Safe Design of Skyrise Greenery in Singapore

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Abstract

Singapore is transforming from a "garden city" to a "City-in-a-Garden". Designing for safety is recognized by researchers and some governments as a best practice in facilitating eventual worker safety within the built environment. This research was undertaken to understand and describe the status of safe design for skyrise greenery in Singapore. Forty-one rooftop and vertical greenery systems were observed with a focus on access, fall from height, and planting considerations. Rooftop greenery systems in Singapore were found to be adhering to safe design principles. Vertical and ledge greenery systems, on the other hand, are newer arrangements and were found to be in need of design for safety guidance. The results add to the body of knowledge in the area of safe design and skyrise greenery and will aid those seeking to understand from a policy and practice perspective.

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Introduction

As research and practice within the built environment advances, safe design is being recognized as a best practice within a holistic approach to facilitating and influencing site safety. Isolating building elements to target site safety risk within the built environment and tracing them back to design decisions has been effectively utilized as a means to identify safe design suggestions that can then be implemented in future designs (Fortunato et al, 2012; Behm, 2005; Gambatese et al, 1997; Gambatese, 1996). The growing interest in the use of greenery systems on the built environment (for both new buildings and existing buildings) means that their design and maintenance have to be investigated more thoroughly in order to determine the sustainability of such systems (Emilsson et al, 2007), and to develop standards and guidelines (Dvorak and Volder, 2010).

The integration of worker health and safety has recently been identified as a necessary green building component to ensure sustainability. The term ‘green’ is not synonymous with the term “sustainable.” Sustainability is a broader concept which, in addition to the environmental aspect, addresses the continuity of economic considerations, resource conservation, and social aspects of human society. Sustainability raises the "green" discussion from materials and processes to include marketing, distribution, disposal and *human labour* (Evans, 2006). Worker safety and health are key issues within the social dimension of sustainability (Behm et al, 2009; Epstein and Roy, 2003). For example, the Las Vegas, NV Mirage City Center received Gold Level Leadership in Environment and Energy Design (LEED) from the U.S. Green Building Council, yet six construction workers died on the job in an 18 month period (CCRT, 2008). In December of 2009, the United States’ National Institute for Occupational Safety and Health (NIOSH) commissioned a workshop titled ‘Making Green Jobs Safe’ to ensure that worker safety is an important consideration in all green jobs (Schulte et al, 2010). Fortunato et al (2012) identified LEED credits where safety risks were increased compared to conventional projects. Behm (2011, 2012) evaluated vegetated roofs in the U.S. from a safety perspective.

Singapore is a leader in skyrise greenery. The Singapore government through the National Parks Board (NParks) as well as Urban Redevelopment Authority (URA) encourages building owners to green their rooftops, ledges, and facades by installing vegetation for environmental benefits and to enhance the city’s image, (NParks, 2009). Under the NParks’ Green Roof Incentive Scheme, NParks funds up to 50 per cent of the cost of installing green roofs on buildings in the Downtown Core and other strategic areas (NParks, 2009). NParks’ Centre for Urban Greenery and Ecology (CUGE) Research aims to be the focal point for skyrise greenery in Singapore by creating a knowledge network with its partners and extending useful information generated from research to the industry (NParks, 2011). URA’s LUSH Programme (Landscaping for Urban Spaces and High rises) was also launched in 2009 to consolidate and synergize a number of new and existing URA green initiatives to strengthen Singapore's distinct identity as a tropical City-in-a-Garden and benefit our environment by mitigating the urban island heat effect and improving air quality. The provision of greenery within developments will also help provide visual relief and improve the quality of life of urban dwellers (URA, 2009). Singaporeans have recognized individual and neighbourhood benefits from skyrise greenery, and would like levels of urban greenery to increase (Wong et al, 2010; Yuan and Hien, 2005). CUGE Research (2010) recognized the need for incorporating safety considerations into the design of skyrise greenery, and in May 2010, published the guidance document, CS E02:2010, Safe Design for Rooftop Greenery.

The research project's specific aim was to identify and evaluate design attributes of skyrise greenery in Singapore with a focus on the safety of workers who must maintain the greenery systems. Site visits to understand safe design status of skyrise greenery systems are summarized. The output is assessment data that measures how the guidance document CS E02:2010 is being utilized and its effect on both worker safety and on rooftop greenery design practice. The Singapore data is compared with a similar study in the United States.

Safety Science Background

Worker safety is a function of the hazard associated with a particular task and the risk of that hazard being realized resulting in injury or illness. Occupational safety and health problem solving science advises that a prescribed hierarchy of controls be followed. For example, the hierarchy of controls in the American National Standards Institute Standard (ANSI) for Occupational Health and Safety Management Systems, ANSI Z-10, lists six ordered elements. In order of preferred problem solving efficacy, they are:

1. Elimination
2. Substitution of less hazardous materials, processes, operations or equipment processes
3. Engineering Controls

4. Warnings
5. Administrative Controls (such as training and procedures), and
6. Person Protective Equipment.

In other words, we want to eliminate hazards rather than training workers about avoiding hazards and giving them personal protective equipment. This hierarchy of controls model aims to draw attention to solutions that permanently remove or reduce hazards and risks from a system, and away from easy, "quick fixes" such as rules, procedures, and personal protective equipment. The lower order solutions (warnings, administrative controls, and personal protective equipment) aim at gaining a higher level of control over behaviour and increasing personal resistance to hazards *within* a work system. In contrast, the higher order solutions aim to gain control *of* a work system whereas the low-order solutions essentially aim to reduce the impact of a system with known risk. To gain control *of the system* rather than *within the system*, we often need to look beyond site management and to site planning, programming, construction methods, permanent works design, materials choices, etc (Culvenor, 2006). This type of upstream control thinking has been regulated in various forms applicable to the built environment. The United Kingdom has regulated safe design and management planning through the Construction Design and Management (CDM) regulations since 1994. Responsibility for site safety under CDM lies not only with the employer, but with the owner (client), design team(s), and a CDM Coordinator, who is appointed by the client. Similar legislation exists in Australia (Bluff, 2003). In the United States, NIOSH initiated a Prevention through Design program with the goal of influencing businesses and designers to commence capital projects with life cycle safety and utilization of the hierarchy of controls at the project conceptual design phase (Schulte et al., 2008). Previous studies in the United States identified access to the roof and falling off the roof as the most dangerous hazards associated with rooftop greenery systems (Behm, 2011).

Review of Rooftop and Skyrise Greenery Safety Standards Review

Germany's Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL), or Landscape Development and Landscaping Research Society, is frequently mentioned in numerous peer-reviewed articles and in discussions the author has had with industry experts. Dvorak and Volder (2010) provided a recent background of the existing guidelines for the vegetated roof industry and described FLL as a recognized source of authority regarding the design, construction and maintenance of green roofs in Europe and throughout the world. The FLL's Guidelines for the Planning, Construction and Maintenance of Green Roofing provide guidance on fall protection, determining design loads, and fire characteristics. Fall prevention during the planning and tendering stages is mentioned. Fall protection and prevention measures from the edge and through building components such as skylights are mentioned. The guidance is written based on the philosophy found in the European Directive 92/57/EEC of 24 June 1992 on the Implementation of Minimum Safety & Health Requirements at Temporary or Mobile Construction Sites in that the responsibility of the protective measures lie with the client and their appointed safety coordinator. However, unlike the Directive, design phase modifications to include or facilitate fall protection measures are not mentioned. Rather, the FLL guidelines are focused on downstream safety measures to be initiated at the site.

The mission of Green Roofs for Healthy Cities, a nonprofit group based in Toronto, is to increase the awareness of the economic, social and environmental benefits of green roofs and green walls, and other forms of living architecture through education, advocacy, professional development and celebrations of excellence (GRHC, 2011). An owner of a green roof installation company who had gone through the GRHC training mentioned that they did discuss OSHA standards for fall protection in the introductory course (personal communication). It appears safe design is not incorporated in to their standards and guidance.

The Association of Standards and Testing Materials (ASTM) develops and publishes numerous green roof standards including one for determining the dead load of green roof systems. There were no specific mentioning of worker safety considerations (falls, access, etc). The American National Standards Institute (ANSI), in cooperation with Green Roofs for Healthy Cities, wrote and published the standard, External Fire Design Standard for Vegetative Roofs in 2010. The National Association of Fire Marshalls created an entire website devoted to fire safety and green buildings, and it includes a vegetated roof section. See http://greenbuildingfiresafety.org/index.html.

Singapore's Design for Safety for Rooftop Greenery (CUGE, 2010) provided the only recommended guidelines for worker safety with a focus on design. According to Singapore's Workplace Safety and Health Act, similar to safe design legislation in Europe and Australia, the person who creates the risk is responsible for mitigation (Workplace Safety and Health Council, 2008). In specifying the design of a building or structure, the designer should understand how the building or structure can be constructed, cleaned, maintained, and decommissioned or demolished safely (Workplace Safety and Health Council, 2008). Therefore, the designer must study and evaluate the risks to those carrying out the proposed works and others affected by it, such as the public or people using the building or structure in the future. The CUGE guideline defines safety considerations for rooftop greenery in the design, installation, and maintenance phases, and includes:

1. Building Considerations. The building's established load bearing capacity; greenery on sloped roofs; protection from falling; roof penetrations (skylights); access; fire safety; working at height; and lightning protection.
2. Service Considerations. Appropriate facilities for washing / potable water; storage provisions; and taking onto account mechanical and electrical systems on the roof in relation to the vegetation.
3. Health Conditions. Reducing the use of hazardous materials; reducing noise through scheduling; and mosquito control.
4. Plant considerations. Plant selection; plant maintenance' proper tree anchorage and maintenance; height control and health of trees; and provisions for tree removal.
5. Work scheduling considerations. Features to reduce the risk of falling; prevention equipment falling from height; design to simplify construction; and the use of crane and aerial platforms.

Developers, designers, and urban planners are increasingly looking to green up the built environment. Safe design is an important method of ensuring worker safety. These circumstances directed our point of departure for the research. The research objective was to evaluate Singapore's skyrise greenery systems from a safe design perspective.

Methods

Sample Selection and Site Visits

The researchers utilized contacts from within the National Parks Board and the Centre for Urban Greenery and Ecology to reach architects, landscape architects, green roof system professionals, landscapers, and developers for the purpose of site visits and interviews. The site selection and interviews were not random, but were purely a convenient sample. This is a limitation to the research. Forty-one unique skyrise greenery systems were evaluated at twenty-seven sites. Since our goal was to evaluate Singapore's skyrise greenery systems from a safe design perspective, and therefore determined observational research during site visits were chosen over other information gathering methods (surveys, focus groups, etc.). Structured observational research provides data on what phenomenon occurs and relies on frameworks of predefined content to fit the activity within the variables and scope of the research question (Leicht et al (2010).

Field Observation Rating System

Because one of the research objectives was to assess skyrise greenery system hazards and risks, we needed to develop a rating system that yielded valid and reliable data across a variety of projects. For rooftop greenery assessment, the CUGE CS E02:2010 – Guidelines on Design for Safety on Rooftop Greenery (2010) were used as a foundation. They were also utilized as the starting point for evaluating safety on vegetated roofs in the United States (Behm, 2012), which found that fall protection and safe access of workers and materials were the two principal safe design issues for rooftop greenery. The scope of this research also included vertical greenery systems (green walls) and ledges. For our starting point in developing a safety observation rating system, we utilized the previous research (Behm 2011, 2012), studied numerous vertical and rooftop greenery pictures, and visited site locations with a landscaping company who explained maintenance procedures. Skaggs (2004) recommended the best tools for observational research are the researcher's knowledge, vision, and memory; a camera and a sketchbook/notebook serve as tools that are reminders of what is observed. The specifications were utilized to evaluate hazards and risks from a design perspective on a rating scale (excellent, good, fair, and poor). The general performance-based philosophy is outlined in Table 1.

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Reliability and Validity

For this research endeavour we wanted to ensure validity and reliability in the observation process. For internal validity in observational research, Leicth (2010) recommended that test and design validities are most important. Test validity refers to the scales utilized, and design validity refers to biases introduced by the researchers. Our four-point scale was driven by our previous studies in the United States (Behm 2011, 2012), and agreed upon by when those observations were reviewed with colleagues in Singapore. A two-point scale for example (good/bad or safe/unsafe) would not have allowed us to describe the variation in observations of the greenery systems safe design status. The biases inherent with the researchers were reduced by their varied backgrounds; one has an occupational safety and health background and the second has an architectural design and plant science background. In addition, the archival photographs allowed the researchers to reflect on their observations without making quick judgments. To reduce researcher bias, prescriptive type specifications based on previous research (Behm, 2012) and the CUGE safe design guidelines were utilized as guidance. Utilizing the previous research and the CUGE guidelines helped to establish content validity and supported overall internal validity. External validity is the degree to which the conclusions in a study would hold for other persons in other places and at other times. Leicht et al (2010) reports that observational research has been criticized for lacking the capacity to extend findings (external validity) beyond those observed in the study. Because our sample was not a random sample and was from a single geographic location (Singapore), external validity in the study could be viewed as weak. However, our goal was not cause and effect. In describing the importance of safe design to skyrise greenery, weak external validity is not a significant detriment to our findings.

The type of reliability most applicable to observational research is inter-rater reliability (Leicht et al (2010). The individual field observations and subsequent rating determinations were made by two researchers which helped to assure validity and reliability. The inter-rater consensus (as suggested by Ross et al, 2004) across the three main dimensions measured (access, fall protection, and planting selection) was 88% (36/41), 90% (37/41), and 92% (35/38) respectively. In previous occupational safety research employing two raters, Lingard (2002) found 89% agreement and concluded this constituted an acceptably high level of agreement. When disagreements occurred, discussions ensued to reach agreement. Photographs were taken of each site so that the researchers could review site conditions with the goal of being reliable in the rating determination. Discussions with professionals who provided access to the sites and observation of installation and maintenance work methods augmented the physical observations. The result was a valid and reliable rating system based on safety science using the hierarchy of controls as guidance, previous research in the U.S., the CUGE guidelines, and current field observations.

Results and Discussion

Site Visits

Forty-one unique skyrise greenery systems were visited at twenty-seven sites. Table 2 summarizes of the type of skyrise greenery at the site. Four of the 41 skyrise greenery sites were under construction during the visit. Extensive roofs are limited to grasses, sedums, and vegetation with shallow root systems and are generally not accessible by the public (Berndtsson, 2010; Cavanaugh, 2008; Collins, 2005). Intensive roof or roof gardens support larger plants with deeper soil layers (Berndtsson, 2010); they are like a conventional garden or park and are usually accessible by the public (U.S. EPA, 2010).

The distinction of public access is essential for this study, as generally if the public can access the roof so can workers. However, workers must access *all* areas of the vegetation for maintenance; total access is not essential for the public and can present unique hazards to workers. In our sample, all extensive roofs were not accessible by the general public, and all intensive roofs were accessible by the public.

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Rooftop Greenery – Structural Integrity

The potential maximum designed load of the vegetation, planting media (including its saturated condition), people (both workers and public), equipment necessary for installation and maintenance, etc, must not exceed the established load bearing capacity of the roof. The structure's load capacity is typically calculated by a structural engineer. In our study, we found only one roof where the vegetation as originally designed did not meet the structure's capacity. Fortunately, this discrepancy was discovered by the green roof systems professional in the pre-installation and planning stages. Calculations of the planting media under saturated conditions revealed an overload. Subsequently, the planting media was reduced by a height of 10cm. This particular rooftop greenery system was a series of sunken gardens. This alteration will cause a slight visual imperfection to the original design intent, and highlights the relationship between safety and aesthetics. Further, it emphasizes the importance of employing highly trained professionals to carry out green roof design and installation.

Rooftop Greenery – Safe Access

Access to the rooftop greenery should be via fixed stairs through the building's core or other appropriate normal entry so that workers and necessary equipment can access all areas of the roof and perform necessary work in a safe and efficient manner. Some roofs are complex in their shape and design, and therefore different parts of the roof present unique access hazards and risks. All portions of the roof must be accessible for workers and their equipment and not present unique and potentially unforeseen hazards during access for both the worker and with equipment. Roof gardens, or intensive green roofs, which are designed for access, generally meet this requirement. Nonetheless, consideration must be given to ensure equipment can safely access all areas where needed. For extensive roofs, where interior stairs are not designed into the structure for worker roof access, an exterior building caged ladder (cat ladder) should be designed for roof access. U.S. OSHA regulations at 29 CFR 1910.27 set specifications for caged cat ladders. Table 3 includes a summary of the safe design access of the 22 rooftop greenery sites.

Rooftop Greenery – Fall Prevention & Protection

Ellis (2001) specifies an explicit hierarchy of fall protection solutions which follows the general hierarchy of controls previously mentioned. In order of preference they include: 1) eliminating fall hazards, 2) preventing fall hazards by guarding, 3) using fall arrest systems, and 4) applying administrative techniques (i.e. a second worker as a monitor). Similarly, in designing fall protection systems, the U.K.'s Health and Safety Executive (2008) recommends passive systems such as nets, guardrails, and parapets (where the individual does not have to do anything to activate the system) over active systems such as harnesses (where the worker has to clip on). A work-restraint system (i.e., harness with a short lanyard), which means it is impossible for the operative to get to a position where they could fall, is preferred over fall arrest systems as they do not prevent the fall, require rescue, and require the worker to have proper equipment (harness and lanyard) and to properly utilize the system and equipment (HSE, 2008). We developed our rating system based on these guidance documents. Preventing falls from occurring is preferred over protecting from falls once they do occur. The fall hierarchy of controls is as follows:

1. Elimination or Substitution: Remove the hazard.
2. Passive Fall Protection: Isolate or separate hazard from workers.
3. Fall Restraint: Prevent the person(s) from reaching the fall hazard.
4. Fall Arrest: Attach a person to a system designed to stop a fall after it has begun.
5. Administrative Controls: Establish work practices or procedures to warn an authorized person to avoid approaching a fall hazard.

Ideally, a minimum 1m parapet or standard type railing around the roof top edge is designed in to serve to isolate workers from the fall hazard during installation, inspection, and maintenance. This is a passive system, meaning the worker does not need to actively do anything to prevent a fall. However, a parapet may be aesthetically unappealing if an intent of the skyrise greenery is that it can be viewed from lower levels. On rooftop gardens, because they are intended to be accessed by the public, guardrail type protection was present on all the roofs visited.

For extensive systems, where parapets are not specified as described above, fall restraint roof-edge restraint systems that limit access where workers could work and thus where they could fall are seen as the next best option. These systems do not allow workers to fall over the edge of the building, but rather they limit or *restrain* the worker's movement thus preventing them from falling. Workers must have the appropriate restraint length congruent with the roof anchor placement. If the restraint line is too short, workers will detach to reach work areas near the edge, but if the restraint line is too long a fall can occur. We observed one system where the restraint lines were already in place for the worker. To protect from weathering, boxes housed the restraint lines. The worker must still provide an appropriate body harness. For restraint type protection, this is viewed as ideal because workers do not need to determine restraint line lengths and their placement since it is designed into the roof for their use. Therefore, any work crew can access the system and safety is built in. While these systems are very good, they require precise engineering in the design stage to ensure adequate access to all areas where maintenance would need to be performed.

Alternatively, where neither parapets nor roof restraint systems are specified, fall arrest systems should be designed into the roof which requires the worker to furnish a body harness and arrest lanyard connected to a pre-determined designed anchor point or horizontal lifeline system. If the worker falls, the system prevents them from hitting the ground. Appropriate rescue measures need to be considered; this means that a lone worker would not be appropriate. On flat roofs, both of these systems (anchor points or lifelines) must be within 3.6m of the roof's edge, and accessed easily from the fixed stairs through the building's core such that the entrance on to the roof facilitates the system's access ensuring the worker does not need to be within 3.6m of the edge unattached. On sloped roofs (>10%), the system must be able to be accessed immediately when stepping onto the roof. 3.6m (approximately 12 feet) is generally recommended by Ellis (2001).

Where no other fall prevention or protection system is designed into a flat extensive roof, a designer could specify vegetation and any rock or decorative border be installed 3.6m from the roof's edge and that the 3.6m border be of a flat traditional roof surface (i.e., not the rock border) to ensure that weeding or other vegetative roof work does not take place within 3.6m of the roof's edge. This form of fall protection would only be acceptable if there is access to the roof through the building's core leading to a centre area of the roof, and if water spigot(s) are available on the roof within 3.6m of the roof's edge. In other words, the work to be performed on the roof should not encourage workers to be within 3.6m of the roof's edge at any time.

Vegetation hanging over the edge of a building's roof (trees, creeper plants, etc.), presents unique safety challenges. Workers may think they can hang over the edge or through guardrails to reach vegetation in need of trimming. Even if a suitable 1m parapet is available here, the scope of the maintenance work could encourage or require workers to use ladders or lean over rendering the parapet ineffective to conduct the necessary work. Safe design takes into account the work that must be accomplished. This also demonstrates the synergies between fall protection and plant selection. Table 3 summarizes the judged safe designed fall protection status as well as access status.

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Vertical Greenery Systems – Safe Access and Fall Protection

Safe access and fall protection for vertical greenery systems are issues that, through our observations, were difficult to separate and as such, they will be discussed together. Ideally, vertical greenery systems will be designed such that workers can safely access them from a secured platform or from ground level without the use of ladders, aerial lifts, etc. Innovative design ideas observed include movable and rotating greenery systems, hinged greenery modules, and rear access systems. We noted two such innovations during site visits. They are highlighted in a later section. Table 4 summarizes observed ratings for safe access and fall protection on the 13 vertical greenery systems assessed.

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Vertical greenery systems presented more potential access and fall protection issues compared to the rooftop greenery. There may be several reasons for this. Vertical greenery systems are newer compared to rooftop greenery, and thus less technical information is available. The CUGE guideline CS E02:2010 was written specifically for rooftop planting. One of our recommendations and areas for future work is to revise CS E02:2010 to include safe design of vertical greenery. Roofs are a more frequently accessed building component compared to walls regardless of the vegetation status; utilities and other components have been traditionally placed on roofs, and access and other safety measures have been considered in the design compared to walls and vertical areas of the built environment. Wong et al (2010) found that there is lack of technical information on vertical greenery systems available in Singapore which results in associated uncertainties such as design and installation requirements.

Some vertical greenery walls can only be accessed and maintained from the front (these vertical greenery systems are installed against a blank wall surface). There are also some vertical greenery walls designed to be accessed and maintained from behind (that is the vertical greenery system is installed against an already accessible space such as a common corridor or a balcony, or a space purposefully provided behind the installed vertical greenery system for maintenance access, etc).

For vertical greenery walls that can only be accessed and maintained from the front, those designed on or close to ground level are less difficult to access and thus do not discourage more frequent maintenance. As the height of a vertical greenery wall increases, aerial lifts of varying sizes will need to be utilized to reach that height; therefore the design should consider the type of lift necessary when designing to allow for such space. For example at one vertical greenery site, the ground surfaces at the base of the green walls sloped, and composed randomly of various finishing materials, ranging from fine gravels, to turf, stone kerbs, and even a pond. These horizontal surfaces which are at times not finished at the same floor level make stabilizing an aerial platform a challenge, thus increasing risk during maintenance work at the elevated environment. Safe design can allow for sufficient room so that all areas of the greenery can be safely accessed by an aerial lift, etc. When designing for the maintenance activities, ensure the access space for aerial lifts or other devices is flat and free of unique hazards (slopes, water, etc.) that might hinder movement of the bucket truck, aerial lift, etc. Alternatively, window washing systems have been utilized safely on skyrise buildings for decades with much success. Similar systems could be designed for vertical greenery systems such that gondola type systems can be utilized. However, these are expensive.

In our site visits, we observed vertical greenery systems above ground level on roofs, terraces, and other above ground level surfaces. These presented unique access and fall hazards. All areas of the greenery must be accessible for replanting and maintenance. Consider similar provisions as previously stated and specify how the greenery is to be accessed to be maintained. Additional provisions could include adequate landing space for scaffolding. We noted one site where the vertical greenery went up a wall at the edge on a twelve-story building. Access to this area presented a fall hazard regardless of the means by which the area would be accessed. This site was rated as poor for fall protection, and fair for access.

For vertical greenery above ground level on roofs, terraces, and other upper surfaces, the height of the greenery should not exceed its horizontal distance from the roof edge or top of parapet unless fall protection measures are provided. In other words, the greenery should be set back from the edge so that if equipment fails or a fall occurs, the distance is limited.

Special Considerations for Ledges

When greenery is designed on to building ledges, both fall protection and safe access suggestions must be considered in the design phase for installation and maintenance. Ledge plantings were observed at six sites. We judged both the access and fall protection to be poor at one site; the others were rated as good. At this particular building, horizontal fall protection systems were installed *after* the building completion and planting of vegetation; it was only then that it was recognized there were no safety measures and workers could not access the vegetation for maintenance. The fall protection system (horizontal lifeline) was designed behind the vegetation. However, the shrubs and bushes are so close to the back wall that workers cannot access points behind the greenery and utilize the horizontal lifeline. Further, the shrubbery is so tall that accessing the ledge from the front makes the fall protection lifeline impractical as it cannot go over the shrubs to access the plantings on the entire ledge. Figure 1 depicts this arrangement. Figure 2 represents a possible safe design solution. A designated walkway behind the greenery would allow workers to latch a restraint line to the horizontal lifeline and travel to all greenery on the ledge to complete necessary maintenance work. There must be sufficient space between the greenery so the worker can access all sides and front of the greenery to complete necessary maintenance work.

<<< Insert Figure 1 here >>>

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At two of the site's ledges, a fall protection system could not be installed as the ledges are so narrow that any access was viewed as impractical. The ledges are simply not maintained in contrast to the building owner's preference. This is a good example of the importance of considering safety at the design phase rather than as an after-thought. The building's structure and its contents are in place and fixed; the standard engineering control for fall protection simply does not complement or work well with the current built environment. Nevertheless, for all maintenance work to be carried out on rooftop and building facades, it is important and necessary for the maintenance workers to conduct site risk assessment prior to carrying out the maintenance work.

Unique Rooftop Building Hazards

Unique building features which can present hazards to skyrise greenery workers include skylights, electrical lines, and mechanical / electrical rooftop equipment. Workers can fall through fragile skylights and other fragile roof materials. When specifying skyrise vegetation, borders which need maintenance, and any irrigation system components near skylights or other fragile roof materials, designers should consider specifying permanent guardrails around these roof openings or that the permanent protective screens within the skylight are installed to prevent falls through to lower levels. Consider the roof and the work to be performed in relation to existing electrical power lines. Power lines should be moved or vegetation not be placed on roof or vertical areas where the work may encourage workers and their equipment to be within 3m of the overhead power line. Mechanical and electrical rooftop equipment can contain unguarded or poorly guarded moving parts. During the site visits, we did not observe any unique building hazards as described herein.

Plant Selection Considerations – Rooftop and Vertical Greenery

Plants are living organisms requiring adequate water, sunlight, and minerals in order to grow as envisaged by the designer and the building owner. Unlike conventional buildings, vegetation on roofs and walls create conditions where maintenance activities, such as weeding, watering, fertigation, plant replacement, etc. are periodically required. These maintenance activities require workers to access vegetated surfaces; therefore, plant selection does affect the frequency of maintenance and inspection activities. Plant materials should be selected such that maintenance can be less frequent (i.e., resilient, and drought, disease, and wind tolerant plants and greenery) and that are congruent with the environmental conditions of the rooftop and vertical greenery surface (i.e., shade, sun, wind). This reduces the frequency that workers need to perform routine maintenance.

To reduce the frequency that workers need to perform routine maintenance, the following planting design suggestions are recommended for considerations on both rooftop and vertical greenery systems. The two skyrise greenery systems have been combined in the considerations and the ratings as planting considerations were applicable to both systems. Table 5 provides general planting considerations, whereas Table 6 provides considerations for rooftop greenery. Table 7 summarizes the planting considerations observed on 38 skyrise greenery systems. The three that were not assessed were under construction and the greenery was not installed at the time of observation. The table shows that vertical greenery systems were not rated as high compared to the rooftop systems. Wong et al (2010) found that information on plants that will perform well on vertical greenery systems in Singapore is limited. A proper planting strategy will reduce the frequency of maintenance and replanting, thus reducing overall worker risk.

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Safe Design – A Source for Skyrise Greenery Innovation

Innovation refers to ideas, practices, or objects that are perceived as new by an individual or other unit of adoption (Kale and Arditi, 2010). The Council on Competitiveness (2005) defines innovation as the "intersection of invention and insight, leading to the creation of social and economic value". Innovations can be categorized as either technological or organizational: the former have a technical or physical character, and typically involve product or process innovation, while the latter are about advanced firm practices, and typically involve marketing or managerial innovation (Manley et al, 2009). Culvenor (2006) originally theorized that safe design could be a source for innovation. By thinking about safety and altering the design of the built environment, new and creative ideas can emerge that not only will facilitate safe places but also lead to an innovative produce that positively affects traditional built environment goals (cost, quality, schedule, etc).

We observed two distinct innovations during the site visits, and contend that by thinking about worker safety in the project's design phase, the final skyrise greenery product will be enhanced because workers will be able to maintain, re-plant, and provide overall care for the plants that make-up the skyrise greenery system. The safe design innovations noted were both on vertical greenery systems, and affected access and falls. However, there is no reason to believe that innovation is limited to vertical systems. We encourage designers and of the built environment to think about safe design not as rule following process, but to consider the innovative potential from thinking about something they normally don't consider.

<u>Example 1</u>

Many times problem solving in relation to safety issues around fall protection and access focuses on how do we get employees to the greenery and how do we protect them once there. However, innovative thinking considers options such as moving the greenery to the worker, rather than getting the worker to the greenery. For example, on a tall vertical greenery system where aerial platforms would be inconvenient, the greenery systems was placed on hinged type doors which open behind the system to a secured access platform to allow for safe worker access. Figures 3 – 5 show the vertical greenery system, the access way, and the hinged doors with guardrail. The safe access, hinged doors, and guardrail allow workers to access the greenery for inspection, maintenance, and replacement without having to think or plan for their safety. Safety is designed and built into the system. Workers do not have to 'be careful' or to wear personal protective equipment. Tools, equipment, and new plants can be moved easily to the places where they will be needed. According to the architect, planning for maintenance needs in the design phase is not only a safety issue, but is important to ensure proper aesthetics. The architect found a win-win innovation.

<u>Example 2</u>

Another innovative design was on an exterior vertical column on a twelfth floor balcony. Rather than bringing the worker outside the guardrail system to access the vegetation using cumbersome fall protection systems, the column mechanically rotated and thus the worker could access each of the six sides safely from the terrace. Further, the rotation of the greenery allows the plants to obtain the necessary levels of sunlight they need thus adding to the overall quality of the project.

<<< Insert Figure 3. Vertical Greenery System >>>

<<< Insert Figure 4. Access >>>

<<< Insert Figure 5. Hinged door and guardrail >>>

U.S. – Singapore comparison

In 2010, a similar study was conducted in the U.S. Seventeen extensive rooftop greenery systems in the U.S. were observed and evaluated using the CUGE guidelines (Behm, 2011). Tables 8 and 9 provide a comparison of U.S. and Singapore's *extensive* roofs systems' safe designed access and fall protection status. We used extensive green roofs only for the comparison as the overwhelming majority of roofs visited in the U.S. study were extensive (as opposed to intensive or roof gardens).

<<< Insert Table 8 here >>>

<<< Insert Table 9 here >>>

Of interest, is that the U.S. dataset contains a higher percentage of 'excellent' but also more 'poor' ratings compared to the Singapore dataset. In fact, the Singapore dataset contains no poor ratings in either category. The U.S. does not have any guidance regarding safe design for rooftop greenery, and safe design is not a standard practice amongst the U.S. design community. The data are not compared statistically due to low sample size.

Limitations

The site visits were not randomly selected, thus they may not be representative of skyrise greenery in Singapore. However, we feel that the sites are representative of Singapore's skyrise greenery systems. The sites were not predetermined by the researchers but by the escorts at the various design and landscaping firms who provided access. Additionally, the total number of skyrise greenery systems visited (n=41) could be viewed as a low number. Access to sites requires coordination to ensure a proper escort who can answer questions about the maintenance and design details. Our intent was to understand the safe design status of skyrise greenery in Singapore. The data presented the first time such a study has been completed; the study met its goal and serves as a foundation for future research.

Conclusions

We evaluated skyrise greenery systems in Singapore utilizing CUGE's CS E02:2010 guidelines and previous research as a foundation. Consideration was given to safe access, fall protection, planting strategies, structural loading for roofs, and other unique hazards. Consideration for worker safety is being adequately addressed in the design of rooftop greenery systems. These systems were all rated as good or excellent in both access and fall protection. The current status of vertical and ledge greenery presents challenges in access, fall protection, and planting considerations. However, these challenges can be overcome by considering the work to be performed in relation to the built environment during the project's design phase. The CUGE CS E02:2010 Guidelines should be updated to include safe design guidance for vertical and ledge greenery systems. Waiting to think about safety until workers need to access the greenery at the site is too late and can place workers in at-risk situations. An important practical design consideration is ensuring that 100% of the vegetation areas and maintenance equipment (irrigation, spigots, etc) are able to be safely accessed and do not present hazards. Cameron et al (2007) noted that during maintenance tasks of short duration and often precarious nature of access to the task, the risk of falls is high. Due to the temporary nature of some maintenance tasks, workers can be tempted to take on unacceptably high risk especially if the task duration is short. Proper design can mitigate this and positively influence the ultimate safety of workers.

This manuscript adds to the body of knowledge in safe design of the built environment by highlighting a recent emerging green building trend, skyrise greenery. As developers, designers, and urban planners look to green up the built environment, they should consider the workers who need to maintain these beautiful living designs. Green building certification systems should seek to include life cycle design for safety considerations as described here. As the green built environment matures to the *sustainable* built environment, worker safety must be considered as a key component of the social dimension. Furthermore, safety need not constrict creative and innovative design. We provide evidence of the contrary and contend this potential for innovation stemming from safe design is an important generalizeable aspect to our research. Future research should evaluate developers and design professionals' perception of safe design, and landscape personnel's view of specific tasks and their safety and risk issues for skyrise greenery. The safe design and management of worker safety for vertical greenery systems should be a focus for future research.

This research also serves to add to the body of knowledge that worker safety considerations should be a design consideration for green roofs, walls, and other vegetated systems. The archival importance is that it serves as the initial safety evaluation of skyrise greenery. Future researchers can utilize the methods and results to extend this research in their local context and as a comparison. Safety and aesthetics are not competing interests. Building owners and designers should look to the Singapore National Parks Board and Centre for Urban Greenery Ecology for safe design guidance so that future skyrise greenery systems can be maintained in safe and efficient manner.

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References

American National Standards Institute Standard (ANSI). "Occupational Health and Safety Management Systems". ANSI Z-10. American Industrial Hygiene Association. Fairfax, VA.

Behm, M. (2005). "Linking Construction Fatalities to the Design for Construction Safety Concept." *Safety Science*. Vol. 43 No. 8, pp. 589-611.

Behm, M., Lentz, T., Heidel, D., and Gambatese, J. (2009). "Prevention through Design and Green Buildings: A U.S. Perspective on Collaboration." *CIB W099 2009 International Conference – Working Together: Planning, Designing and Building a Safe and Healthy Construction Industry*. Melbourne, Australia.

Behm, M. (2011). "Rooftop Vegetation: An Opportunity to Influence Green Buildings via Prevention through Design." *CIB W099 International Conference – Prevention: Means to the End of Construction Injuries, Illnesses, and Fatalities. Washington, DC.*

Behm, M. (2012). "Safe Design Suggestions for Vegetated Roofs." Accepted in *Journal of Construction Engineering and Management*. doi:10.1061/(ASCE)CO.1943-7862.0000500.

Berndtsson, J. (2010). "Green Roof Performance Towards Management of Runoff Water Quantity and Quality: A Review." *Ecological Engineering*. Vol. 36 No. 4, pp. 351–360.

Bluff, L. (2003). "Regulating safe design and planning of construction works: a review of strategies for regulating OHS in the design and planning of buildings, structures, and other construction projects". Working Paper 19. The Australian National University, Canberra.

Cameron, I, Gillan, G., and Duff, R. (2007). Issues in the Selection of Fall Prevention and Arrest Equipment. *Engineering, Construction and Architectural Management*, Vol. 14 No. 4, pp. 363-374.

Cavanaugh, L. (2008). Redefining the Green Roof. *Journal of Architectural Engineering*, Vol. 14 No. 1, pp. 4-6.

Council on Competiveness (2005). Innovate America, National Innovation Summit and Report – Thriving in a World of Challenge and Change. ISBN 1-889866-20-2.

Center for Construction Research and Training (2008). "Worksite Assessment Team Site Visit Report for City Center and Cosmopolitan Construction Projects, Las Vegas Nevada." November 2008. Silver Spring, MD.

Centre for Urban Greenery and Ecology (CUGE) (2010). *Guidelines on Design for Safety on Rooftop Greenery*. CS E02:2010, Guidelines on Skyrise Greenery, Singapore.

Collins, K. (2005). "Green Roofs and Roof-Top Gardens – A Growing Source of Claims?" *Greening Rooftops for Sustainable Communities*. *May 4-6, 2005. Washington DC.*

Culvenor, J. (2006). "Creating Transformational Change Through Innovation in Risk Management". Keynote Address *in Risk Management Research and Practice: An Educational Perspective*, Welsh Risk Pool and University of Wales, Bangor, Trearddur Bay Hotel and Conference Centre, Holyhead, Anglesey, UK. 30-31 March 2006.

Dvorak, B. and Volder, A. (2010). "Green Roof Vegetation for North American Ecoregions: A Literature Review." *Landscape and Urban Planning*, Vol. 96, No. 4, pp. 197-213.

Ellis N. (2001). *Introduction to Fall Protection*, 3rd edition. American Society of Safety Engineers: Des Plaines, IL.

Emilsson, T., Berndtsson, J., Mattssona, J., and Rolfa, K. (2007). "Effect of using conventional and controlled release fertilizer on nutrient runoff from various vegetated roof systems." *Ecological Engineering*, Vol. 27, No. 4, pp 260-271.

Epstein, M., and Roy, M. (2003) "Making the business case for sustainability: Linking social and environmental action to financial performance". *The Journal of Corporate Citizenship*, Spring, 79-96.

Evans, L. (2006). "Goodbye to green, hello to sustainability." San Francisco Chronicle. February 1, 2006. http://www.usgbc.org/News/USGBCInTheNewsDetails.aspx?ID=2182 (Accessed 2 January 2012).

Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau (FLL) (2008). "Guidelines for the Planning, Construction and Maintenance of Green Roofing." Bonn, Germany.

Fortunato, B., Hallowell, M., Behm, M., and Dewlaney, K. (2012). "Evaluation of Safety Risks for High Performance Sustainable Construction Projects". Accepted in *Journal of Construction Engineering and Management*. doi:10.1061/(ASCE)CO.1943-7862.0000446.

Gambatese, J.A. (1996). Addressing construction worker safety in the project design. Doctor of Philosophy Dissertation, University of Washington, Seattle, Washington, USA.

Gambatese, J.A., Hinze, J.W., Haas, C.T. (1997). "Tool to design for construction worker safety." *Journal of Architectural Engineering*, Vol. 3 No. 1, pp. 32-41.

Green Roofs for Healthy Cities (2011). http://www.greenroofs.org/index.php/aboutus. (Accessed 30 December 2011).

Kale, S. and Arditi, D. (2010). "Innovation Diffusion Modeling in the Construction Industry." *Journal of Construction Engineering and Management*, Vol. 136 No. 3, pp. 329-304.

Leicht, R.M., Hunter, S.T., Saluja, C., and Messner, J.I. (2010). "Implementing Observational Research Methods to Study Team Performance in Construction Management." *Journal of Construction Engineering and Management*, Vol. 136, No. 1, pp. 76-86.

Lingard, H. (2002). The Effect of First Aid Training on Australian Construction Workers' Occupational Health and Safety Motivation and Risk Control Behaviour. *Journal of Safety Research*, Vol. 33 No. 2, pp. 209-230.

National Parks Board (NParks) (2009). Annual report 2009/2010. Singapore Botanic Gardens, 1 Cluny Road, Singapore.

National Parks Board (NParks) (2011). http://www.cuge.com.sg/. (Accessed 30 December 2011).

Ross, A.J., Wallace, B., and Davies, J.B. (2004). "Technical Note: Measurement Issues in Taxonomic Reliability." *Safety Science*, Vol. 42 No. 8, pp. 771-778.

Schulte, P.A., Heidel, D., Okun, A., and Branche, C. (2010). "Making Green Jobs Safe." *Industrial Health*, Vol. 48 No. 4, pp. 377-379.

Schulte, P., Rinehart, R., Okun, A., Geraci, C., and Heidel, D. (2008). "National Prevention through Design (PtD) Initiative." *Journal of Safety Research*, Vol. 39 No. 2, pp. 115-121.

Skaggs, P. (2004). “Observational Research: Formalized Curiosity”. *Technology Teacher*, Vol. 64 No. 1, pp. 11-13.

United States Environmental Protection Agency (EPA) (2010). “Reducing Urban Heat Islands: Compendium of Strategies.” Green Roofs Compendium. Washington DC, USA.

Urban Redevelopment Authority (URA) (2009). “LUSH Programme - Landscaping For Urban Spaces and High Rise”. http://www.ura.gov.sg/circulars/text/lushprogramme.htm

Wong, N.H., Tan, A.Y.K., Tan, P.Y., Sia, A., and Wong, N.C. (2010). “Perception studies of vertical greenery systems in Singapore”. *Journal of Urban Planning and Development*, Vol. 136, No. 4, pp. 330-338.

Workplace Safety and Health Council (2008). “Guidelines on Design for Safety in Buildings and Structures.” Singapore Workplace Safety and Health Council, Ministry of Manpower. November 2008.

Yuen, B., and Hien, W.N. (2005). “Resident perceptions and expectations of rooftop gardens in Singapore”. *Landscape and Urban Planning*, Vol. 743, No. 4, pp. 263-276.