementation of DCWS /PtD can have a positive impact on construction safety, cost, schedule, productivity and quality of construction; however the widespread implementation of DCWS/PtD by U.S. design firms has been lacking.

A Building Information Model (BIM) is a digital representation of the physical and functional characteristics of a facility. The information maintained and produced in the BIM approach includes both geometric (e.g. 2D drawings, 3D models, dimensional and spatial relationships and Virtual Reality) and non-geometric data (e.g. annotations, textual information, reports, tables, charts, freehand illustrations, graphs, images, audio-visual data). BIM is expected to enable improved interdisciplinary collaboration across distributed teams, intelligent documentation and information retrieval, greater consistency in building data, better conflict detection and enhanced
Capacity Management. Hence, the purpose of this research is to explore the use of Building Information Modeling (BIM) technology in conjunction with DCWS/PtD principles to reduce the potential for fatalities and injuries on construction job projects.

LITERATURE REVIEW

Design for Construction Workers Safety (DCWS)

Design for Construction Worker Safety (DCWS) requires consideration of the safety of construction workers in the design of a project (Gambatese et al. 2005). Since the design determines the building components and configuration, the design also affects the construction process and the consequent safety hazards (Gambatese 2000). Previous research found that widespread implementation of design for construction worker safety by the United States design firms was lacking (Hinze and Wiegand 1992, Gambatese et al. 1997, 2005, Toole 2005). Some of the reasons for the designers’ minimal knowledge of DCWS principles were identified by researchers as:

- Failure to offer construction safety courses in engineering programs at universities (Gambatese 2003, Toole, 2005).
- Narrow specialization of design (Gambatese et al. 2005).
- Designers’ minimal to nonexistent construction experience and understanding of the construction process (Gambatese et al. 2005, Toole, 2005).

Early research on DCWS identified the need for a single source/repository compiling the various design concepts that had been successfully implemented on past construction projects (Hinze 1997, Gambatese et al. 1997). The proposed DCWS/PtD Wiki allows for this compilation of DCWS/PtD design concepts into a centrally maintained and available body of knowledge, while at the same time establishing a mechanism for adding and vetting new concepts to that body of knowledge.

A study by Gambatese (2005) showed that 47% of the interviewed designers used DCWS principles without giving an indication of how or when safety was addressed in their designs. Designers typically address safety during the value engineering phase of the project and 42% of the designers indicated that they made modifications in their designs to improve construction worker safety.

Several researchers have recommended a variety of approaches to implement DCWS in practice and these approaches include:

- Creating a motivational force to implement DCWS/PtD (Hinze 1997, Gambatese et al. 2005).
- Increasing the knowledge of designers about DCWS/PtD as well as about the construction process (Gambatese et al. 1997, 2005, Toole 2005).
- Integrating safety in the engineering curriculum (Toole 2005).
- Encouraging the use of the design-build project delivery method that involves close collaboration between designers and constructors (Gambatese et al. 2005).
- Creating construction documents that facilitate worker safety (for example, technical specifications that include safety standards) (Toole 2005).
- Encouraging facility owners to insist that designers implement DCWS/PtD in their designs (Hinze, 1997, Gambatese et al. 1997, 2005).
- Revising current contract documents to include requirements for including DCWS/PtD (Gambatese et al. 1997, 2005, Toole 2005).
- Utilizing consultants for safety to mitigate the lack of knowledge of designers about construction safety (Gambatese et al. 2005, Toole 2005).
Designers can potentially be involved in a number of activities related to construction safety. These include the review of designs to ensure that safety is addressed, the creation of construction documents that implement DCWS/PtD principles, and the adaptation of practices to ensure safety is adequately addressed in procurement practices, submittal reviews, and site inspections (Toole 2005).

How does DCWS/PtD affect construction safety? The design of connection details, selection of the materials and the way building components are put together directly affect the way construction workers perform their work. If designers know about modified design approaches that can improve worker safety, they have an ethical responsibility and obligation to apply these approaches in practice (Hinze 1997). Previous research has shown that the implementation of DCWS/PtD had a positive impact on construction safety as well as on cost, schedule, productivity and quality of construction (Gambatese et al. 1997, 2005).

Building Information Modeling (BIM)
In 2004, the U.S. National Institute of Standards and Technology (NIST) published a report stating that poor interoperability and data management costs the construction industry approximately $15.8 billion a year (Gallaher et al. 2004). Since that report was publicized, many have dubbed Building Information Modeling (BIM) as an emerging technological information management process and product that holds the key to resolving this interoperability problem. The National BIM Standard (NBIMS) defines a BIM (e.g. a single Building Information Model) as “a digital representation of physical and functional characteristics of a facility” (Kennett 2005). Furthermore, a BIM represents a shared knowledge resource, or process for sharing information about a facility, forming a reliable basis for decisions during a facility’s life-cycle from inception onward.

Building Information Modeling (BIM) is an Information Technology (IT) enabled approach that allows for improved inter-disciplinary collaboration across distributed teams, intelligent documentation and information retrieval, greater consistency in building data, better conflict detection and enhanced facilities management. BIM facilitates the storage, management, sharing, access, update and use of all the data relevant to a project throughout the project life-cycle in the form of a data repository. The information maintained and produced in the BIM approach includes both geometric as well as non-geometric data. Geometric data includes 2D drawings, 3D models, dimensional and spatial relationships and Virtual Reality (VR). Non-geometric data could mean annotations, textual data, reports, tables, charts, freehand illustrations, graphs, images, audio-visual data and any other forms of information generated during the project. BIM is expected to enable improved interdisciplinary collaboration across distributed teams, intelligent documentation and information retrieval, greater consistency in building data, better conflict detection and enhanced facilities management (Kunz and Fischer 2007; Haymaker et al. 2005).

Computer Programs for Safety in Construction
Computer tools have been developed to address construction worker safety in design. Gambatese et al. (1997) created the Design for Construction Safety ToolBox that offered a variety of project-specific design suggestions that would improve construction worker safety. The tool incorporated diverse approaches for reviewing a construction project, and had the ability to identify safety hazards and to document the results in reports. The tool allowed the user to follow one of three paths when selecting design for safety suggestions, namely 1) project components, 2) construction site hazards, and 3) project systems. The potential benefits of ToolBox included: utilization of the tool by a design team as well as by the entire project team; management and control of the review process; accurate and thorough record keeping on a project; improved safety through the life-cycle of the building; and a safety instructional tool for architectural and engineering curricula.

Hadikusumo and Rowlinson (2004) developed the Design-for-Safety-Process (DFSP) Tool that had the ability to identify safety hazards on a construction site and to suggest precautions to avoid the occurrence of accidents in the presence of those hazards. The DFSP Tool was developed based on three components: design for X-ability (DFX), virtual reality (VR) and construction site safety. The DFSP Tool had a safety database that consisted of: construction components, possible safety hazards, and accident precautions. The DFSP Tool enabled a user to walk-through and to observe a virtually real construction site. The user could select a virtually real construction
component that might be considered a possible safety hazard and the Tool would list possible safety hazards from the safety database. The benefits of the DSFP Tool were: 1) VR could represent the virtually real project in a 3D model that is easier to understand than 2D drawings; and 2) the virtually real construction process is easier to understand than the conventional method of representing the process as text or diagram.

PROBLEM STATEMENT
There is a need to develop a strategy for the integration of DCWS and BIM. The lack of such strategy is an important problem because of the following reasons:

• Construction documents define the end result, but not the construction means, methods and process. Construction documents are presented in the format of 2D drawings and written specifications, and these are not easily understood when compared to the 3D, nD or virtual reality models that might be developed for construction projects.

• Commercially available BIM software does not incorporate DCWS/PtD tools to check for safety compliance.

• Existing computer programs that were developed for DCWS/PtD are not readily available and are therefore not extensively used.

• There is currently no widespread implementation of DCWS/PtD by U.S. design firms.

• The knowledge of designers about construction worker safety and the construction process is limited. Most designers do not have: 1) adequate university-level training related to construction safety and construction processes, and 2) construction experience.

• The DCWS/PtD tools and guidelines are inadequate. Currently available safety checklists, manuals and guidelines are not compiled and organized in a format that is useful for designers.

• Traditional Design-Bid-Build projects are created by architects and engineers with their collaboration being limited to ensuring building code compliance, without any regard for worker safety. On conventional projects, construction worker safety is considered for the first time when the contractor undertakes the construction of the facility.

RESEARCH OBJECTIVES
The purpose of this research is to explore the integration of construction worker safety into Building Information (BIM). The users include designers, contractors, and facility owners, while the ultimate beneficiaries are the construction workers. Ideally, during the design phase of a project architects and engineers could analyze projects in terms of the safety of the construction workers and implement design principles that would provide for the safety of the construction workers during the life cycle of the project (including construction, operation or occupancy, and maintenance phases). In turn, the contractors and facility owners develop their site specific safety plans for the execution of the projects by using the safety-related BIM information. Figures 1-3 show some examples of DCWS/PtD concepts which include simple, yet highly effective design features that have been shown to increase worker safety.
1. Design parapets to be 107 cm high (Figure 1). This accident precaution provides safety during the construction, operation and maintenance phases.

![Figure 1 Parapet 107 cm high.](image1)

2. Install permanent roof anchors (Figure 2). This measure would provide for safety during the construction, operation and maintenance phases of the facility.

![Figure 2 Permanent roof anchors attached to the trusses.](image2)

3. Use of #5 rebar at a 7.5 cm spacing instead of using #10 rebar at a 30 cm spacing provides a walking platform for construction workers (Figure 3). This precaution provides safety during the construction phase.

![Figure 3 Rebar #5 @7.5 cm provides working platform.](image3)

The objective of this research is to develop a strategy that would help implement DCWS/PtD principles similar to those listed above in the design phase of a project. This strategy includes:

1. Creating a knowledgebase (checklist/guidelines) of the DCWS/PtD principles.
2. Establishing a multi-media DCWS/PtD website that will provide the opportunity for adding new suggestions for DCWS concepts/principles to the existing database.
3. Developing a framework for a DCWS/PtD checking tool for use in BIM that checks for compliance with DCWS principles and as is customary with other BIM tools:
   - Highlight and display graphically on the BIM the problem areas and the DCWS/PtD diagnostics.
   - Provide the ability to link each building component to related safety measures.
   - Provide the ability to link each construction activity of the project schedule to the required safety measures, that is, create a schedule of the implementation of the particular safety practices.
The tool can use the Model View Definition (MVD), Information Delivery Manual (IDM) and Industry Foundation Classes (IFC) approaches developed by the International Alliance for Interoperability, as espoused by the National BIM Standard (NBIMS) and the buildingSmart™ Alliance.

RESEARCH METHODOLOGY

The overall objective of this research is to devise a strategy for the incorporation of the principles of DCWS/PtD into BIM software. In order to develop a strategy for integration of DCWS/PtD and BIM, the following tasks are suggested:

Strategy 1: Create a knowledgebase of the DCWS/PtD principles.

- Develop and compile suggestions for design for construction worker safety. These basic safety principles are obtained from literature sources, DCWS/PtD Wiki, accident statistics, and other industry records.
- Convene a panel of safety professionals to help compile a knowledgebase with DCWS/PtD suggestions.
- Develop knowledge-base rules for DCWS.

Strategy 2: Establish a multi-media DCWS/PtD Wiki.

- Create and support a DCWS/PtD Wiki to augment the DCWS/PtD knowledge base.

Strategy 3: Develop a conceptual framework for a DCWS/PtD checking tool for use in BIM.

- Evaluate existing BIM software and select appropriate software for the DCWS/PtD application.
- Create a DCWS/PtD code checking prototype tool for use with BIM, based on MVD, IFD, IDM principles.

Strategy 4: Validate the DCWS/PtD checking tool by using the buildingSmart™ Alliance methodology.

- Perform a pilot case study to validate the DCWS/PtD code checking tool. Organize a focus group of construction safety experts that would walk through a specific project and identify potential safety problems, especially those which could be addressed by the modifications to the design. Subsequently, the safety hazard simulation of the same project would be conducted by using the developed DCWS/PtD code checking tool to evaluate the framework performance.

STRATEGY FOR INTEGRATION OF BIM AND DCWS

Table 1 shows the barriers to the implementation of DCWS/PtD by the designers that were identified in previous research and how they can be favourably impacted by the strategy for integration of DCWS/PtD and BIM developed by this research.

Table 1 Barriers to DCWS and the Impact of the BIM for DCWS Strategy on Those Barriers

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<tr>
<th>Barriers to DCWS</th>
<th>Impact of the BIM for DCWS strategy on barriers</th>
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<tr>
<td>Designers have minimal knowledge of construction worker safety (Gambatese et al. 1997, 2005, Hadikusumo and Rowlinson, 2004, Toole 2005).</td>
<td>Development of a BIM system that can alert designers to safety issues through safety code checking enhances their knowledge and ability to take worker safety into consideration.</td>
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There is limited availability of the DCWS tools and guidelines (Gambatese et al. 2005).

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<th>Traditional project delivery systems limit collaboration between the designers and constructors (Gambatese et al. 2005).</th>
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<td>The shift towards BIM with a single model to be used by all parties has started to eliminate these barriers.</td>
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<td>Construction documents define the end result, but not the construction means, methods and process (Hinze 1997).</td>
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<td>By using the BIM features that allow the construction processes to be defined, safety, safety training, and coordination of the schedule with safety toolbox talks are taken into consideration.</td>
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<td>Designers have the perception/concern that implementation of DCWS will require more time and increase the cost of design (Toole 2005, Gambatese et al. 2005).</td>
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<td>With the tools to be developed the DCWS code compliance checking could be executed as a feature of the BIM software used, similar to the way tools are currently used to conduct Building Code and ADA compliance checking.</td>
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<td>Regulatory mandates to implement DCWS are lacking (Hinze 1997, Gambatese et al. 2005, Toole, 2005).</td>
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<td>With the availability of BIM-based tools which reduce the cost of DCWS implementation, regulatory bodies may consider mandating DCWS.</td>
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<td>Motivation to implement DCWS is lacking (Gambatese et al. 2005).</td>
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<td>Once the DCWS tools are developed, code compliance checking will aid in constructability and value engineering reviews.</td>
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<td>Designers have traditionally not been asked to apply DCWS (Young 1996, Hinze 1997, Toole 2005).</td>
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<td>The integration of DCWS and BIM will secure a footing for safety-minded design in the burgeoning world of BIM, which is rapidly becoming standard practice for large owners such at the GSA and U.S. Army Corps of Engineers.</td>
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**RESEARCH CONTRIBUTIONS**

This proposed research is innovative because it is the first study to address in depth the problem of the integration of BIM and DCWS/PtD. The strategy developed by this research makes a positive impact in the area of the application of BIM for safety in construction. Benefits of the integration of BIM with DCWS/PtD include:

- Enhancing communication, knowledge and collaboration.
- Providing more timely design acceptance and approval.
- Improving construction worker safety and performance.
- Reducing construction, administration, and design costs.
- Opportunity for the broad application of BIM with DCWS/PtD tools in the construction industry.

While some attempts have been made to develop computer programs that will address the issue of DCWS/PtD, they remain relatively unused in the industry. One reason is that these programs are not readily available for use. For those firms that have utilized these software programs, some have commented that they are too cumbersome to use. In addition, these design for construction worker safety software programs run independent of the design software, so it is not integrated into...
the design process, i.e., a specific effort must be expended to utilize the software to address DCWS/PtD.

The DCWS/PtD code checking tool for BIM can build on existing applications for building code compliance checking, structural analysis, and constructability analysis. Thus, DCWS/PtD becomes an integral component of the BIM software, just as quality, cost, schedule information, structural analysis, HVAC load and building code compliance checking tools are currently available for BIM. By integrating DCWS/PtD into the BIM for a project, safety is not an afterthought, but it is on equal basis with the other design parameters addressed by BIM. In light of the increased focus on software interoperability, economic and workforce globalization, and software vendor adoptability, a BIM-centric approach is required for having relevance to the future of the facility lifecycle.

CONCLUSIONS
Integration of DCWS/PtD and BIM enriches the education of future designers and construction managers and enhances human sustainability by reducing safety hazards encountered on construction projects. In addition, the strategy for the BIM integration can also be applied to other design and construction issues ranging from checking designs for compliance with building code requirements, including structural, life safety, and disability codes. Furthermore, the research establishes a global virtual community of professionals interested in DCWS/PtD issues and educators that can greatly facilitate knowledge sharing and dissemination.

The need for BIM-savvy employees in the design and construction industry seems to be endless. Integration of BIM and safety brings together a diverse group of researchers, engineers, architects and construction managers into a virtual community. The integration of Web 2.0 technology and DCWS/PtD provides an open, extensible infrastructure. The infrastructure implemented in this research can be applied to other research domains such as manufacturing and other general applications relying on semantic web technologies for consensus building. The advancement in the DCWS/PtD can be used synergistically with other information technologies to explore, develop and advance new integration strategies that are more practical and applicable, in order to better address the central issue information integration and knowledge management for sustainable human development in the design and construction areas. The results obtained from this research can potentially lead to major breakthroughs and open up new directions for research.

REFERENCES


