Godfrey, R., Mutis, I. and Shiratuddin, M.F. (2008) ***Fall prevention methodology through the generation of 3rd Virtual Environments.*** **In: 18th Annual Construction Safety Conference and Expo, 12 - 14 February, Rosemount, USA.**

METHODOLOGY FOR FALL PREVENTION UTILIZING 3D REAL-TIME VIRTUAL ENVIRONMENTS

Ray Godfrey, Ivan Mutis and Mohd Fairuz Shiratuddin
School of Construction
The University of Southern Mississippi
Hattiesburg, MS 39406

Abstract

In 2006 the construction industry accounted for 1,226 fatal occupational injuries. With nearly 21% of all occupational work related fatalities for each of the years between 2001 and 2006, the construction industry has consistently produced the most fatal work injuries than any other industry sector. As construction workers displayed the highest risk for fatal workplace falls during the years 1992-2006, these falls continue to be a leading cause of fatality in the industry. This research explores new strategies to mitigate construction work place injury and fatality through the identification of hazardous situations through the use of real-time Virtual Environment (VE) technologies. This investigation focuses on the identification of relevant conditions necessary to assess fall related hazards, integrative design of fall protection systems and the effective implementation of fall prevention management protocols.

The utilization of VE allows for the generation of 3D visual and anthropometric measurements of workers in real-time. A motion capture suit worn by human subjects enables the capturing and representation of the construction worker's actual movement in the VE. Subsequently, new worker-environment profiles can be generated with respect to fall-related hazards by employing different scenarios in the VE. Human subjects will be exposed in these scenarios to generate visual and numerical motion data. By following this systematic process, this investigation proposes a methodology for data analysis and fall prevention strategies which can be used by safety experts to indentify potentially hazardous conditions within particular scenarios.

Keywords: anthropometric, construction fatalities, fall injuries, fall prevention, fall protection, virtual environment

Introduction

The construction industry is one of the largest industries in the United States. It employs approximately 7.3 million individuals and in the U.S. economy, the construction industry employs about 5% to 6% of all workers. It is well known that construction is also one of the most dangerous industries. Construction work frequently involves cluttered work environments, extreme temperatures, confided work spaces, ***elevated work spaces***, operation of power tools and heavy machinery, the use of various sharp objects, overhead tasks, and work demanding frequent bending, twisting and strenuous handling of equipment and materials of significant weight. The construction work environment is subject to constant flux and imposes the need for workers to be attentive to potential new hazards. Construction is also characterized by a highly transient worker population which frequently change employers and work sites.

According to the United States Bureau of Labor Statistics (USDOL-BLS, 2006) the private construction industry accounted for 1,186 fatal work injuries, the most of any industry sector and accounted for nearly one out of every five fatal work injuries recorded in 2005. Reasons for the higher worker fatality rates in the construction industry include contact with high-voltage industrial wiring and machinery (Ore and Casini, 1996; Pratt, Kisner and Moore, 1997; Robinson, C.F., Peterson, M. and Palu, 1999), exposure to toxic agents (Dorevich, Forst, Conroy and Levy, 2002), working at elevations which increase the risk of serious falls, involvement in work related activities that increase the risk of fatal encounters with heavy equipment (Pratt *et al*, 1997; Cattledge, Hendricks and Stancvich, 1996), and materials, and motor vehicles (Ore and Fosbroke, 1997).

In 2005, about 22% of all fatal on-the-job injuries occurred in construction which was over three times its 6% share of the total employment (USDOL-BLS, 2006). From 1992 through 2005 there was an increase of fatalities within the US construction industry as a percent of all occupational fatalities (Figure 1).

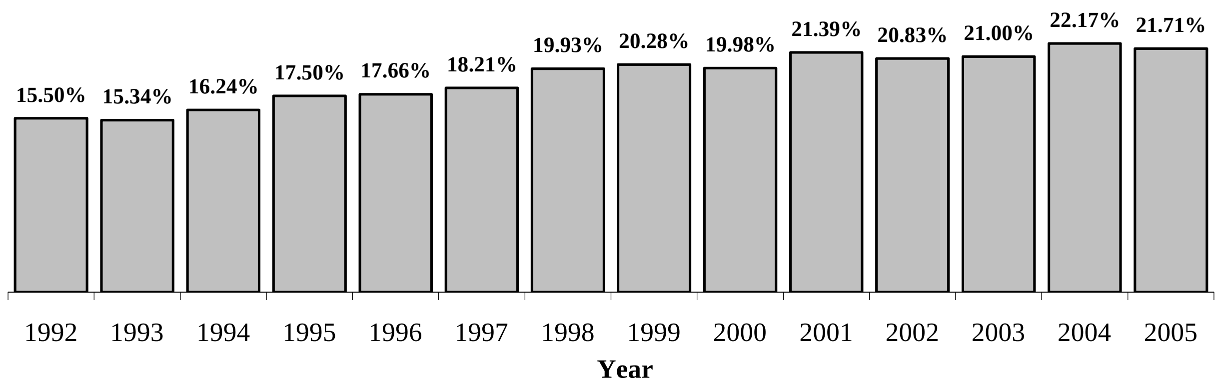

Figure 1: Yearly construction fatalities as a percent of all occupational fatalities (USDOL-BLS, 2006)

There has been a trend of a reduced frequency of occupational fatalities among all industries between 1992 and 2005. However, within the US construction industry a slightly reversed trend is suggested. This trend does not reflect the increase in construction employment that occurred during this period (Figure 2 and Figure 3).

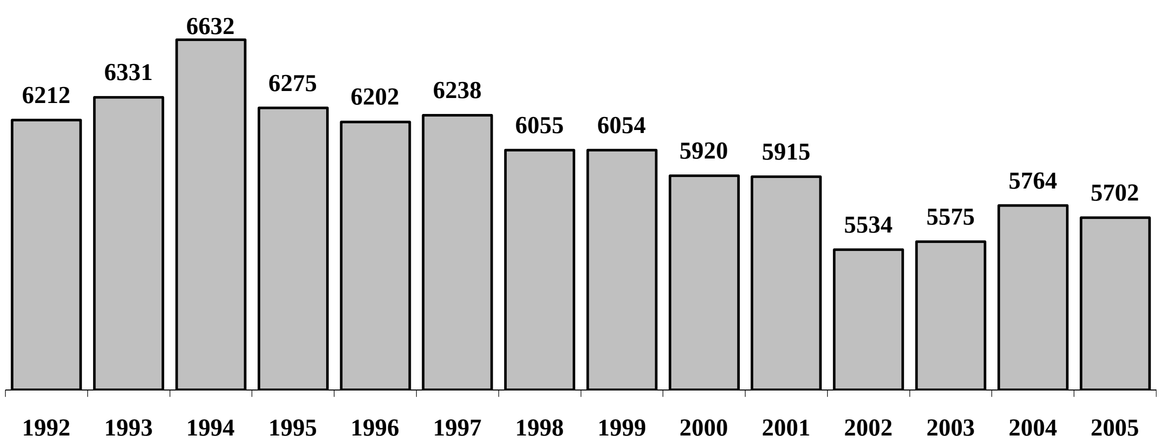

Figure 2: Frequency of occupation fatalities for all industries 1992-2005 (USDOL-LS, 2006)

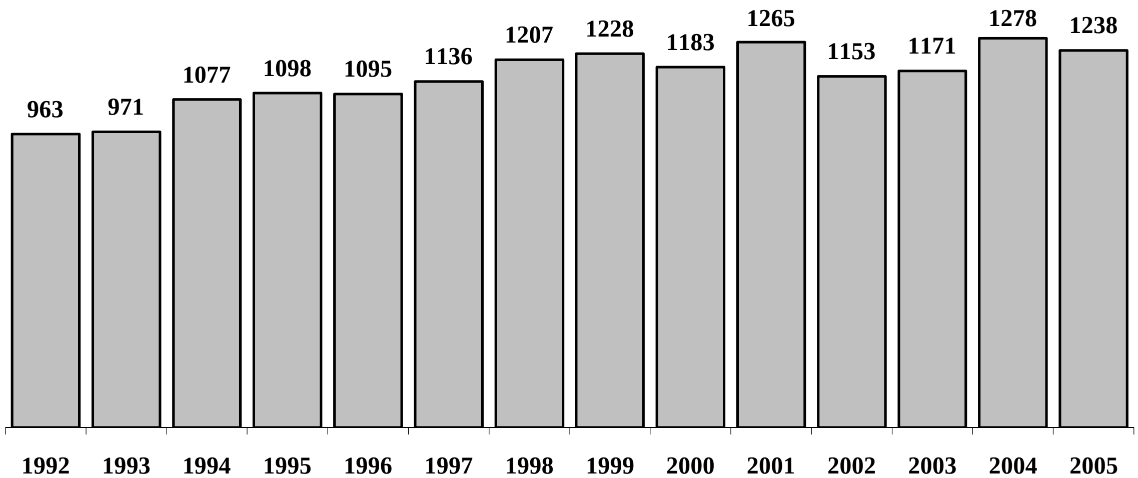

Figure 3: Frequency of occupation fatalities for the construction industry, 1992-2005 (USDOL-BLS, 2006)

The construction industry is also identified as having high rates of reported nonfatal occupational injuries (Gillen *et al*, 1997), including eye injuries (Lombardi *et al*, 2005; Welsh, *et al*, 2001), hearing damage (Hessel, 2000), musculoskeletal disorders (Goldsheyder, 2004; Schneider, 2001; Lipscomb *et al*, 1997; Holmstrom, *et al*, 1995) , burns (Islam, *et al*, 2000; Zwerling *et al*, 1996), and psychosocial disorders (Savitz, Boyle and Holmgreen, 1994).

This paper focuses on fatal and non-fatal injuries to construction workers generated from falls to a lower level; more specifically falls from ladders. Falls from elevated locations result in a high number of fatal and non-fatal injuries to construction workers each year. From 1992 through 2005 over 10% (N = 8,722) of all occupational fatalities in the United States were attributed to a fall to a lower level. Over half of these fatalities (N = 4,953) were experienced by workers in the construction industry. As shown in Figure 4, falls to a lower level were associated with, at the least, 4% of all occupational fatalities in 1992 to almost 8% of all the fatalities in 2004 (USDOL-BLS, 2006). Within the construction industry, falls to a lower level have consistently been associated with over 26% of all occupational fatalities within that industry (Figure 4).

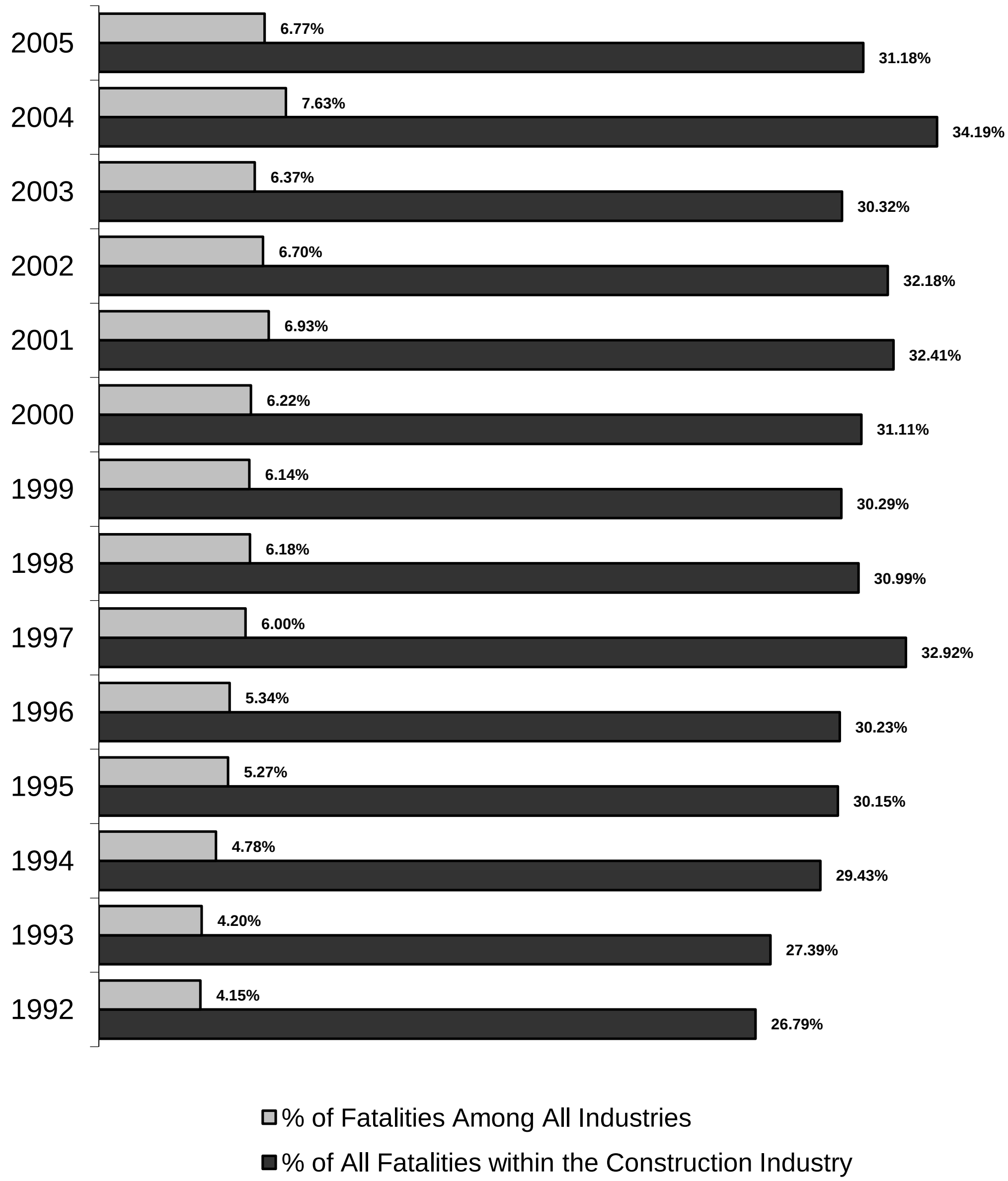

Figure 4 - Percentage of occupational fatalities attributed to falls to a lower level, 1992 – 2005 (USDOL-BLS, 2006)

A further examination of US occupational fatalities due to falls to a lower level from BLS data between 1992 and 2005 revealed that among all industries a minimum of around 14% (N = 76), in 1993, of such fatalities were directly attributable to falls from a ladder with a maximum of almost 20% (N = 126) occurring in 2002 (N = 126) and 2005 (N = 129) (Figure 5). Within the US construction industry, between 1992 and 2005, a minimum of 12% (N = 32) of fatalities from a fall to a lower level were attributable to a fall from a ladder in 1993, while a maximum of just over 19% (N = 72) was reflected in 2002. Figure 5 indicates an upward trend of ladder related fatalities between 1992 and 2005 as measured among all industries and as measured specific to the US construction industry. Figure 6 shows the US construction industry as consistently being the primary contributor to all occupational fatalities due to a fall from a ladder between 1992 and 2005.

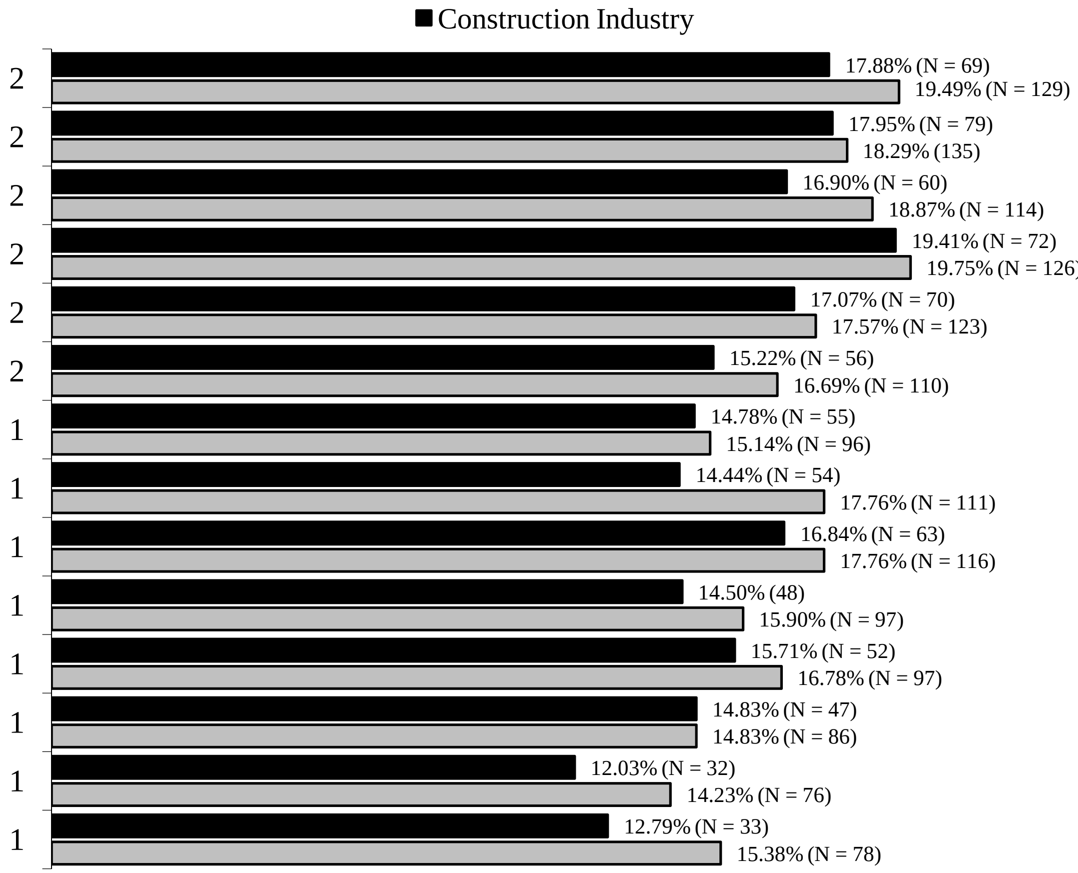

Figure 5: Percentage US Occupational Fatalities Due to Falls to a Lower Level Directly Attributed to Fall From a Ladder, 1992 - 2005 (N = Frequency of Fatalities from Falls From a Ladder) (USDOL, 2006)

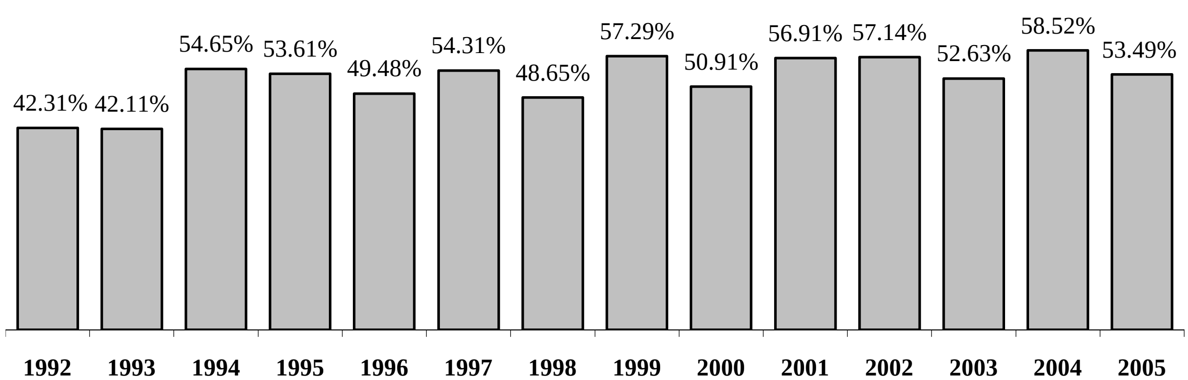

Figure 6: Construction Fatalities Due to Fall from a Ladder as a % of All US Occupational Fatalities Due to Fall from a Ladder

In a recent study by Godfrey (2007), information provided by a large private construction worker's compensation insurance provider regarding the number of injuries by the "General Cause of injury" was provided for 43,550 injury cases between 1992 and 2006. (Table 1). The three leading "General Cause of Injury" classifications were straining during an occupational activity (n = 12,324, 28.30%), followed by ***falling or slipping (n = 7,179, 16.48%)***, and being struck by some kind of object or individual (n = 6,008, 13.80%).

General cause of injury	Number of injuries	%	Cumulative %
Strain	12,324	28.30%	28.30%
Fall or slip	***7,179***	***16.48%***	***44.78%***
Struck by	6,008	13.80%	58.58%
Cut, puncture, or scrape	5,545	12.73%	71.31%
Foreign body	4,093	9.40%	80.71%
Striking against or stepping on	2,942	6.76%	87.47%
Caught in or between	2,348	5.39%	92.86%
Absorption, ingestion or inhalation	1,197	2.75%	95.61%
Burn	949	2.18%	97.79%
Animal or insect bite or sting	551	1.27%	99.05%
Motor vehicle	414	0.95%	100.00%
Total	**43,550**	**100.00%**	

Table 1: General cause of injury (Godfrey, 2007, pg 143).

A further examination of the 7,179 "Fall or Slip" cases showed (Table 2) that falls and slips from ladders or scaffolds comprised nearly 20% (n = 1,388) of injuries caused by falls or slips (Godfrey, 2007).

Cause of Injury	Number of Injuries	%	Cumulative %
On Same Level	1,569	21.86%	21.86%
To A Different Level	1,400	19.50%	41.36%
From Ladder or Scaffolding	1,388	19.33%	60.70%
Other NOC	1,118	15.57%	76.27%
On Ice or Snow	589	8.20%	84.47%
Slip (No Fall)	342	4.76%	89.24%
On Stairs	328	4.57%	93.81%
Into Openings	313	4.36%	98.17%
Of Liquid or Grease Spills	132	1.84%	100.00%
Total	**7,179**	**100.00%**	

Table 2: Causes of injuries from falls and slips (Godfrey, 2007, pg 151)

Using a five point Likert scale to measure injury severity (1 = Medical Only to 5 = Death) injuries caused by motor vehicles and ***falls or slips*** were shown to have had significantly higher injury severity means than all of the remaining general causes of injury (Godfrey, 2006, pp. 80-90, 142-144, 150-152) (see Figure 7).

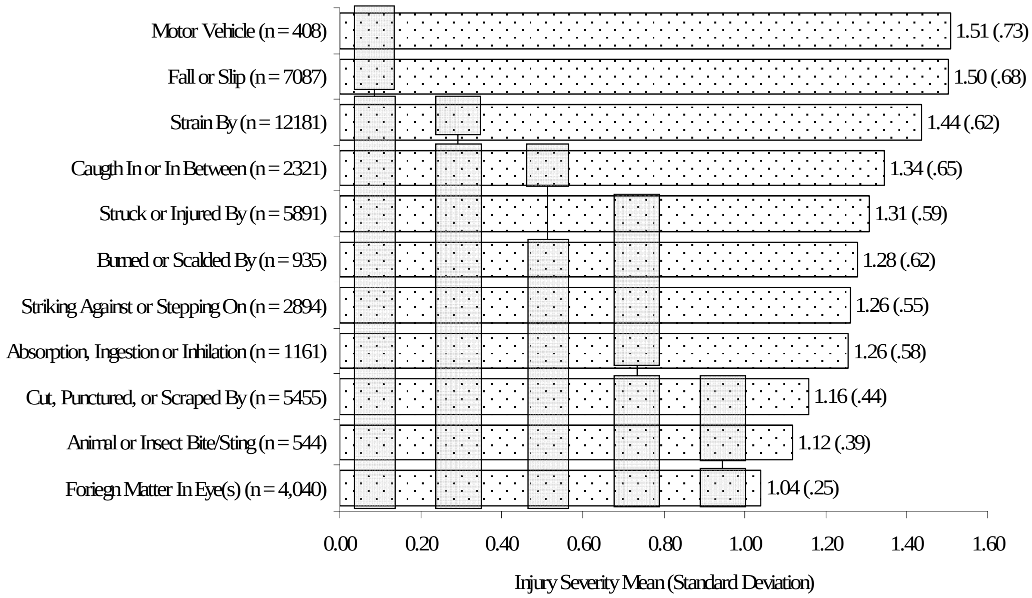

Figure 7 - Comparison of injury severity means by “General Cause” of injury (Statistically significant differences, at $p \leq 0.05$, are illustrated by connecting homogeneous groupings of means, depicted with transparent boxes) (Godfrey, 2007, pg144)

Godfrey (2007) conducted a further examination of the of the injuries from falls and slips and found falls from ladders or scaffolds to have had an injury severity mean significantly greater, at $p \leq 0.05$, than that for falls or slips of liquid or grease spills, falls on the same level, other causes NOC, and injuries from falls or slips on ice or snow (Figure 88). Injuries caused by falls from different levels showed a significantly greater injury severity mean, at $p \leq 0.05$, than injuries due to falls on the same level, falls or slip of causes NOC, and injuries from falls or slips on ice or snow. Falls into openings had a significantly greater injury severity mean, at $p \leq 0.05$, than falls or slips from miscellaneous causes NOC, and falls or slips on ice or snow.

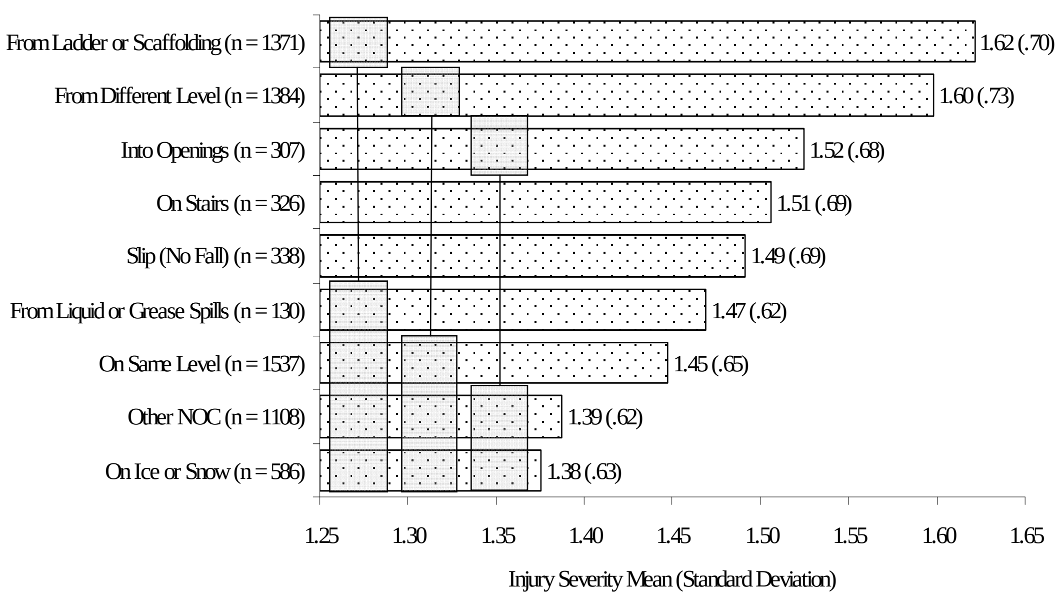

Figure 8 - Differences of injury severity means between causes of falls and slips (Statistically significant differences, at $p \leq 0.05$, are illustrated by connecting homogeneous groupings of means, depicted with transparent boxes) (Godfrey, 2007, pg 152)

Fall Protection through the use of Virtual Environment

Neville (1998) and Chantawit *et al* (2005) suggested that training is important for rehearsal purposes and to prevent accidents and injuries. Currently, 2D drawings are used as visual representations of the elements of the construction project, and specifications indicate a *declarative* form of describing these elements as well as modeling a *procedural* form of the construction process. The 2D drawings and specifications are the main source of information for the safety managers for their safety planning. The identification of the hazard situations during any stage of the construction project is difficult to prompt with the only aid only the safety plans and traditional training methods.

The utilization of VE technologies will allow researchers to identify hazard situations that have not been taken into account within the safety plans and with the training manuals of the construction firms. The deployment of a VE-based tool can aid safety managers of the project to visualize in real-time 3D from any perspective the components and elements involved during the construction.

Barsoum *et al* (1996) developed an interactive virtual training model, SAfety in construction using Virtual Reality (SAVR), to train construction workers on avoiding falls from platform-metal scaffolding. Using HMDs, users are able to interact with the VE and detect hazardous conditions (e.g. missing guardrails, loose, weak or inadequately spaced planks, inadequate connections between scaffolding components, and defective components) and attempt to eliminate it. A scoring system is used to evaluate performance of participants. SAVR comprised of two main modules; an erect module, and an inspection module. The erection module is used to demonstrate appropriate procedures to erect scaffolding. The inspection module is used to detect and correct the potential causes of falls. Soedarmono *et al* (1996) also developed a prototype VE model for training personnel on avoiding falls during construction. Occupational Safety and Health Administration (OSHA) regulations were integrated into the model as 2D text and audio information. Warning messages (i.e. required safety standards) are displayed or announced when a user approaches a working platform in the VE from which they could fall.

Our purpose of utilizing VE-based tool is to aid the recognition of hazard situations that are difficult to identify with the use of current construction documents. VE will be able to show the construction elements that are represented in the documentation in real-time 3D. The uniqueness of our approach is the integration of actual human-motion data obtained from a motion-capture suit (Figure 9). The motion data will then be utilized and displayed in the VE. The advantages of our approach for safety hazard recognition are the actions that can be captured and then set up for safety plans, a better visualization of additional temporary works for safety purposes, and the strategies for risk assessments. We intend to use VE as a preventive strategy which can give better information of the possible safety hazards than that of the traditional site inspections. We plan to use VE to develop a preventive methodology for fall protection.

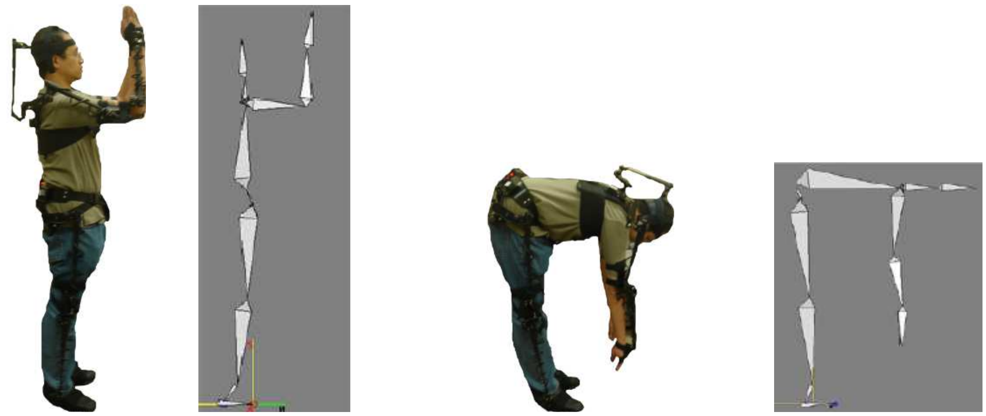

Figure 9: One of the authors in the motion-capture suit, and the corresponding avatar that is used to capture the motion data

Methodology for Analysis

Our proposed workplan is based on the following steps: a categorization of scenarios where construction workers will face possible hazard situations, capturing of human-motion data based on the defined scenarios, construction of the VE, simulation of scenarios in the VE, safety hazard analysis of the resulting visualizations, and the prevention analysis which results in the elaboration of preventive and safety plans (Figure 10).

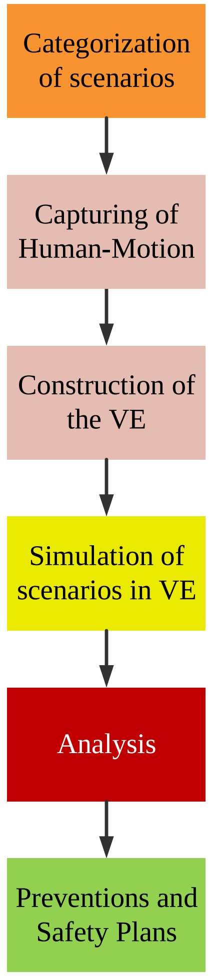

Figure 10: Proposed workplan

As our approach has a preventive character for early detections of hazard situations, a better design of the construction process can be generated. The resulting analysis of the scenarios can be reutilized for future projects where the patterns of the scenario can be reproduced. For this purpose, our team will elaborate a database that can be further used to build decision models on designing multiple construction processes. For example, if one hazard situation has been identified, the contextual elements that constitute that specific situation are registered as a pattern of risk within a database. The variables develop the patterns are considered for future analysis of hazard situations. The resulting analysis of patterns is one of the most valuable tools for the safety manager will have to elaborate prevention and safety plans for future projects.

References

Barsoum, A., Hadipriono, S.F.C and Larew, R.E. (1996), Avoiding Falls From Scaffolding in Virtual World, Proceedings of the 3rd Congress in Computing in Civil Engineering, ASCE, pp 906-912.

Cattledge GH, Hendricks S, Stancvich R (1996): Fatal occupational falls in the U.S. construction industry, 1980-1989. Accident Analysis and Prevention. 28 (5) 647-654.

Cattledge HH, Schneiderman A, Stanevich R, and Greenwood J (1996): Nonfatal occupational fall injuries in the West Virginia construction industry. Accident Analysis and Prevention. 28 (5): 655-663.

Damrong Chantawit, Bonaventura H.W. Hadikusumo, and Chotchai Charoenngam 4DCAD-Safety_visualizing project scheduling, Construction Innovation 2005; 5: 99–114

Dorevetich S, Forst L, Conroy L and Levy P (2002): Toxic inhalation fatalities of US construction workers, 1990 to 1999. Journal of Occupational and Environmental Medicine. 44 (7): 657-662.

Ellis, J. Nigel (2001). Introduction to Fall Protection, American Society of Safety Engineers; Des Plaines, Ill., pp. 85-94)

Gillen M, Faucett JA, Beaumont JJ, and McLoughlin E (1997): Injury severity associated with nonfatal construction falls. American Journal of Industrial Medicine. 32: 647-655.

Godfrey, R.J (2007). Analysis of construction worker injury informatioin from a workers' compensation databse. (Doctoral dissertation, University of Florida, 2007).

Hadikusumo, B.H.W., and Rowlinson, S. (2002). "Integration of virtually real construction model and design-for-safety-process database." Automation in Construction, Vol. 11, pp. 501-509.

Hessel PA (2000): Hearing loss among construction workers in Edmonton, Alberta, Canada. Journal of Occupational and Environmental Medicine. 42: 57-63.

Huang, X., and J. Hinze.(2003) "Analysis of Construction Worker Fall Accidents," Journal of Construction Engineering and Management, Vol. 129, No. 3, pp. 262-271.

Islam SS, Nambiar AM, Doyle EJ, Velilla AM, Biswas RS, Ducatman P, and Alam M (2000): Epidemiology of work-related burn injuries: Experiences of a state-managed workers' compensation system. Journal of Trauma: Injury, Infection, and Critical Care. 49 (6): 1045-51.

Lombardi D A, Pannala R, Sorock G S, Wellman H, Courtney T, Verma S, and Smith GS, (2005): Welding related occupational eye injuries: A narrative anaylsis. Injury Prevention. 11 (3): 174-179.

Neville, H. (1998). Workplace accidents: they cost more than you think. Industrial Management, Vol. 40, No 1, pp 7-10

Ore T and Casini V (1996): Electrical fatalities among U.S. construction workers. Journal of Occupational and Environmental Medicine. 38: 587-592.

Ore, T. and Fosbroke, D.E. (1997). "Motor Vehicle fatalities in the United States Construction Industry." Accident Analysis and Prevention, Vol. 29, No. 5, pp. 613-626.

Pratt SG, Kisner SM, and Moore PH (1997): Machinery-related fatalities in the construction industry. American Journal of Industrial Medicine. 32: 42-50.

Robinson CF, Peterson M and Palu S (1999): Mortality patterns among electrical workers employed in the U.S. construction industry, 1982-1987. American Journal of Industrial Medicine. 36: 630-637.

Soedarmono, D.R., Hadipriono, F.C. and Larew, R.E. (1996) Using Virtual Reality to Avoid Construction Falls, Computing in Civil Engineering (New York), 1996, pp.899-905.

Tawfik, H. and Fernando, T. (2001). "A Simulation Environment for Construction Site Planning." Proceedings of the Fifth International Conference on Information Visulization, IV. IEEE Computer Society: Washington, D.C., pp. 199-204.

United States Department of Labor (2007): "Bureau of Labor Statistics: National Census of Fatal Injuries from 1992 through 2005. Retrieved on September 14, 2007 from http://www.bls.gov/news.release/pdf/cfoi.pdf . Washington, DC: USDOL, BLS

United States Department of Labor (2006): Bureau of Labor Statistics: National Census of Fatal Injuries from 1992 through 2005. Retrieved on September 14, 2007 from http://www.bls.gov/iif/oshwc/cfoi/cfnr0012.txt. Washington, DC: USDOL, BLS