Application of Scaled World Model for Usability Testing of Fall Arrest System in Residential Construction

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Falls from heights in residential construction continue to be a leading cause of fatalities and severe injuries. Field studies are difficult to implement in residential construction, because companies are hesitant to allow observers on site to collect data while tasks are being conducted. Use of scaled world models has been recommended for experimental contexts that require high levels of ecological validity as well as internal (control) validity . In this project, we explored several attributes to design a scaled world model of residential roofing that would support controlled trials to evaluate usability and to conduct load testing, in a realistic setting. Features of the scaled world model were selected to support validity and ease-of-measurement while participants conducted roofing tasks. Several validity constraints were explored, including ecological, structural, psychological and process validity. Possible in-lab roofing task attributes were discussed and heuristic guidelines for scaled world models were provided. Lastly, an example of a scaled-world model was assembled to test the fall arrest system. The design team continues to develop the model, which will be reviewed by residential roofing experts for realism and accuracy.

INTRODUCTION

Recent data from the Bureau of Labor Statistics (2011) indicates that 34.6% of construction fatalities result from falls: of these falls, 33.8% occurred as a result of roofing work. As a result of the danger of falls, OSHA enacted directive 1926.501(b)(13) in September 2011 to require residential construction employers to implement the use of fall protection on all work at heights in excess of six feet unless technical infeasibility can be proven. Therefore, fall protection is required to residential as well as commercial (post frame) construction workers, who had been using fall protection already.

Despite the OSHA requirements, recent research (Smith-Jackson et al., 2011) has revealed barriers among roofers to adapt fall arrest systems (i.e., harness, anchor, rope to connect the harness and anchor). Roofers self-reported primary reasons for reluctance to conform with fall arrest requirements (Figure 1), remarking that the harness is "uncomfortable," stating that it is "difficult to move" while using the fall arrest system, complaining that the "rope gets entangled," and discussing that the harness is "difficult to put on/take off." Most of those reasons were attributed to low usability of fall arrest system; therefore, further research is needed to understand construction workers' negative perceptions toward existing fall arrest systems and address opportunities to improve their usability levels.

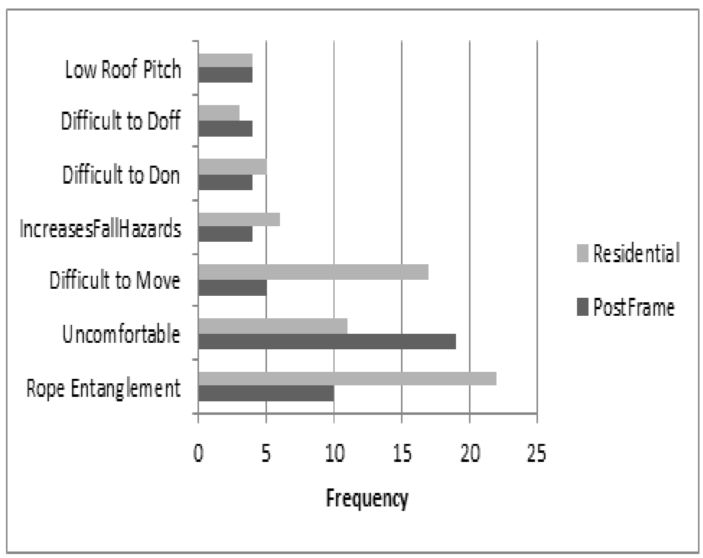

Figure 1: Barriers to Fall Arrest Technology Adoption (Smith-Jackson et al., 2011)

Construction safety and health research provides many advantages and opportunities to improve the usability of fall arrest systems with consequent benefits to adoption and use. However, it is not always feasible to study construction workers in a field setting, since construction companies rarely welcome external distractions such as those imposed by on-site usability tests. Construction work sites contain hazards that place workers at risk, but also place researchers at risk while

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collecting data. Despite confidentiality protections, construction companies have reservations regarding research participation, and construction workers also have fears of repercussions resulting from participation in research. Additional concerns from construction managers include potential work slowdowns and interruptions associated with research activities.

This paper describes a scaled world as a solution to conduct off-site usability tests of fall arrest systems for construction workers. Substantial benefits can be gained from the study of fall arrest system usability in controlled environments such as scaled worlds.

SCALED WORLDS

A scaled world is a simulated task environment that focuses on certain functional relationships identified in a complex task environment while excluding non-essential aspects (Ehret, Gray, & Kirschenbaum, 2000). The research question of interest determines which functional relationships should be maintained in reduction of the real world task to the scaled world; therefore, research findings can be generalized to the original task as opposed to a particular task environment (Gary, 2002). Scaled worlds can also provide researchers with a controllable and replicable environment in which unpredictable variables may be eliminated for studying complex tasks such as roofing.

Further beneficial factors of implementing a scaled world environment include the ability to collect more precise data. Field studies allow only a one-time opportunity to record data (Elson, 2003). In a scaled world, repeated audio and video recordings can be used to keep accurate records of each participant's performance. These repeated recordings would allow the researcher to devise methods of consistently coding data, and to return to the data for further review. Additionally, controlled environments such as a scaled world can ultimately be less costly than implementing a field study and the controlled environment would allow for multiple replications of task simulation.

Ehret et al. (1998) delineated possible threats to validity as a result of the scaled world approach. Naturalism of the true work environment is lost, and workers may not perform in a real world manner. In condensing a work environment to a scaled world, elements of the real world will inevitably be lost. Retained elements should be carefully selected to minimize loss of ecological validity. Therefore, the original work system should be the frame of reference for the scaled world reduction. Figure 2 illustrates the constraints involved with the reduction to a scaled world.

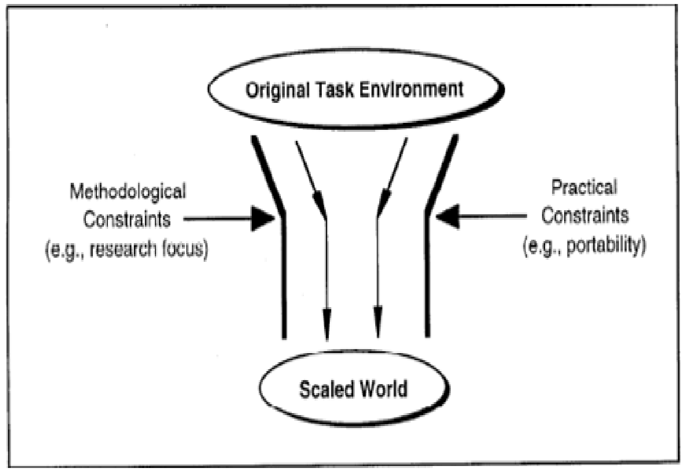

Figure 2: Schematic Representation of Scaled World Development (Ehret et al., 1998)

KEY VALIDITY FOR SCALED WORLDS

Ecological Validity

The need for ecological validity in usability testing imposes concerns when replicating a real world scenario within a laboratory setting such as scaled worlds. In the context of this paper, the term "ecological validity" is used to describe the degree to which the replicated environment can be generalized to its real world counterpart. Brewer (2000) states ecological validity requires that the methods, materials, and setting of a study must approximate a real life situation. As the methods and materials used in real world residential roofing construction can be simply replicated in a simulated environment, the setting is of primary concern in this paper.

Prioritizing ecological validity in research has an established history in psychology and has been generalized to a number of disciplines including engineering. Bronfenbrenner's (1977) definition presents a perspective on ecological validity that easily generalizes and is compatible with more recent perspectives on system fidelity in engineering. Bronfenbrenner (1977) describes numerous layers of the ecological system that impact individuals, and defines validity as "…the extent to which the environment experienced by subjects in a scientific investigation has the properties it is supposed or assumed to have by the experimenter (p. 516)." Key to Bronfenbrenner's concept of ecological validity is the importance of context as a necessary component of research design to ensure results are externally valid (i.e., generalizable to individuals who are similar to the participants who were included in the study).

Other researchers have identified dimensions of ecological validity as environmental setting, stimulus realism, and task type (Figure 1 in Brunswick, 1943; LeBlanc et al., 2011; Neisser, 1976; Rivera, 1999). The environmental setting is reflected in the relevance or naturalness of the setting. Situating the study in a naturalistic or realistic setting provides contextual realism so participants' behaviors and cognitions represent the real world to the greatest extent possible.

Stimulus realism relates to the unit of activity within the research setting. Reductionist approaches tend to present participants with stimuli in reduced forms with the belief that minimalized or artificial stimuli provide the most valid means to infer cause and effect. However, minimalized stimuli are not represented in the real world in their purist form but are often embedded in complex foregrounds, backgrounds, and even in combination with other stimuli. Ecological validity exists only when the stimulus is represented in the same way it occurs in the real world, inclusive of the multiple layers and complex units that coexist with that particular stimulus.

A third dimension of ecological validity is the task or behavior to be studied. It is important that the tasks used in the study are similar to the tasks to be performed in the real world setting. Additionally, the tasks studied should elicit the same behavioral and cognitive responses that occur when they are performed in the real world. In summary, ecological validity in the study of fall arrest systems can provide the optimal setting to study a phenomenon of importance, while maintaining acceptable internal and external validity.

Structural, Psychological, Process Validity

In addition to ecological validity, structural, psychological, and process validity must also be considered in the creation of a scaled world model (Marks et al., 2004). Structural validity should be maintained such that participants physically interact with the environment in a similar manner as they interact with a real world environment. A psychologically valid design should provide participants with the impression that they are working in their original work environment. The observed processes should be analogous to those observed in the real environment, lending to process validity. Although the scaled world might reduce the quantity of processes, the processes that remain in representation should be faithful recreations of the original system.

SCALED WORLD MODEL FOR FALL ARREST SYSTEM USABILITY TESTING

Roofing tasks

The typical residential construction site utilizes a variety of workers performing simultaneous tasks. For the scaled world approach, the environmental setting should capture the areas and structures that roofers conduct their work. Non-roofers would be considered "noise" in the context of this study, as only workers required to use fall arrest systems are of interest. Strategically selected components of the work system may be left intact in the scaled world, while non-related subsystems (e.g., the work of plumbers or electricians) can be eliminated through the experimental approach.

In a typical roofing environment, multiple workers are utilized in an array of task types. For the purposes of an in-lab exercise, a single participant will be required to perform all roofing tasks in one session. The scaled world approach allows for the combination of functions in a concise format such that participants can efficiently complete a variety of tasks.

Tasks must be designed carefully within the constraint of the scaled world to reduce loss of realism when observing participants singly. As roofers rely on input of co-workers for achieving certain tasks (e.g. lifting materials to the roof's surface), these tasks must either be eliminated or redesigned in the experimental setting. Thus, a sub-set of realistic tasks conducive to the setting of a single participant on a scaled world roof was devised. Researchers pre-determined a set of three tasks that participants (residential roofers) will perform based on ubiquity of the tasks in all residential construction. The tasks include installation of oriented strand board sheathing, water shield, and shingles. The scaled world roof provides a base on which each of these tasks may be consecutively executed during each participant session.

Heuristic guidelines

The following heuristic guidelines were developed in the process of designing the scaled world model for construction roofing (Table 1). Note that safety issues are included in compliance with human subject ethics, although ecological and/or structural validity is reduced.

Table 1: Heuristic guidelines and validity for scaled world models (SWMs) in construction roofing.

	Guideline	**Validity**
1	Design to provide a perception of height using 2 to 3 feet of elevation, but fall hazards must be minimized.	Ecological
2	Design to provide multiple viewing and videoing angles for researchers by situating the SWM in a location that allows free walking and unobstructed viewing on all sides.	Ecological
3	Use materials that are natural to the real world roofing materials.	Structural
4	Provide participants with appropriate safety gear, including hard hats, tool belts, boots, and tools.	Ecological, Structural, Psychological, Process
5	Design to support camera placement on the SWM as well as placement on participants as needed.	Ecological
6	Install movable joints and hydraulic systems to allow researchers to adapt the research to reflect various roof types and pitches, while these systems are not placed to become obstacles for participants to perform tasks.	Structural, Process
7	Place audio speakers in the SWM environment to provide real world construction sounds if the research goals require this level of realism.	Ecological, Structural
8	Select tasks that are indicative of the behavioral demands of real roofing tasks, including amount of time to complete, number of roofers required, and physical and mental exertion.	Structural, Psychological, Process
9	Place safety systems around the SWM (e.g., mats and nets to arrest or cushion falls).	Ecological, Structural
10	Design to provide unlimited space above and on sides when the participant conducts tasks on the roof	Ecological, Structural

Scaled World Roof

A scaled world model has been developed to examine fall arrest system usability and load testing roof trusses in residential roofing. To design the environment, review of the literature and team design meetings were conducted. The model was created to accommodate performance of tasks as previously described, such that one worker can achieve each of the tasks with minimal assistance of researchers.

The scaled world roof is assembled on top of an existing testing system that has been used to determine structural properties of members used in truss construction. This system is assembled in an indoor laboratory in the Department of Sustainable Biomaterials' facility at Virginia Tech. Figure 3 shows an offset view of the currently assembled system. Between each participant, the roof is disassembled to the trusses. For purposes of demonstration, a sheet of OSB sheathing and a sheet of shingles are shown on this model. Figure 4 shows a worker in process of installing shingles on top of the assembled model.

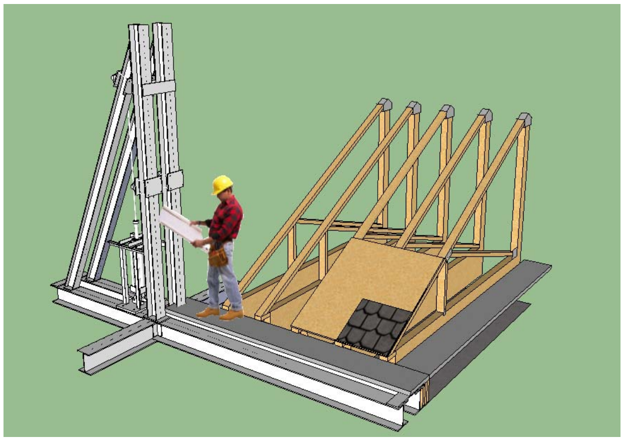

Figure 3: Offset View of Scaled World Roof

Figure 4: Roofer Performing Shingling Task On Assembled Scaled World Roof

CONCLUSIONS

Scaled world models provide a useful and valid means to test fall arrest system design and investigate usability issues, which could not be feasible in the field setting. The context of the scaled world roofing should provide situated cues for construction roofers, while maintaining their safety and naturalistic behaviors. Roofers' observed behaviors and feedback will help develop more user-friendly fall arrest systems, reducing barriers and increasing adaptation among residential roofers.

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