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ABSTRACT

Falls are one of the leading causes of workplace death, lost work time, and costs to the construction industry. The goal of this study was to develop an assessment tool to evaluate fall safety in general construction among five construction trades and among five types of equipment throughout different stages of construction. The GW Audit of Fall Risk (GAFR) was developed by modifying three existing assessment tools (according to applicable OSHA standards), validated by a panel of experts, tested during a two-week pilot study, and used during a 12-month observation period. The overall mean safety compliance was 98.9%. Lowest mean safety compliance was found with ironworkers (97.0%), the use of personal fall arrest systems (96.3%), and during the concrete pouring/placement phase (97.3%). The findings indicate there was a high level of safety compliance throughout the project and across the skilled trades. Ironworkers may be at higher risk and deserve increased attention and support on the job. Use of personal fall arrest systems, especially during the earlier phases of construction was also a context that emerged deserving continued and heightened attention.

KEY FINDINGS

- The study context afforded a unique opportunity to perform multiple repeat assessments on one general contractor site during the bulk of construction activity.
- The GAFR was constructed to respond to a gap in systematic fall hazard assessment tools for general construction, and yielded valuable data on which various site characteristics and work practices could be scored.
- The high mean safety compliance overall was primarily due to the strong safety culture fostered by the site superintendent. Site superintendent training should emphasize the importance of cultivating a safety culture on each project to make personal safety an inherent part of the job for each worker.
- The use of personal fall arrest systems resulted in the most recurring issues throughout the observation period. These issues include the misuse or lack of use of a proper personal fall arrest system (e.g. not tying off to an appropriate structure, extending a retractable lifeline too far and negating swing fall clearance). Because these systems are essential for safely working with different

types of suspended platforms, focused and regular training should be given to all workers.

- Ironworkers were found to have the highest number of recurring issues with the use of personal fall arrest systems and scaffolding, and may therefore be at higher risk of falling. The site superintendent should work with the ironwork subcontractors to ensure adequate training and consistent reminders of proper fall safety procedures for the use of personal fall arrest equipment, aerial lifts, scaffolding, and any other pieces of equipment. Furthermore, subcontractors should ensure adequate supply and accessibility of equipment for these workers.
- Significant differences were found when mean safety compliance for carpenters was compared to that of electricians and painters. Carpenters may be at a higher risk of falling and should be monitored by the site superintendent and carpentry subcontractor to ensure these workers are able to perform their work safely.
- Lowest overall safety compliance was found during the concrete pouring/placement phase during the first and second months of observation. Because observation of the site began just as this phase ended, this finding was not robust enough to assume that lower safety compliance was consistent during the entire phase. However, because ladder and lift usage is inherently intense during this phase workers' are likely to be at heighten risk of falling during this early stage of a project and fall safety protection should receive added attention.

INTRODUCTION

Prevalence of Fall Hazards in the Construction Industry

Falls are one of the leading causes of workplace death, lost work time, and costs to industry, particularly in construction (Leamon & Murphy 1995, Courtney, Sorock et al. 2001, Courtney, Matz et al. 2002). In fact, falls are considered one of construction's "Fatal Four" (along with struck-by-object, electrocutions, and caught-in/between) and contribute roughly 35% of these injuries that are responsible for more than half of deaths within general construction, as of fiscal year 2012 (OSHA, 2013). One study of 1,025 carpenters found that 16% had personally fallen in the past year and 51% knew someone who had fallen from a height at work (Kaskutas, Dale et al. 2010). Falls in construction incur the highest workers' compensation and hospitalization costs (Derr, Forst et al. 2001). Furthermore, the duty to provide fall protection (29 CFR 1926.501) is one of the ten most frequently cited OSHA standards violated, along with the OSHA standards to ensure safety protection and safe construction of scaffolding (29 CFR 1926.451) and ladders (29 CFR 1926.1053), as of fiscal year 2013 (OSHA, 2013).

Previous Literature on Fall Safety within the Construction Industry

Only a few surveillance studies have been conducted to evaluate fall safety practices among construction workers. The unit of observation in these studies has typically been either at the worksite or at the individual worker-level to determine compliance with fall prevention practices. For example, a Washington University construction safety team based in St. Louis, MO studied worksite fall safety by developing a tool to assess fall hazards and control practices in residential construction sites based on the Occupational Safety and Health Administration's (OSHA) fall prevention standards for residential construction (Kaskutas, Dale et al. 2008). The tool was successfully utilized in measuring fall prevention practices in 197 residential sites. Data collected determined that truss settings met the safety criteria on average 28% of the time and use of personal fall arrest and monitoring of unguarded floor openings were rare at the worksites studied (Kaskutas, Dale et al. 2009). Likewise, Becker and his colleagues at West Virginia University developed an audit tool to assess fall safety practices in general construction and administered the tool to evaluate the impact of their organizational intervention on improvement of fall prevention practices in general construction setting (Becker, Fullen et al. 2001).

Alternatively, some studies have focused on fall safety practices at the individual-worker level. Lipscomb and her colleagues analyzed the fall injuries among union carpenters over a three-year period using an active injury surveillance system of individual injured workers as well as worksites where fall injuries occurred (Lipscomb, Dement et al. 2003). Because ladders are a major source of falls in construction, our previous work has developed a tool to assess individual-level ladder safety practice; it includes 24 within 5 ladder use domains and was tested with 771 stepladder observations (Perry and Ronk 2010, Ronk, Dennerlein et al. 2011).

However, these previous studies have limitations (Becker, Fullen et al. 2001, Kaskutas, Dale et al. 2008, Sparer & Dennerlein 2013). First, although both significantly contribute to fall risks, to our knowledge, no previous study has sought to assess worksite- and individual-level fall prevention practices simultaneously. One previous study worked to identify contributing factors of fall injury at the individual- and worksite-level, but this study interviewed individual workers and visited worksites to assess their safety practice after fall injuries occurred (Lipscomb, Dement et al. 2003). In addition, none of the previous surveillance studies have considered specific construction trades, such as electricians, painters, and carpenters, as differing in their risks of falling (Wang 1999, Derr, Forst etal. 2001, Dong, Fujimoto et al. 2009) as compared to other trades. Finally, fall risks have not been systematically quantified among the skilled trades and this is necessary for developing more tailored and effective intervention strategies to reduce fall injury among general construction workers.

OBJECTIVES

Specific Aims

Specific aims of this study were to:

1. Develop and evaluate an effective fall practices assessment instrument relevant to the commercial construction setting.
2. Determine heightened risk of falling for each of the seven types of equipment targeted throughout different stages of construction.
3. Identify vulnerable trades at specific periods with higher risk of falling, which may be targets for intervention.

METHODS

Setting and Study Population

The study was conducted at the new George Washington University Milken Institute School of Public Health building site, 950 New Hampshire Avenue, Washington, DC 20052. The study population consisted of all construction workers (Whiting-Turner and other trade-specific contractors) on the site during each observation. Only those workers of the carpentry, electrician, ironwork, paint, and roofing trades working from a height of six feet or more are to be observed.

Unit of Observation

This study had two units of observation. First, safety compliance related to the use of ladders, aerial lifts, personal fall arrest systems, and scaffolding (mobile) was assessed by observing individual employees within the five occupational construction trades targeted for this study (i.e. carpenters, electricians, ironworkers, painters, roofers) working from elevations of six feet or higher at the time of observation. During the course of observation, if a worker was observed to be working at heights in more than one context, each occurrence will be treated as a separate observation. Second, safety compliance was assessed in relation to scaffolding (fixed), guardrails, safety net systems, and roof sheathing through the observation of the work environment.

Assessment Tool

The instrument was developed by modifying three existing construction safety audit tools: a fall safety assessment tool developed for general construction (Becker, Fullen et al. 2001), the St. Louis Assessment of Fall Risks (SAFR) for residential construction (Kaskutas, Dale et al. 2008), and the Ladder Assessment Tool (Dennerlein, Ronk et al. 209, Perry and Ronk 2010). Based on the review of these tools, an extensive list was developed of items to assess fall safety practices in general construction in a comprehensive way. Modifications were made to this list and choice items based on OSHA construction standards to reflect fall hazards for general construction settings (e.g. the incorporation of work platforms on mobile scaffolding due to their frequent use in general construction). These modifications were determined by first reviewing the OSHA standards and other relevant literature to identify fall hazards specifically for general construction settings. The draft instrument was then shared with a convening expert panel, including the on-site superintendents, to review and provide feedback on the modified instrument. Finally, a two-week pilot test was conducted using the draft instrument to determine ease-of-use, as well as areas for improvement and further refinement. Further modifications occurred after the observations ceased and the researcher assessed the relevancy of the audit tool items and its overall usability.

Assessment Protocol

Each item of observation was scored dichotomously as to whether or not it was observed, and if observed, whether or not it meets the established definition of best safety practice. In each domain for audit, the average number of items not meeting the safety criteria was calculated to estimate potential heightened risk (as noted as lower safety compliance) for that domain.

The average duration of each site visit was one hour spent going through each of the building's nine floors (including the two basement levels) and the roof, when safe to inspect, as directed by the Whiting-Turner site superintendent, Mike Whitmore. The date, floor number, phases of construction, entry for each applicable item on the assessment tool, the profession (if applicable), and any notes were recorded during each site visit. Whiting-Turner utilizes a subcontractor logging system that identifies the workers and their company according to the number of their hard hat. Thus, the researcher did not need to interact with the workers in order to identify their trade and no individual persona data will be collected. Mr. Whitmore confirmed the accuracy and appropriateness of phases of construction upon completion of this project. In addition, he authorized the use of pictures to be used in future presentations and reports.

Data Analysis

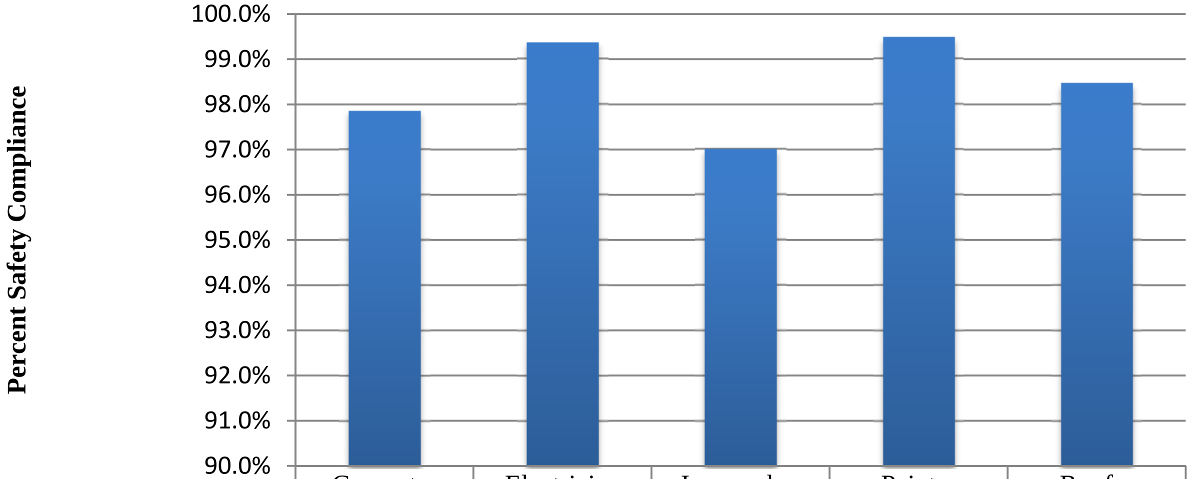
Data were collected using the assessment tool and scored dichotomously, from which, the following comparisons will be made: safety compliance for each equipment domain (ladder, aerial lift, personal fall arrest equipment, guardrails, scaffolding, roof sheathing, safety net system) across each phase of construction (concrete pouring/placement, skin, roofing, interior rough-end, interior finishes), as well as among each trade (carpenter, electrician, ironworker, painter, roofer) across each phase of construction, each trade per domain, and overall safety compliance among each domain, trade, and phase of construction. These comparisons were documented in individual Microsoft Excel spreadsheets (accompanied with a data dictionary) and were analyzed using SAS 9.3 software. One-way ANOVA and unpaired (independent) t-test analyses were derived to evaluate differences in fall safety (as evidence of lower safety compliance) among types of equipment, occupational trades, and phases of construction.

RESULTS

Trades Targeted for this Study

The purpose of this first analysis was to determine whether there was a relationship between the profession of a worker (trade) and their risk of falling from a significant height (six feet or higher), as determined by lower mean safety compliance. Specifically, this analysis was carried out to determine whether there are significant differences between carpenters, electricians, ironworkers, painters, and roofers. Thus, the null hypothesis states that in the subject population, there is no difference between subjects of one trade versus those of another trade, with respect to their mean safety compliance scores. The alternative hypothesis states that there is a significant difference between at least one of the targeted trades and another targeted trade. Total worker compliance for this project was 98.5%. Figure 1 displays the mean safety compliance for each trade during this study.

Figure 1: Mean Safety Compliance among Targeted Trades



	Carpenter	Electrician	Ironworker	Painter	Roofer
Mean Safety Compliance	97.9%	99.4%	97.0%	99.5%	98.5%

Compared to the other four trades that were targeted for this study, ironworkers were clearly at the lower end of compliance, and therefore, at higher risk of falling, supporting the research hypothesis. Carpenters and roofers were also found to have lower safety compliance compared to electricians and painters, indicating their heightened risk of falling. To determine the presence of significant differences between trades, a one-way ANOVA (Analysis of Variance) was conducted. Results were analyzed with one between-subjects factor and did not reveal any significant treatment effect for safety compliance by trade, ($F(4, 322) = 1.21$, MSE = 0.007, p = 0.3081) nor did Tukey's HSD test with alpha set at 0.05 (see Table C-1 in Appendix C for results). Therefore, each relationship was compared using an unpaired (independent) t-test, results of which displayed in Table 1.

Table 1: Mean Safety Compliance and Independent (Unpaired) T-Test Results

Trade Comparison	Mean Safety Compliance (%)	Difference Between Means (95% Confidence Limits)	*p*-value
Carpenters – Electricians	97.9 99.4	-0.015 (-0.025, -0.006)	0.002
Carpenters – Ironworkers	97.9 97.0	0.008 (-0.021, 0.038)	0.572
Carpenters – Painters	97.9 99.5	-0.016 (-0.027, -0.006)	0.003
Carpenters – Roofers	97.9 98.5	-0.006 (-0.039, 0.028)	0.719
Electricians – Ironworkers	99.4 97.0	0.024 (-0.005, 0.052)	0.105
Electricians – Painters	99.4 99.5	-0.001 (-0.009, 0.006)	0.773
Electricians – Roofers	99.4 98.5	0.009 (-0.007, 0.025)	0.276
Ironworkers – Painters	97.0 99.5	-0.025 (-0.054, 0.004)	0.094
Ironworkers – Roofers	97.0 98.5	-0.014 (-0.049, 0.020)	0.400
Painters – Roofers	99.5 98.5	0.010 (-0.006, 0.026)	0.215

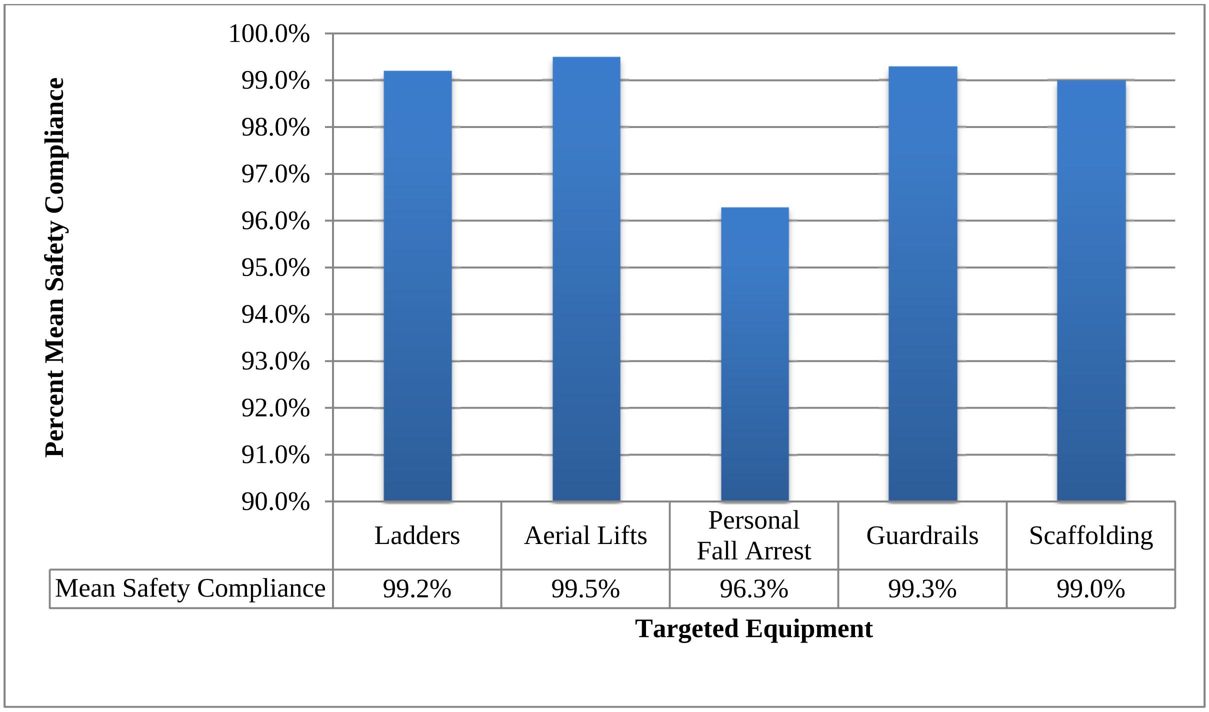
This analysis involved one predictor variable and one criterion variable. The predictor variable was the targeted occupational trade (carpenters, electricians, ironworkers, painters, and roofers), as noted as a dichotomous variable for each pairing (e.g. carpenters versus electricians, carpenters versus painters). The criterion variable was a continuous variable measuring mean safety compliance for these trades. This analysis revealed a significant difference in safety compliance between carpenters and electricians, $t(184) = -3.14$, $p = 0.0021$, and between carpenters and painters, $t(118) = -3.06$, $p = 0.0028$. The sample means for safety compliance are displayed in the second column of Table 1 and show that carpenters scored lower in terms of safety compliance compared to electricians and painters. The observed difference between the means for carpenters and electricians was -0.0151 and the 95% confidence interval for the difference between means extended from -0.0247 and -0.00560. The observed difference between the means for carpenters and painters was -0.0162 and the 95% confidence interval for the difference between means extended from -0.0267 and -0.00571. The remainder of the results from this independent-samples t-test analysis revealed non-significant differences between the other trades. This information is also displayed in Table 1.

Equipment Targeted for this Study

The purpose of this second analysis was to determine whether there was a relationship between the types of equipment or a worksite safety element and a worker's risk of falling from a significant height (six feet or higher), as determined by mean safety compliance. Specifically, this analysis was carried out to determine whether there is a difference in safety compliance between the use of a ladder, an aerial lift, a personal fall arrest system, scaffolding, and the presence of guardrails.

Total compliance based on equipment usage/presence was 98.9%. Figure 2 displays the total safety compliance values for each type of equipment observed. The frequency tables that informed Figure 2 for each assessment item and mean safety compliance can be found in Appendix A. Mean safety compliance values for each domain are also displayed in Figure 2.

Figure 2: Mean Safety Compliance among Types of Targeted Equipment



	Ladders	Aerial Lifts	Personal Fall Arrest	Guardrails	Scaffolding
Mean Safety Compliance	99.2%	99.5%	96.3%	99.3%	99.0%

Compared to the other four types of equipment/worksite safety elements, use of a personal fall arrest system was the lowest in compliance compared to the other targeted equipment observed. Additionally, lower safety compliance was found with the use of scaffolding was lower than other types of equipment. To determine the presence of significant differences between these equipment/worksite elements, a one-way ANOVA (Analysis of Variance) was conducted. Results were analyzed with one between-subjects factor and did reveal a significant treatment effect for safety compliance and equipment used/present on the worksite, ($F(4, 639) = 3.32$, $MSE = 0.005$, $p = 0.0105$). Tukey's HSD test revealed significant differences between personal fall arrest systems and guardrails, as well as personal fall arrest systems and scaffolding, with alpha set at 0.05 (see Table C-2 in Appendix C for results). Therefore, these relationships and those between the other types of equipment were compared using an unpaired (independent) t-test, results from which displayed in Table 2.

Table 2: Mean Compliance and Independent (Unpaired) T-Test Results For Equipment

Equipment Comparison	Mean Safety Compliance (%)	Difference Between Means (95% Confidence Limits)	*p*-value
Ladders – Aerial Lifts	99.2 99.5	0.0021 (-0.0060, 0.0103)	0.6016
Ladders – Personal Fall Arrest	99.2 96.3	0.0295 (-0.0018, 0.0608)	0.0640
Ladders – Guardrails	99.2 99.3	0.0002 (-0.0084, 0.0089)	0.9510
Ladders – Scaffolding	99.2 99.0	0.0021 (-0.0039, 0.0080)	0.4935
Aerial Lifts – Personal Fall Arrest	99.5 96.3	0.0317 (-0.0003, 0.0636)	0.0524
Aerial Lifts – Guardrails	99.5 99.3	0.0019 (-0.0092, 0.0130)	0.7397
Aerial Lifts – Scaffolding	99.5 99.0	0.0042 (-0.0049, 0.0133)	0.3631
Personal Fall Arrest – Guardrails	96.3 99.3	0.0298 (-0.0024, 0.0619)	0.0691
Personal Fall Arrest – Scaffolding	96.3 99.0	-0.0274 (-0.0590, 0.0041)	0.0874
Guardrails – Scaffolding	99.3 99.0	0.0023 (-0.0073, 0.0120)	0.6338

This analysis involved one predictor variable and one criterion variable. The predictor variable was the type of targeted equipment (ladders, aerial lifts, personal fall arrest systems, guardrails, scaffolding), as noted as a dichotomous variable for each pairing (e.g. ladders versus aerial lifts, ladders versus guardrails). The criterion variable was a continuous variable measuring mean safety compliance for these domains. This analysis did not reveal a significant difference in safety compliance between any of the types of equipment/worksite elements, although the relationship between aerial lifts and personal fall arrest systems was very close to being considered significant ($p = 0.0524$). The sample means for safety compliance are displayed in the second column of Table 2 and show that personal fall arrest system use was scored lower in terms of safety compliance compared to the other types of equipment. The remainder of the results from this independent-samples t-test analysis revealed non-significant differences between the other domains. This information is also displayed in Table 2.

Compliance to safety protocols was lowest with the use of personal fall arrest systems, with recurring issues regarding the lack of use of appropriate personal fall arrest equipment for specific jobs. Other issues of non-compliance regarded the use of ladders (e.g. climbing up and down the correct way without tools in-hand) and regarding the use of scaffolding (e.g. wheels locked during use). Furthermore, the presence of guardrails, especially toeboards, was a recurring issue of non-compliance.

Phases Targeted for this Study

The purpose of this third analysis was to determine whether there was a relationship between the phases of construction and a worker's risk of falling from a significant height, as indicated by lower safety compliance. Specifically, this analysis was carried out to determine whether there is a difference between the risk during the concrete pouring/placement phase, the skin phase, the roofing phase, and interior rough-end phase, and the interior finishes phase. Figure 3 displays the trend in overall compliance across the months of observation (April 2013 to March 2014) and the trend with differentiations of the span of each phase. Table 3 displays the time period of observation and mean safety compliance for each phase of construction.

Figure 3: Mean Safety Compliance Across Months of Observation Highlighting Span of Phases of Construction

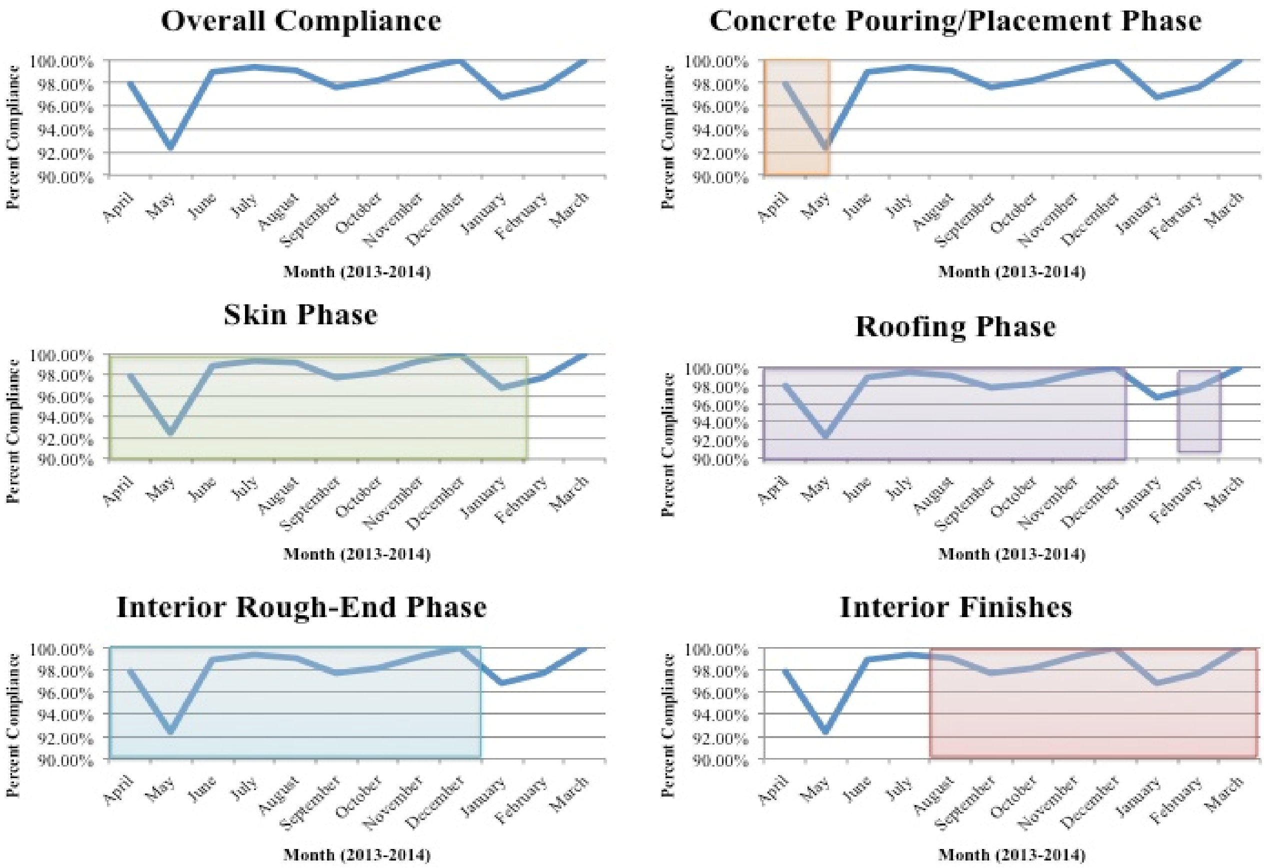


Table 3: Compliance Across Targeted Phases of Construction

Phase	Time Period	Mean Safety Compliance (%)
Concrete Pouring/Placement	Before April 2013 – Mid-April 2013	97.3
Skin	Before April 2013 – January 2014	98.4
Interior Rough-End	Before April 2013 – December 2014	98.9
Roofing	Before April 2013 – Mid-December 2013, January 2014 – February 2014	98.9
Interior Finishes	July 2013 – March 2014	99.1

To determine the presence of significant differences between these equipment/worksite elements, a one-way ANOVA (Analysis of Variance) was conducted. Results were analyzed with one between-subjects factor and did not reveal any significant treatment effect for safety compliance by phase of construction, ($F(4, 2189) = 0.98$, MSE = 0.004, $p = 0.4159$) nor did

Tukey's HSD test with alpha set at 0.05 (see Table C-3 in Appendix C for results). Therefore, each relationship was compared using an unpaired (independent) t-test, results from which displayed in Table 4.

Table 4: Mean Compliance and Independent (Unpaired) T-Test Results among Phases of Construction

Phase Comparison	Mean Safety Compliance (%)	Difference Between Means (95% Confidence Limits)	*p*-value
Concrete Pouring/Placement – Skin	97.3 98.4	-0.0161 (-0.0365, 0.0043)	0.3964
Concrete Pouring/Placement – Interior Rough-End	97.3 98.9	-0.0158 (-0.0367, 0.0052)	0.4070
Concrete Pouring/Placement – Roofing	97.3 98.9	-0.0164 (-0.0365, 0.0038)	0.3881
Concrete Pouring/Placement – Interior Finishes	97.3 99.1	-0.0185 (-0.0380, 0.0009)	0.3293
Skin – Interior Rough-End	98.4 98.9	0.0003 (-0.0074, 0.0081)	0.9309
Skin – Roofing	98.4 98.9	-0.0003 (-0.0077, 0.0071)	0.9410
Skin – Interior Finishes	98.4 99.1	-0.0024 (-0.0101, 0.0052)	0.5205
Interior Rough-End – Roofing	98.9 98.9	-0.0006 (-0.0082, 0.0070)	0.8731
Interior Rough-End – Interior Finishes	98.9 99.1	-0.0028 (-0.0106, 0.0051)	0.4772
Roofing – Interior Finishes	98.9 99.1	-0.0022 (-0.0097, 0.0054)	0.5646

This analysis involved one predictor variable and one criterion variable. The predictor variable was the targeted phases of construction (concrete pouring/placement, skin, interior rough-end, roofing, and interior finishes), as noted as a dichotomous variable for each pairing (e.g. skin versus interior rough-end, skin versus interior finishes). The criterion variable was a continuous variable measuring mean safety compliance for these domains. This analysis did not reveal a significant different between any two phases of construction. The sample means for safety compliance are displayed in the second column of Table 4 and show that safety compliance during the concrete pouring/placement phase was lower compared to the other phases. The results from this independent-samples t-test analysis are displayed in Table 4.

Additional Results

Consistent with the first goal of this study, mean safety compliance was computed for each of the five trades using each of the four types of targeted equipment (i.e. ladders, aerial lifts, personal fall arrest systems, fixed scaffolding). Results are displayed in Table 5.

Table 5: Mean Compliance for each Trade using each Type of Targeted Equipment

	Ladders % mean safety compliance (number of observations)	**Aerial Lifts % mean safety compliance (number of observations)**	**Personal Fall Arrest System % mean safety compliance (number of observations)**	**Scaffolding (mobile) % mean safety compliance (number of observations)**
Carpenters	98.26% (23)	97.22% (9)	87.04% (36)	89.47% (19)
Electricians	99.43% (82)	97.22% (9)	100% (4)	91.67% (4)
Ironworkers	99.67% (20)	100% (24)	94.23% (52)	94.44% (6)
Painters	99.74% (26)	100% (4)	100% (2)	66.67% (1)
Roofers	100% (5)	Not Observed	Not Observed	100% (1)

Results from this table show the lowest overall compliance among the use of these types of equipment and the targeted trades was the use of mobile scaffolding by painters (66.67% compliance). However, due to this being a single observation, the most notable lowest mean compliance was attributed to carpenters not using personal fall arrest systems correctly (87.04%). Overall, ironworkers were the most frequent users of personal fall arrest systems and aerial lifts, with safety compliance over 90%. Electricians were the most frequent users of ladders by far, but with higher compliance than the other targeted trades, including carpenters, with the lowest compliance of 98.26%. Carpenters contributed to the lowest compliance and most consistent use of mobile scaffolding (excluding the single observation of a painter using a mobile scaffolding system with 66.67% compliance to safety protocols).

Consistent with the second goal of this study, mean safety compliance was computed for each of the five types of targeted equipment included in this analysis (i.e. ladders, aerial lifts, personal fall arrest system, guardrails, scaffolding) across each phase of construction (i.e. concrete pouring/placement, skin, interior rough-end, roofing, interior finishes). Results are displayed in Table 6.

Table 6: Mean Safety Compliance for each Type of Targeted Equipment over each Phase of Construction

	Concrete Pouring/Placement Phase **Mean Safety Compliance (Number of Observations)**	**Skin Phase** **Mean Safety Compliance (Number of Observations)**	**Interior Rough-End Phase** **Mean Safety Compliance (Number of Observations)**	**Roofing Phase** **Mean Safety Compliance (Number of Observations)**	**Interior Finishes Phase** **Mean Safety Compliance (Number of Observations)**
Ladders	98.2% (5)	99.2% (136)	99.1% (125)	99.2% (141)	99.3% (114)
Aerial Lifts	100% (2)	99.3% (38)	99.6% (35)	99.3% (38)	99.2% (33)
Personal Fall Arrest System	88.5% (12)	96.1% (90)	96.0% (87)	96.1% (90)	98.6% (52)
Guardrails	100% (20)	99.6% (229)	98.8% (217)	99.7% (238)	99.4% (153)
Scaffolding	99.5% (18)	99.1% (88)	99.2% (82)	99.1% (89)	98.8% (62)

Of the 644 observations of the five types of equipment/worksite elements during the five phases of construction, the lowest compliance was found with the use of personal fall arrest systems during the concrete pouring/placement phase (88.5%). Likewise, safety compliance regarding the use of personal fall arrest systems was consistently lowest across all phases of construction. Overall mean safety compliance was lowest during the concrete pouring/placement phase, although the mean safety compliance for both aerial lifts and guardrails was 100% during this phase.

CHANGES/PROBLEMS THAT RESULTED IN DEVIATION FROM THE METHODS

Originally, the intent was to have two on-site observations per week, but given the necessity of the site superintendent to escort the researcher around the site, it was unreasonable to ask for two site visits per week given the site superintendent’s schedule.

APPLICABLE RESULTS AND RELEVANCE

The fall safety record of this construction project was excellent, as no accidents resulted from a fall of six feet or higher. However, this study did illuminate some opportunities to improve fall safety. First, the most commonly observed issues included the improper use of mobile scaffolds (specifically, not locking wheels while the scaffold is in use) and the improper use of safety harnesses, which includes issues ranging from not tying off to a structurally-sound point or the omission of use altogether while performing a task that requires the use of one. Additional recurring issues observed on the worksite included workers demonstrating improper use of ladders, including climbing techniques (i.e. climbing with tools in hand, not facing the ladder while climbing), working from the top rung, or choosing to use a ladder that is inappropriate for the task.

Worksite elements that provide fall safety were found to also have issues throughout the course of the project, including damage to or absence of guardrails along the perimeter of the atrium and along the stairwells. Roof sheathing was only observed during the first five observations with no issues. However, when assessing the usability and relevancy of the GAFR assessment tool, it is of the researcher's opinion that this worksite element does not provide any semblance of fall safety and should therefore not be included in the analysis nor the next iteration of the GAFR. Likewise, safety net systems were not used on this project and were not observed; therefore, this element was not included in the analysis.

The phases of construction overlapped throughout the majority of the project, providing a difficult way to measure risk throughout each individual phase. According to frequency of issues resulting in heightened risk of falling due to some instance of non-compliance to safety protocols, the issues with safety non-compliance occurred during the concrete pouring/placement phase, although it's brief period of observation may account for this. Likewise, safety compliance was lowest regarding equipment usage/presence during this period with the use of personal fall arrest systems. However, safety compliance did not appear to differ greatly across phases of construction.

The workers found to be most at risk of falling were ironworkers, carpenters, and roofers, as they accounted for the majority of instance of non-compliance to safety protocols. Along with ironworkers, carpenters were observed using personal fall arrest systems, accounting for lowest compliance among trades using the targeted construction equipment. Therefore, ironworkers and carpenters using personal fall arrest systems can be considered worker populations more vulnerable to falls and should therefore be targeted for fall prevention education. The most frequently recurring observation was the use of ladders by electricians, and although the mean safety compliance remained above 95%, they are considered more vulnerable to the risk of falling.

The unique architectural design of this building presented some opportunities for innovation in terms of construction fixed scaffolding or ladder usage and worker's methods for following safety protocols, such as using a harness and tying off to an appropriate structure. Ironworkers were most frequently involved in accessing difficult-to-reach locations, and were more likely to make compromises in order to effectively complete their tasks.

FUTURE FUNDING PLANS

Funding opportunities to expand this work by using the GAFR in repeat assessments in multiple sites will be explored next.

PRESENTATIONS AND PUBLICATIONS

This project was presented twice at The George Washington University's Research Days (2013 and 2014), first as an introduction to this project and then with preliminary findings.

A manual describing the research study has been uploaded to the CPWR website and continues to be distributed throughout various construction safety networks.

DISSEMINATION PLAN

The research team will work with CPWR's dissemination group to market this work to major stakeholders, particularly in the general construction trades. Likewise, the research results and the tool will be presented at a professional association or construction safety conference (e.g. Washington Metro Area Construction Safety Association (WMACSA) event or the American Society of Safety Engineers (ASSE) conference).

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GW Audit of Fall Risk

Date ________________________

Time ________________________

Stages of Construction (circle all that apply):

Concrete Pouring/Placement   Skin   Interior Rough-End   Interior Finishes   Roofing

Total number of workers observed during the time of observation ________________________

Number of on-site workers observed during the time of observation:

Electricians (_____)   Painters (_____)   Carpenters (_____)   Ironworkers (_____)   Roofers (_____)

LADDER

	Trade / Hard hat number						
General							
Straight and free of cracks, broken parts, defects, mud, and ice	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Clear of electrical hazards	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Bottom clear of trip hazards	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Set up on level and solid base, securely set at the bottom	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Correct size for the job	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
General (Extension and Job-Made)							
Ladder tied or secured	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Installed at correct angle of 1:4 ratio	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Side rails extend three feet above working surface	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Area around all access points clear	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Specifications by Type							
Extension Ladder							
Extension not overextended	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Job-Made Ladder							
Filler blocks between cleats	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Double cleated when simultaneous two-way traffic exists	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Portable Ladder							
Set-up							
Fully opened and spreader bars locked	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Firm foundation for all ladder feet	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Extension/Job-Made/Portable Ladder							
Climbing							
Gets on/off the bottom of the ladder only	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Stays off the top two steps	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Moves slowly	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Facing the ladder	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Checks stability of setup and ladder before climbing	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Hands are free of objects while climbing	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Drags excess mud off of shoes before climbing ladder	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Maintains three points of contact; does not carry supplies up the ladder	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Does not work from top three rungs (top rung nor platform)	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Keeps belt buckle within side rails and both feet on ladder	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Proper climbing procedures being followed	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Working from							
One person on the ladder	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Holding only one tool	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Keeps center of mass within ladder’s support	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Uses minimum forces	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**

AERIAL LIFT

	Trade / Hard hat number						
Only authorized person operating lift	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Fall protection attached to boom or basket, not the structure	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Full body harness being used	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Employee standing firmly on floor of basket	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Brakes set on vehicle while in use	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Wheels chocked when on incline	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Not moved while occupied unless designed to be	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Free from obvious defects	Y N	Y N	Y N	Y N	Y N	Y N	Y N

PERSONAL FALL ARREST

	Trade / Hard hat number						
General							
Anchor point proper and capable of withstanding 5000 lbs.	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Free fall limited to 6' or less	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Sufficient total fall clearance	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Attachment point to worker in center of back	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Snaphook and connector are locking type	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Being used properly and not being bypassed	Y N	Y N	Y N	Y N	Y N	Y N	Y N
System free from obvious defects	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Specifications by Type							
Harness and Lanyard							
Deceleration device being used	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Harness Retractable							
Rigged to avoid swing fall	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Harness and Horizontal Lifeline							
Designed, installed, and used under supervision of qualified person (hat tag)	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Lifeline anchor points capable of twice the intended load	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Harness and Vertical Lifeline							
Lifeline limited to one worker	Y N	Y N	Y N	Y N	Y N	Y N	Y N
Rigged to avoid swing fall	Y N	Y N	Y N	Y N	Y N	Y N	Y N

GUARDRAIL	B2	B1	1	2	3	4	5	6	7	R
Wood and Wire Rope										
Toeboards installed and structurally sound	**Y N**	**Y N**								
Smooth and free from defects	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Being used properly and not being bypassed	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Top edge between 39" and 45" and at least 2" x 4" construction	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Midrail centered and at least 1" x 6" or 2" x 4" construction	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Posts no more than 8' apart and at least 2" x 4" construction	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Guardrail capable of withstanding 200 lb. force	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Midrails capable of withstanding 150 lb. force	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Flagged every 6' (*Wire Rope*)	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Supplementary										
Surfaces >6' above lower level are protected by guardrail or erected wall	**Y N**	**Y N**								
Surfaces >6' above lower level without guardrail have warning line (6' from edge)	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Guardrails for openings are constructed sturdily with 2 x 4's, top rail 42", mid rail 21"	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**

SCAFFOLDING	B2	B1	1	2	3	4	5	6	7	R
General										
Competent person present during erection	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
System plumb, level, rigid, and square	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
All braces present and properly installed	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
All components compatible with each other	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
All pins, clips, and locking mechanisms installed	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Safe means of access provided	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Proper guardrails or other form of protection present when above 10 ft.	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Working surface fully planked	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Working surface clean and not slippery	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Free from obvious defects	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Specifications by Type										
Fixed Scaffolding										
Scaffold base on firm foundation or adequate sill	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Below point of required tying to structure or tied to structure	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Mobile Scaffolding										
Scaffold wheels on firm base	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Scaffold wheels locked during use	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Worker not riding unless height-to-base width ratio is 2 to 1 or less	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**

SAFETY NET SYSTEM

	B2	B1	1	2	3	4	5	6	7	R
Installed as close as possible under working surface	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Installed to prevent individual from striking object below	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
System is free from obvious defects and scraps, tools, etc.	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Being used properly and not being bypassed	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Is not any further than 30' from working surface	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Extends out at least 8' for work surface distance up to 5'	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Extends 10' for work surface distance more than 5' and up to 10'	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Extends 13' for work surface distance more than 10' and up to 30'	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Installation has been drop tested or certified	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**

ROOF SHEATHING

	B2	B1	1	2	3	4	5	6	7	R
Bottom row of roof sheathing installed from truss web, ladder, or scaffold	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Workers install slide guard on first row of sheathing before installing next row	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Slide guards are ≥ 2x4 boards, bottom guard is perpendicular to sheathing	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Slide guard intervals: pitch up to 9 in 12 at 13' intervals, >9 in 12 at 4' intervals	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Slide guards are installed across full width of the roof and on all sides of roof	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
Roof is clear of sawdust, debris, and dew/snow/ice if workers are on roof	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**
If slide guards are not used, fall arrest is properly used by all workers on roof	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**	**Y N**

Fall Hazards in Commercial Construction: Lessons Learned from a Unique Opportunity

Milken Institute School of Public Health
THE GEORGE WASHINGTON UNIVERSITY

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Section 1

A unique opportunity to Study Fall Hazards in Commercial Construction

The Opportunity

Researchers at The George Washington University Milken Institute School of Public Health recognized that they had a rare opportunity when the university made the decision to construct a new building to house the school on the university's Foggy Bottom campus in Washington, D.C. The occupational health and construction safety experts in the school's Department of Environmental and Occupational Health understood that the project presented the chance to use the construction site as a "living laboratory." Their research showed that fall hazards in commercial construction had received much less attention than in residential construction.

Researchers visited the construction site 38 times between April 2013 and March 2014.

A team led by Melissa Perry, Professor and Chair of the school's Department of Environmental and Occupational Health, created a new assessment tool, the GW Audit of Fall Risks (GAFR), to aid in the study. This assessment instrument is designed to collect information about the use of equipment at construction sites including guardrails, scaﬀ lding, ladders, aerial lifs , and safety harnesses. It enables researchers to assess whether the equipment is being used in accordance with the safety guidelines established by the Occupational Safety and Health Administration (OSHA).

Timeline

2012

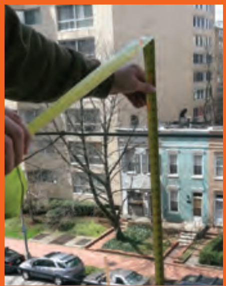
JUNE
Project planning

JULY
Early construction: Creating basement levels

AUGUST
Early construction: Sheeting and shoring process

Timeline

2013



MARCH
Pilot testing

MARCH
Initial site visit

MARCH
Concrete placement phase

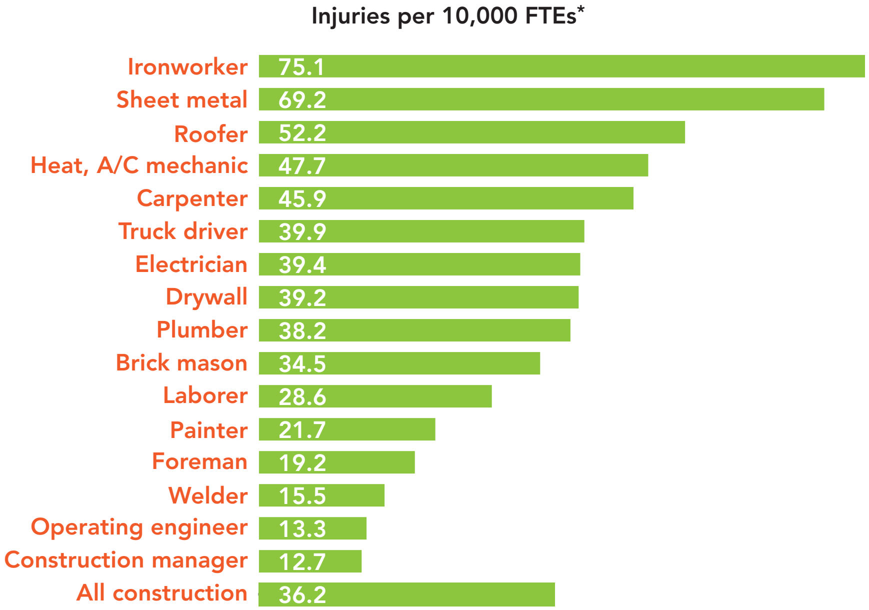
GW researchers used the GAFR tool to make systematic observations of worker- and worksite-level fall prevention practices throughout different phases of the new building's construction from April 2013 to March 2014. The building officially opened in May 2014.

The study was made possible by a partnership between the university and the general contractor for the project, The Whiting-Turner Contracting Company. CPWR, the Center for Construction Research and Training, funded the creation of this manual to raise awareness about fall hazards in commercial construction.

Why Study Fall Prevention?

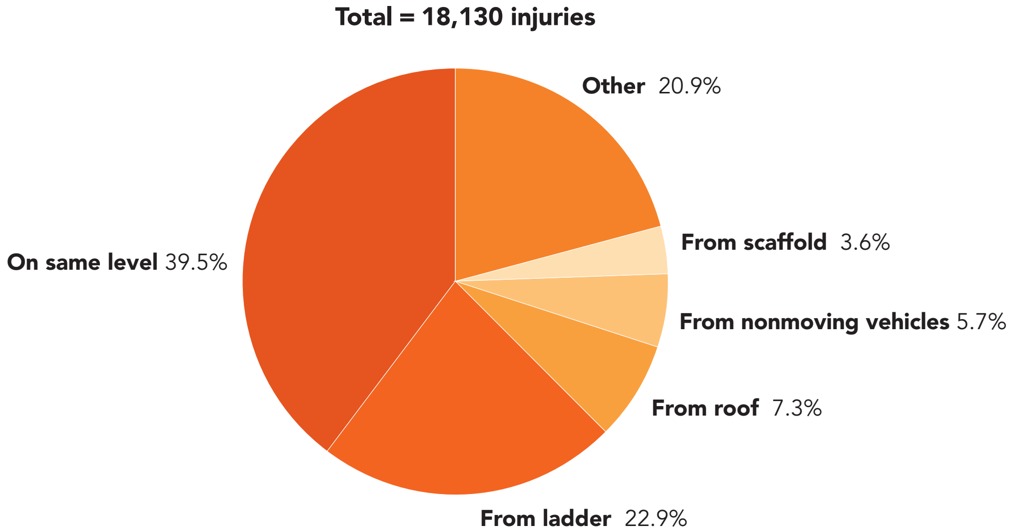
Falls are one of the leading causes of workplace death, lost work time, and costs to industry, particularly in construction. In fact, falls are the construction industry's number one cause of fatal injuries, according to the Occupational Safety and Health Administration (OSHA). In 2010, falls accounted for about one-third of construction fatalities. They are also a major cause of construction workplace injuries. When the construction industry is cited for OSHA standard violations, it is frequently for issues with fall protection (29 Code of Federal Regulations 1926.10), general scaffolding (29 CFR 1926.451), and ladder (29 CFR 1926.1053) requirements, according to fiscal year 2013 OSHA data.

Rate of nonfatal injuries from falls resulting in days away from work, selected construction occupations, 2010
(Private wage/salary workers)



*FTEs = Full-time equivalents

Causes of nonfatal injuries from falls resulting in days away from work, selected construction occupations, 2010
(Private wage/salary workers)



The chart above and the graph to the left were created by CPWR using U.S. Bureau of Labor Statistics data

Focus on Risks to Groups of Tradespeople and Differing Construction Phases

The GW study is unique in its approach of simultaneously assessing worksite- and individual-level fall prevention practices. The researchers focused on hazards and compliance with fall safety practices related to the use of ladders, aerial lifts, scaffolding, and personal fall arrest equipment among five construction trades documented to be at high risk of falling: electricians, painters, carpenters, ironworkers (including welders and window glazers), and roofers. The graph and chart above suggest that workers in these trades experience falls at a concerning rate.

The Study Tool: GW Assessment of Fall Risks (GAFR)

The GW Audit of Fall Risks (GAFR) assessment instrument developed by the researchers in the Milken Institute School of Public Health's Department of Environmental and Occupational Health was used to conduct the study of fall hazards in commercial construction as the new building was being constructed. The GAFR was developed based on a review of OSHA standards and relevant literature, as well as three existing assessment tools. (See *Appendix C* for more details.)

The tool enables users to systematically observe the condition and use of equipment known to increase the likelihood of worker injuries at the site. A printable version of the tool's list is available at http://www.elcosh.org/.

> "This was a very unusual and complicated job site. The opportunity to see this project through the eyes of public health researchers helped me appreciate the value of safety training even more."
>
> –Mike Whitmore
> Senior Superintendent at the Whiting-Turner Contracting Company

Timeline

2013

MARCH
Roofing phase

JULY
Skin phase

AUGUST
Roofing continues

Study Results in a Nutshell

The safety record of this construction project was excellent, as no accidents resulted from a fall of 6 feet or higher. Even so, the study did identify opportunities to improve on safety.

- The safety compliance issues seen most frequently were the use of mobile scaffolds without locking the wheels and the improper use of safety harnesses—or the omission of their use.
- The researchers also observed improper climbing techniques on ladders, including working from the top rung, climbing with tools in hand, and the inappropriate choice of ladders.
- During the construction process, the researchers documented damaged or absent sections of wooden guardrails.
- The highest prevalence of issues was documented during the skin and interior rough-in phases.
- Ironworkers and electricians are at the highest risk of falling because they work at high elevations most frequently.

Section 2

Controlling Fall Hazards at a Commercial Construction Site

Fall Hazard Definitions

According to OSHA, a fall hazard is "anything at your worksite that could cause a worker to lose his balance or lose bodily support and result in a fall." Almost any walking or working surface at a construction site has the potential of being a fall hazard, especially when it is elevated four feet or higher off of the ground. In OSHA's revised construction industry safety standards (29 CFR, Subpart M, Fall Protection, 1926.500, 1926.501, 1926.502, and 1926.503), the threshold for a fall hazard is six feet; therefore, protection must be provided for workers who are operating at elevations six feet or higher off of the base surface.

Major Types of Fall Hazards

OSHA's records show the major types of fall hazards in a general construction setting are:

- Unprotected roof edges, roof and floor openings, structural steel beams creating leading edges, etc.
- Improper scaffold construction
- Unsafe portable ladders

Figure 1: Unprotected roof edge

Figure 2: Damaged portable ladder

Figure 3: Improperly secured base on mobile scaffolding

Timeline

2013

AUGUST
Interior rough-in phase

SEPTEMBER
Interior rough-in continues

NOVEMBER
Interior finishes phase

"From our analysis, we see that ironworkers and electricians in particular spend a lot of time in situations that can be risky. Knowing this, employers need to examine their procedures for equipping and training these workers, in particular, to ensure that they're properly protected from fall hazards."

—Melissa Perry

PROFESSOR AND CHAIR
MILKEN INSTITUTE SCHOOL OF PUBLIC HEALTH
DEPARTMENT OF ENVIRONMENTAL AND OCCUPATIONAL HEALTH

Why This Study Was Conducted

To the knowledge of the authors, commercial building construction has not been the subject of any recent fall study. In addition, no previous study on any type of site has sought to simultaneously assess worksite- and individual-level fall prevention practices. The specific aims of this study were developed based on the major findings of existing literature on construction safety and the gaps within this research. (See *Appendix B* for more details.)

GW Fall Hazard Research Project Chronology

FEBRUARY 2013	Identification of Study Goals
MARCH 2013	Development of the Assessment Tool • Review of the existing fall safety tools • Review of the existing relevant literature • Feedback from panel of experts
	GW Assesssment of Fall Risk (GAFR)
	Final Draft of GAFR
APRIL 2013	Pilot testing of GAFR
	Final modifications of GAFR
APRIL 2013–MARCH 2014	Site Observations
	Data Collection
MAY 2014	Data Analysis
AUGUST–SEPTEMBER 2014	Final Report

Data Collection

Milken Institute School of Public Health Research Assistant Amanda McQueen administered the GAFR assessment tool weekly from April 2013 to March 2014, accompanied by the site safety manager/superintendent, evaluating fall prevention safety practices for the following (see *Appendix A* for further definitions):

- Five trades of interest (carpenters, electricians, ironworkers, painters, and roofers)
- Five different phases of construction (concrete pouring/placement, skin, interior rough-in, interior finishes, roofing)
- Four types of equipment (ladders, mobile scaffolding, personal fall arrest equipment, aerial lifts)
- Three types of worksite elements (guardrails, scaffolding, and roof sheathing)

Use of the GAFR Tool

The Milken Institute School of Public Health researchers designed the GAFR assessment tool in a checklist format to collect information about each site visit. Research auditors using the tool begin by evaluating the condition of more static elements of the worksite, such as guardrails and scaffolding. From there, the tool helps auditors assess specific pieces of equipment used while workers are elevated, such as ladders, harnesses, and aerial lifts. The instrument includes guidelines for evaluating whether workers are following the list of criteria that OSHA guidelines stipulate must be met for each piece of equipment to be considered "safe for use." The auditor can track instances of "unsafe work practices" by recording the floor number, worker hard-hat number (for anonymous identification), and additional details about any criteria that are not met.

Section 3

Findings, Observations, and Conclusions

The overall level of worker compliance with fall safety requirements, as observed by the GW researchers, for the construction project was over 95%. However, the observed instances demonstrating a potential for fall risk were noteworthy. The majority of these instances resulted from situations where workers neglected to either readjust current equipment, to obtain a more suitable piece of equipment, or to modify their working habits for safety purposes in order to work more efficiently. The GW researchers observed some instances where workers continued to work unsafely after the site superintendent instructed them to take steps to increase their safety (for example, working from the top rung of a ladder instead of retrieving a more suitable one).

Ladders. GW researchers observed ladders in use 156 times. Of these, two were extension ladders, three were job-made, and the remaining 151 were portable. Electricians were the workers most often observed using ladders, and they were the group most often seen climbing and working from ladders in unsafe ways, followed by carpenters and painters. Although work with ladders took place during every phase of construction, the bulk of the work requiring ladders was completed during the skin, interior rough-in, and roofing phases, during which the potential for fall hazards increased.

Lifts. During the research project, GW researchers observed aerial scissor and boom lifts in use 46 times, primarily by ironworkers during the skin and interior rough-in phases. However, the issues involving the improper use of personal fall protection equipment occurred when carpenters and electricians were using this equipment.

Timeline

2013

DECEMBER 2013 - JANUARY 2014
Completion of skin and interior rough-in phases

2014

FEBRUARY
Continued interior finishes

APRIL
Completed building

Worker-Specific Findings Based on Equipment

Ladders	Aerial Lifts	Personal Fall Arrest
• Increased risk of falling resulted from: – Not facing the ladder while climbing up or down – Working from the top two steps of the ladder – Not maintaining three points of contact while climbing up or down the ladder • Electricians were the most frequent users during the skin and interior rough-in phases	• Increased risk of falling resulted from: – Failing to have fall protection equipment attached to the designated place on the lift – Failing to wear a full-body harness correctly (or at all) while working from the lift • Ironworkers were the most frequent users during the interior finishes phase	• Increased risk of falling resulted from: – Not being used correctly or being bypassed altogether • Ironworkers and carpenters were the most frequent users during the skin and interior rough-in phases

> "These findings underscore the value of applying a hierarchy of controls on all projects and increasing vigilance when personal protective equipment, like fall arrest harnesses, must be used because PPE represents the bottom of the hierarchy."
>
> —Bruce Lippy
>
> Director of Safety Research for CPWR

Personal Fall Arrest Equipment. The majority of the 94 pieces of personal fall arrest equipment observed in use were by ironworkers and carpenters during the skin and interior rough-in phases. The level of compliance with requirements for proper use of this equipment was lower than for either ladders or lifts. Most of the instances of fall risk occurred due to a worker using the personal fall arrest system incorrectly, such as tying off too far from the area of work, not wearing the harness correctly, or not using one at all. The main types of personal fall arrest systems observed in use were retractable harnesses and harnesses with lanyards. These two harness types were used improperly most frequently.

Guardrails. During the construction project, guardrails were in place to provide fall protection on each of the nine floors and roof. These guardrails were observed 252 times during the project. Overall, the use and structural quality of the wooden and wire rope guardrails was compliant with OSHA guidelines. In cases where portions of the guardrails, such as the toeboards, were missing or damaged, repairs were made immediately.

Scaffolding. This equipment was observed on every floor and on the roof during every site visit. The majority of the 96 recorded observations were of fixed scaffolding, but the most frequently occurring issues, overall,

Worksite-Specific Findings

Guardrails	Scaffolding	Roof Sheathing
• Increased risk of falling resulted from: – Damaged or absent sections of wooden guardrails, specifically, toeboards not installed properly or not installed at all • Use of wooden guardrails occurred primarily during the concrete placement, skin, roofing, and interior rough-in phases	• Increased risk of falling resulted from: – Lack of proper guardrails and other forms of protection while in use, including not securing the guardrail door or having any guardrails at all along the structure – Not locking wheels of a mobile scaffold while in use • Use of both fixed and mobile scaffolding occurred primarily during the skin and interior rough-in phases	• No issues, although shortest time of possible observation during this study • Construction and placement of roof sheathing occurred during the skin and roofing phases

Trade-Specific Findings

Carpenters	Electricians	Ironworkers	Painters	Roofers
Total of 68 observations • Primarily observed using ladders and personal fall arrest equipment	Total of 95 observations • Primarily observed using ladders	Total of 96 observations • Primarily observed using personal fall arrest equipment • Highest risk of falling, overall	Total of 32 observations • Primarily observed using ladders	Total of 5 observations • Primarily observed using ladders

were instances where workers used mobile scaffolds without first locking the wheels to prevent the equipment from moving. Although observed less often, another issue resulting in the increased risk of falling was the lack of proper railings on a mobile scaffold. According to observer notes, carpenters were the most common users of mobile scaffolds during the skin and interior rough-in phases.

Roof sheathing. Although no issues were seen, installation of sheathing was only observed during the first six site visits.

> "I hope we can use other building sites as teaching laboratories in the future. It is a win-win for all involved."
>
> —Lucy Lowenthal, Study Advisor
> Project Manager, Office of the Dean
> Milken Institute School of Public Health

Observations

GW researchers made specific observations of skilled trade workers at the construction site. **Carpenters** were most often observed using ladders and personal fall arrest equipment. Their increased risk of falling resulted mainly from the improper use of personal fall arrest equipment. The researchers also made many observations of **electricians** using ladders. The safety issue observed most frequently for this group was working from the top two rungs of a ladder, often because it was not the correct height.

"This was the first time at The George Washington University that a professor used a construction site as a teaching laboratory. The Milken Institute School of Public Health Building was the perfect site to pilot this collaboration."

–Lucy Lowenthal,
Study Advisor
Project Manager, Office of the Dean
Milken Institute School of Public Health

Ironworkers were frequently observed using all three types of equipment, particularly personal fall arrest equipment. Due to the nature of the work of welders and window glazers, they were most commonly found working unsafely over ledges or platforms. Increased risk of falling among this group mainly resulted from not tying personal fall protection systems to a structurally-sound tie-off point or not using the system at all.

The workers observed least frequently were **painters** and **roofers.** They were primarily observed during the interior rough-in/interior finishes and roofing stages, respectively. Workers from both trades were most commonly observed using ladders, with the most frequent instance of increased fall risk resulting from climbing up and down the ladder with tools in hand, and therefore not maintaining three points-of-contact.

The main worksite issues observed by GW researchers during the project were with mobile scaffolding. Many of the workers using this scaffolding were puzzled when asked by the construction supervisor what was wrong with their set-ups. These problems were almost always due to the wheels being unlocked while in use.

Field Notes and Anecdotes

The average duration of each site visit by GW researchers was 60 minutes spent going through each of the building's nine floors (including two basements). Although there was no evidence of specific actions taken against a particular worker, many of the scaffolding and ladder usage issues were attributable to the same workers during certain periods of the project. Noting this, the site superintendent made it clear to these workers' foreman that additional supervision or training was needed.

Mid-way through the project, the site superintendent stopped the work entirely in order to conduct an all-hands training session focused on the proper use of ladders, scaffolding, personal fall arrest equipment, and other issues linked to safety compliance. It was inspired by having workers sent home for safety violations, resulting in lost work time and decreased productivity.

The tasks performed by ironworkers typically involved accessing difficult-to-reach locations while using bulky equipment. Therefore, they would more frequently have to make compromises in order to effectively complete their tasks.

Conclusions

Workers are under constant productivity pressure, which can make it difficult to conduct their work safely despite their best intentions. Whiting-Turner's supervisor for the project, Mike Whitmore, worked hard to uphold safety standards. He ably demonstrated his ability to keep safety concerns on the minds of his company's contractors. However, the GW researchers observed some notable unsafe practices, and there was some room for improvement.

Even though high safety standards were maintained throughout the construction project, fall hazards still occurred. No accidents resulted from a fall from six feet or higher during the entirety of the project. The worksite provided adequate fall protection for workers throughout the entirety of the project, with over 95% compliance. Even so, the wheels of mobile scaffolds were not always locked while the equipment was in use. Guardrails are subject to a great deal of wear and tear during construction projects, and some sections of the site's wooden guardrails, primarily the toeboards, were damaged or absent entirely. Fall protection equipment was used most heavily during the skin and interior rough-in phases, but noncompliance was also frequently observed during those phases.

The results of this study suggest that tasks involving the use of personal fall arrest equipment should be monitored to ensure proper use, with a particular focus on ironworkers. Consistent training and reminders to workers about the proper utilization of equipment are likely to help reduce the potential for falls on commercial construction sites and, thus, potential for injury due to falls.

Taken together, the observations reflect the reality that fall prevention requires constant vigilance on the part of everyone at a worksite. These observations reinforce that achieving high construction safety requires proper design, a strong safety culture, and supportive worker training.

Project Principal Investigator Dr. Melissa Perry, Site Superintendent Mike Whitmore, and Student Researcher Amanda McQueen at the construction site.

"Researchers are rarely able to have this kind of access to a worksite for a prolonged period of time, so this gives us an opportunity to make a unique contribution to construction-safety research.

"Although I was intimidated during the first few visits, I became more comfortable on the work site and more accustomed to pinpointing hazards."

—AMANDA MCQUEEN
MPH STUDENT
MILKEN INSTITUTE SCHOOL OF PUBLIC HEALTH
DEPARTMENT OF ENVIRONMENTAL AND OCCUPATIONAL HEALTH

Appendices

Appendix A: Definitions

EQUIPMENT

Ladder

Portable Ladder = a ladder that can be readily moved or carried.

Extension Ladder = a non-self-supporting portable ladder adjustable in length, consisting of two or more sections traveling in guides or brackets so arranged as to permit length adjustment.

Job-Made Ladder = a ladder that is fabricated by employees, typically at the construction site, and is not commercially manufactured.

Aerial Lift

Boom Lift = an aerial device (except ladders) with a telescopic or extensible boom.

Scissor Lift = although not technically a type of aerial lift, these are any lift with platforms that extend beyond the equipment's wheelbase.

Personal Fall Arrest [System]

Lanyard = a flexible line or rope, wire rope, or strap which is used to secure the body belt or body harness to a deceleration device, lifeline, or anchorage.

Lifeline = a component consisting of a flexible line for connection to an anchorage at one end to hang vertically (Vertical Lifeline), or for connection to anchorages at both ends to stretch horizontally (Horizontal Lifeline), and which serves as a means for connecting other components of a personal fall arrest system to the anchorage.

Retractable Lifeline/Lanyard = a deceleration device which contains a drum wound line which may be slowly extracted from, or retracted onto, the drum under slight tension during normal employee movement, and which, after onset of a fall, automatically locks the drum and arrests the fall.

Guardrail

Wooden = most common among inner and outer regions of the building.

Wire rope = commonly used around outer perimeter of each floor.

Scaffolding

Mobile = a powered or unpowered, portable, caster or wheel-mounted supported scaffold.

Fixed/System = a scaffold consisting of posts with fixed connection points that can be interconnected at predetermined levels.

Suspension = one or more platforms suspended by ropes or other non-rigid means from one overhead structure(s).

Roof Sheathing = any stiff sheet material, such as plywood or boarding, laid above rafters or trusses as a base for roofing material.

PHASES

Concrete Placement = the laying, pouring, or pumping of fresh concrete into formwork, molds, excavations, etc., to attain its final shape.

Skin = method of construction of walls, floors, and panels in which boards or membranes are fixed to either side of a frame or series of structural members as bracing.

Interior Rough In = the laying out of basic infrastructure without covering materials (walls, ceilings, flooring) and without making electrical or plumbing connections.

Roofing = the placement of impermeable surface and finish material that provides waterproof and weatherproof protection for roof.

Interior Finishes = the final treatment, layer of material, or coating for an interior surface or component.

TRADES

Carpenter = worker who performs carpentry tasks, including interior and exterior finishes.

Electrician = worker who installs electrical systems.

Ironworker = worker who performs ironworking tasks, including welding and window-glazing.

Painter = worker who applies primer, paint, putty, and any other substance to walls, ceilings, or floors.

Roofer = worker who performs roofing tasks, including the installation of roof sheathing.

Appendix B: Why This Study Was Conducted

To the knowledge of the researchers, no previous study has sought to assess worksite- and individual-level fall prevention practices simultaneously. Therefore, the specific aims of this study were developed based on the major findings of existing literature on construction safety and the gaps within this research:

Specific Aim I: To quantify trade-level hazards and compliance with fall safety practices related to ladder, aerial lift, and personal fall arrest use among five construction trades: electricians, painters, carpenters, welders, and roofers; and to determine whether there are differences among these trades.

- Researchers of a Harvard University study developed an assessment tool to assess individual-level stepladder safety practice.
  - Is renovation riskier than new construction? An observation comparison of risk factors for stepladder-related falls published in the *American Journal of Industrial Medicine* (Ronk et al., 2011)
- Analysis of contributing factors of fall injuries among union carpenters over a three-year period using an active injury surveillance system to interview individual injured workers and the incident location.
  - Falls in residential carpentry and drywall installation: findings from active injury surveillance with union carpenters published in the *Journal of Occupational and Environmental Medicine* (Lipscomb et al., 2003)
- Additional surveillance studies considering specific construction trades, such as electricians, painters, and carpenters, as differing in their risks of falling.
  - Mortality among North Carolina construction workers, 1988-1994 published in *Applied Occupational and Environmental Hygiene* (Wang, 1999)
  - Fatal falls in the US construction industry, 1990 to 1999 published in the *Journal of Occupational and Environmental Medicine* (Derr et al., 2001)
  - Fatal falls among Hispanic construction workers published in *Accident Analysis & Prevention* (Dong et al., 2009)

Specific Aim II: To quantify worksite-level fall prevention practices related to scaffolding, guardrails, safety nets, and roof sheathing across different construction phases (i.e., concrete placement, skin, interior rough-in, interior finishes, and roofing).

- A Washington University construction safety team based in St. Louis, MO developed a tool to assess fall hazards and control practices in residential construction sites based on OSHA's fall prevention standards for residential construction.
  - Development of the St. Louis audit of fall risks at residential construction site published in the *International Journal of Occupational and Environmental Health* (Kaskutas et al., 2008)
- Researchers at West Virginia University developed an audit tool to assess fall safety practice in general construction and administered the tool quarterly to evaluate the impact of their organization intervention on improvement of fall prevention practice.
  - Prevention of construction falls by organizational intervention published in *Injury Prevention* (Becker et al., 2001)
- Harvard University studies developing an assessment tool for ladders and evaluating safety inspection data collected from Harvard University-owned construction projects.
  - Portable ladder assessment tool development and validation
  - Quantifying best practices in the field published in *Safety Science* (Dennerlein et al., 2009)
  - Preventing falls from ladders in construction, Harvard University (Perry & Ronk, 2010)
  - Determining safety inspection thresholds for employee incentives programs on construction sites published in *Safety Science* (Sparer & Dennerlein, 2013)

Appendix C: Development of the GW Audit of Fall Risks (GAFR) Assessment Instrument

The GW Audit of Fall Risks (GAFR) assessment instrument was developed using the following process:

- Review of OSHA standards and relevant literature, as well as three existing assessment tools to develop an extensive list of items to assess fall safety practices in general construction:
  - Fall safety assessment tool for general construction (Dennerlein et al., 2009)
  - St. Louis Assessment of Fall Risks tool for residential construction (Kaskutas et al., 2008)
  - Ladder assessment tool from the Harvard University studies (Perry & Ronk, 2010)
- Review of this list by an expert panel, including on-site safety superintendents, for feedback on usability and inclusion of appropriate fall safety assessment criteria
- Two-week Pilot test using the newly drafted instrument to determine areas for improvement and refinement

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