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Discovering Synergies among Sustainable Rating Systems in Green Roof Analysis

Kanaan Hardaway
University of Arkansas, Fayetteville

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Biological Engineering Program

Biological and Agricultural Engineering Department

College of Engineering

University of Arkansas

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Abstract

As awareness has grown of the impacts the built environment has on the natural environment and the human psyche, methods to create more sustainable living environment have been developed. Green infrastructure is well-known for its environmental benefits. Emerging literature suggests green infrastructure have aesthetic qualities conducive to mental restoration, as well. To analyze the multi-benefits of green infrastructure, a green roof is studied for its aesthetic qualities and its impact on LEED, SITES, and WELL certification.

A questionnaire was administered to individuals on the University of Arkansas campus to quantify human perceptions and attitudes toward a green roof on a campus building. The questionnaire also asked participants to evaluate the advantages and disadvantages of green roofs. The study population was largely students. The questionnaire showed most participants viewed the green roof favorably, but the most positive attitudes were those of individuals classified as *familiar* with green roofs.

From a review of LEED, SITES, and WELL documents, green roofs were shown to contribute to 7 LEED, 6 SITES, and 3 WELL prerequisites and credits, for 11 points, 23 points, and 3 points available in each, respectively. LEED and WELL also had credits available to projects that used multiple sustainable rating systems. Based on these credits, several redesign concepts were produced emphasizing each sustainable rating system. The new layouts were evaluated to determine the number of credits they would earn under each sustainable rating system.

To optimize the number credits in each sustainable rating system, an intensive design green roof design will be required. However, the full potential of green roof installation may not be realized until the benefits of green roofs are better known.

Introduction

1.1 Background

In the last 30 years, the urban world population increased by nearly 2 billion people and, in the next 3 decades, is expected to increase by a further 2.5 billion people (UN DESA, 2019). Sprawling urbanization can degrade ecological systems (McKinney, 2008; Rose, et al., 2001) and quality of life, which has led to the development of sustainable rating systems to encourage sustainable design (IWBI 2019; SITES, 2014). Sustainable rating systems—as opposed to green building rating systems—refer to any technical instrument developed to evaluate the environmental, economic, and social longevity of a building project.

As these facets of sustainability have become better understood, sustainable rating systems have been developed to quantify the impacts of the built environment on each facet. The most common sustainable rating system in the U.S. is Leadership in Energy and Environmental Design (LEED) from the U.S. Green Building Council (USBGBC). LEED focuses on the construction and quality of a building and has become a standard for green building construction in the U.S (Bernardi, et al., 2014). In 2013, the U.S. Department of Energy (DOE) recommended all new federal buildings to be either Green Globe or LEED certified, preferably achieving at least 2 Green Globes or LEED Silver requirements (DOE, 2013). Similarly, the U.S. Department of Defense has enacted a policy that its new buildings achieve at least LEED Silver (Carter & Fowler, 2008). The Sustainable SITES Initiative developed the sustainable rating system SITES to complement LEED by providing a rubric for grading the sustainability of landscapes (SITES, 2014). Even more recently, the International WELL Building Institute (IWBI) developed the WELL Building Standard (WELL) to provide an index focused on human experience with the built environment (IWBI, 2019). WELL considers the features of the interior and exterior of a building to determine its WELLness score. Together, LEED, SITES, and WELL may provide a rubric for evaluating the sustainability of building design and construction, landscape design and construction, and the social implications of comprehensive design and construction. The Center for Sustainable Landscapes at Phipps Conservatory, which opened in 2012, demonstrates the union of all three sustainable rating systems. The site has achieved LEED v2.2 Platinum, 2019 SITES v2 Platinum, and WELL Platinum (pilot) certification and extensively uses green infrastructure (Phipps, 2020).

Green infrastructure refers to the interconnected array of natural systems that provide ecosystem services to the world (Benedict & McMahon, 2002). Green infrastructure is commonly rebuilt in urban areas through low-impact development (LID) to mitigate stormwater runoff from cities and provide resiliency to a city (Ahiablame, et al., 2012). Green roofs, swales, rain gardens, and other bioretention areas are all types of LID. Though LID is stormwater-based, there are further benefits from the green spaces from LID including visual quality and cooling effects (Baycan-Levent, et al., 2009). The green space provided by LID has both physical and mental health benefits, as well (Lee & Maheswaran, 2010). Understanding how the public perceives the different types of LID and green spaces can help urban centers best make use of this green infrastructure (Derkzen, et al., 2017). Many of the effects of LID and green space are also represented in LEED, SITES, and WELL scoring (IWBI, 2018; SITES, 2014; USGBC, 2020)

Green roofs, also known as living roofs or vegetated roofs, uniquely may contribute significantly to each of the three sustainable rating systems. A combination of the three rating systems (LEED-SITES-WELL) is not only convenient but also may be necessary to accurately and holistically gauge the impact of a building with a green roof. First, a green roof enhances the quality of a building by meeting certain LEED Sustainable Sites and Water Efficiency criteria (USGBC, 2020). Furthermore, a green roof acts as a sustainable landscape for the building site (Getter & Rowe, 2006). Finally, green roofs are an example of biophilic design that can have restorative psychological benefits (Gillis & Gatersleben, 2015) as well as other visual benefits. In the 1990s John Elkington introduced a triple-bottom line (TBL) of sustainability that includes environmental quality, economic welfare, and social coherence (Alhaddi, 2015). While economic welfare has an inherent measure of value in the form of monetary currencies, the standards provided by sustainable rating systems create an avenue for valuing environmental quality and social coherence in the context of development. To comprehensively account for the sustainable impact of a green roof, a synergistic model of the three rating systems could be applied to green roof building construction.

Green roofs have well-documented environmental benefits, or ecosystem services (Berardi, et al., 2014; Oberndorfer, et al., 2007). Stormwater management (Versini, et al., 2015), urban heat island mitigation (Li, et al., 2014), and enhancement of urban biodiversity (Williams, et al., 2014) are often cited benefits of green roofs. These environmental impacts support the inclusion of LEED and SITES in a synergistic model. Additionally, research on the restorative benefits of green spaces such as green roofs provides the basis for the inclusion of WELL (Kaplan, 1995; Lee, et al., 2015). Current literature connects green roofs to LEED certification (Boschmann et al., 2012). In fact, Sheng, et al. (2011) concluded that a green roof can provide up to 8.5 credits toward LEED certification. Literature connecting green roof installations to SITES and WELL projects is more difficult to find, perhaps due to the more recent development of these two sustainable rating systems.

Previous studies have shown people generally view green roofs favorably (Jungels, et al., 2013; Loder, 2014; White & Gatersleben, 2011). However, when considering these studies it is important to note there are three distinct types of green roofs: extensive, semi-intensive, and intensive. Extensive green roofs have a layer of media ranging from 6 to 20 cm with low-lying vegetated surfaces. Intensive green roofs have a media greater than 15 cm with the ability to support a greater diversity of plants and human uses (Cantor, 2008; Fernandez-Cañero, et al., 2013). Some authors also recognize a third classification of semi-intensive for a green roof design with a media thickness typically between 12 and 25 cm (Pittaluga, et al., 2011). Fernandez-Cañero et al. (2013) used simulated images of the types of green roofs to compare how aesthetic perceptions differed among the types of green roofs and concluded people found well-maintained roofs most attractive. Loder (2014) noted the surrounding landscapes of cities influence the extent to which green roofs are perceived as a natural landscape in the urban area. Prairie-like green roofs do not have the same sense of a natural landscape to residents in Toronto, who have a boreal forest to the north, as they did to residents of Chicago, who live near prairies.

There is some evidence that the visual quality of green roofs is unimportant to the public. In a study from the Netherlands, over 30% of respondents rated "recreation, visually attractive" as the least important ecosystem service provided by green roofs, which was a much greater percentage than the other five green infrastructure types studied (Derkzen, et al., 2017). The stigma that green roofs are for environmental benefits and not for aesthetic benefits may subdue interest in green roof installation in the residential sector (Smith & Boyer, 2007). Nevertheless, residential green roofs are becoming more acceptable with developing green home movements and incentive programs such as Portland's Ecoroof Incentive (City of Portland, 2020).

Further research into perceptions of green roofs is necessary to contribute to a more robust database on green roof attitudes. Using a green roof on the University of Arkansas (UA) campus, we will analyze the perceptions and attitudes of visitors to the UA campus toward the green roof on Hillside Auditorium. Adhering to the rubrics laid down in LEED, SITES, and WELL, we will redesign the green roof on Hillside Auditorium to better achieve credits in LEED, SITES, and WELL certification. The redesign will provide an arena in which the feasibility of combining the three certifications can be analyzed.

1.2 Objectives

The objectives of this study are (1) to determine the aesthetic social performance of the green roof on Hillside Auditorium, University of Arkansas, (2) to review the current literature on the synergies among LEED, SITES, and WELL, (3) to highlight the synergies of the LEED-SITES-WELL model and green roofs, and (4) to redesign the layout of the green roof on Hillside Auditorium to better achieve all the credits available to green roofs in each of LEED, SITES, and WELL.

2. Methods

2.1 Questionnaire Design

A perceptions questionnaire was developed 1) to determine general attitudes toward green roofs, 2) to identify specific aesthetic reactions to a green roof, 3) to determine the extent of the role of green roof preconceptions, gender, age, education attainment, and past and current living environments affect attitude, 4) to compare to the literature on previous green roof perception questionnaires, and 5) to format a metric that accurately represents the attitudes of individuals. The questionnaire needed to identify if individuals experienced green roofs enhancing, detracting from, or having no effect on the surrounding environment. Other considerations of importance included what factors might influence the perspective of an individual, like their background or preconceptions of green roofs. A section dedicated to preconceptions of green roof performance was included to show if preliminary green roof knowledge impacted an individual's perceptions. For clarity in comparison of the results this study henceforth will be referred to as the UA study.

2.2 Site Description

The site under study is located on the UA campus in Fayetteville, AR (36º04'00" N, 94º10'23" W). Hillside Auditorium has three tiers. The top tier has an open pavilion area for human use rimmed with trees while the middle and bottom tiers are covered with grasses. Of specific interest to this study is the extensive green roof on the middle tier, which has the greatest area (933 m^2). Plants species present on the green roof include species of *Erigeron* (fleabane)*, Euphorbia,* and *Antirrhinium* (yellow snapdragon), most of which arrived on the roof unintentionally. The middle tier was designed as a viewing roof, but a gate allows access for maintenance. A fence on the green roof sections off 536 m^2 accessible by the gate. To the north and east, the buildings adjacent to Hillside Auditorium are within 10 meters of the roof and rise five to seven stories (Figure 1). The west side of the green roof is level with the ground and an adjacent walkway provides the best view green roof. The land on the west side rises with a Greek-style theater that maintains a view on the green roof. Across a city street to the south are single-story classroom buildings with conventional gray roofs. The green roof is not visible from inside the building it rests atop but is visible from the upper tier and the western side of the building where the roof meets the ground surface.

For further contextualization of the project, the UA campus is situated in the center of Fayetteville, Arkansas, 1.5 km west of the city's historic square. The US Census Bureau estimates the population of the Fayetteville municipal area to be 86,751 as of 2018 with a density of 1600 residents per square mile. In 2017 the University of Arkansas reported 27,558 students enrolled. Both the university and city have increased in population during the last decade. The university has experienced a 38.8% increase from 2009 to 2017, and the city has experienced a 17.9% increase from 2010 to 2018 (US Census Bureau, 2018; University of Arkansas, 2019). As the population of Fayetteville continues to grow, preserving and cultivating green spaces becomes more difficult. Identifying the impacts of the existing green spaces in growing urban areas like Fayetteville is important for determining the usefulness of these spaces in the urbanizing landscape.

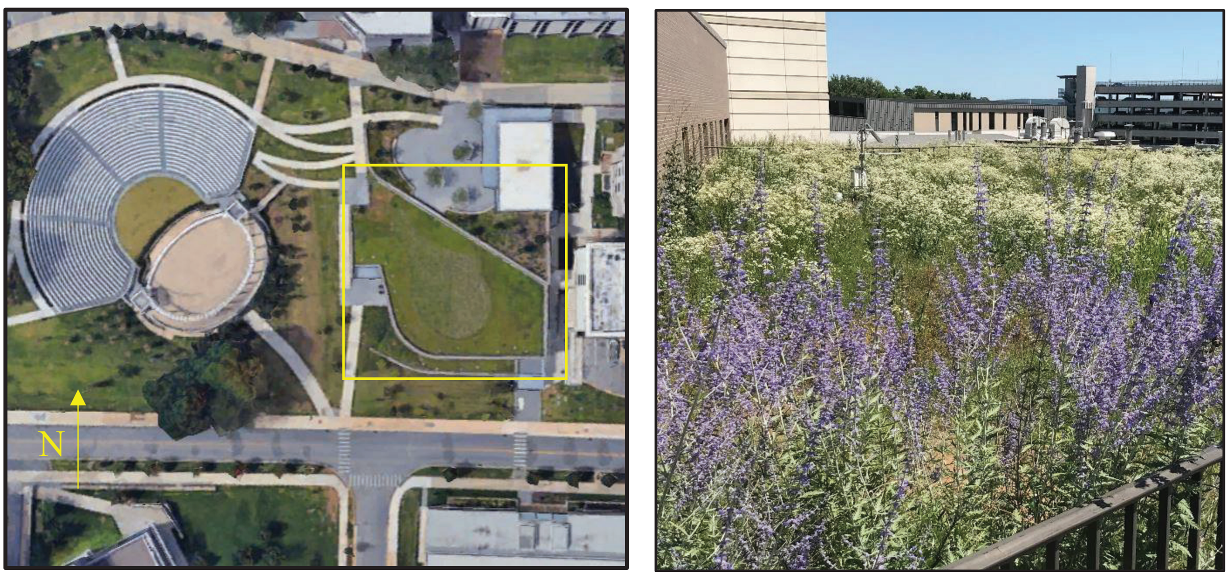

Figure 1. On left, the middle tier of the green roof (inside yellow box) and surrounding landscape including Greek-style theater to the west. A faint contrast in vegetation indicates the area within the fence on the roof. Satellite image retrieved from Google Earth (2019). On right, photograph of green roof on 13 June 2019 (taken by Kanaan Hardaway).

2.3 Questionnaire Development

When developing the questionnaire, previous studies were assessed to offer a comparison to existing studies and enable the use of questions with predetermined validity and reliability. The literature was explored for questionnaire-based studies using Google Scholar, Web of Science, and Science Direct. The University of Arkansas Libraries and InterLibraryLoan were also searched for potential studies. Search terms such as “questionnaire,” “structure,” “perceptions,” “landscape,” and “LID” were used in a variety of combinations to find satisfactory studies. Studies were selected based on relevance and preferred question structure. Studies with open response questions were not considered due to the ambiguous nature of the question type and the time cost to evaluate the responses. Studies with questions following a Likert scale structure were preferred to maintain a range of responses but also keep the number of possible responses low to encourage individuals to complete the questionnaire.

Questions for the questionnaire were taken from two recent studies (Fernandez-Cañero et al., 2013; Jungels et al., 2013) focused on perceptions and attitudes toward green roofs. Fernandez-Cañero et al. (2013) had developed twenty-one simulated images of the three general types of green roofs (extensive, semi-intensive, and intensive) for respondents to rate. The study specifically focused on which green roof types respondents viewed most favorably, The 450 respondents of the study comprised visitors at a local trade fair and students from several public high schools in southern Spain and the Technical School of Agronomic Engineers at the University of Seville. The study provided a broad outline for collecting information on green roof perceptions, but respondents rated the twenty-one simulated images of green roofs and not existing green roofs. Jungels et al. (2013) surveyed in the northeastern United States, including sites in Ithaca, NY; Philadelphia, PA; New York, NY; and Chicago, IL. Five of the green roofs were sedum-planted extensive green roofs, and the other two green roofs were semi-intensive roofs with perennial plant species. All seven of the sites were located on college campuses or non-profit gardens or land organizations. This study specifically focused on the aesthetics of green roofs with their surrounding environment. The study collected 145 responses.

The UA questionnaire comprised five sections: (1) General Aesthetics, (2) Specific Aesthetics, (3) Preconceptions, (4) Attitudes, and (5) Socio-demographics. Questions concerning (3) and (5) were taken from Fernandez-Cañero et al. (2013), and questions concerning (1), (2) and (4) were taken from Jungels et al. (2013). General and Specific Aesthetics referred exclusively to the visual quality of the green roof under study while Preconceptions and Attitudes referred to green roofs in general.

The two aesthetics sections sought to identify both the aesthetic compatibility of the green roof with an urban environment and to assess the independent aesthetic quality of the green roof. General

Aesthetics asked respondents to rate on a scale of 1 to 5 their agreement with the statements, "The green roof blends well with the surrounding landscape," and "The green roof improves the appearance of the building." The purpose of the General Aesthetics was to gauge overall impressions of the green roof, which could indicate the level of compatibility the green roof displayed with the surrounding urban environment. Jungels et al. (2013) reported a Cronbach's alpha of 0.761 for the General Aesthetics section. Following Jungels et al. (2013), the Specific Aesthetics section asked respondents to indicate their agreement with statements identifying specific qualities of the green roof, such "The green roof is 'clean, tidy'" and "The green roof is 'fresh, innovative.'" The Jungels study formulated the descriptions they used in the Specific Aesthetics section by asking twelve individuals to write down positive and negative one-word descriptions of pictures of ten green roofs. The Specific Aesthetic section was designed to provide a direct evaluation of the green roof on Hillside Auditorium for comparison with the reactions to green roofs in the Jungels study. Jungels et al. (2013) reported a Cronbach's alphas of 0.710 and 0.810 for positively and negatively connotated Specific Aesthetic descriptions, respectively.

The Preconceptions section comprised 16 potential effects of a green roof on a site, where 11 were positive effects and 5 were negative effects. Fernandez-Cañero et al. (2013) included a Preconceptions section to analyze what preconceptions—both postive and negative truths and myths—the respondents hold toward green roofs. This analysis was also of interest in the UA study; however, the UA study expanded the use of the Preconceptions study to determine how *familiarity* with green roofs impacted respondents' appraisal of aesthetic qualities. Respondents were classified as *familiar* if their responses in the Preconceptions section agreed with the literature at least two-thirds of the time. As defined, *familiarity* may not account for individuals who have had multiple interactions with a green roof but who do not demonstrate a knowledge of the costs and benefits of green roofs. We recognize a position of *familiarity* could also represent strong intuition about roof performance rather than actual, learned awareness. For ease of understanding we describe both positions together as *familiar*. All other respondents were classified as *unfamiliar*, which may include groups who either have misconceptions about green roofs or display uncertainties about the effects of green roofs. Respondents who "Agreed" or

"Strongly Agreed" (a score of 4 or above on the Likert scale) were considered as agreeing the literature. Once the *familiar* and *unfamiliar* groups were established, T-tests assuming unequal variances were performed in Microsoft Excel on the perceptions of each group to determine if the aesthetic reactions and attitudes differed between the groups.

The Attitudes section was the final section with questions concerning the green roof. Attitudes represented the sum of a respondent's thoughts on green roofs. Located after the Aesthetic and Preconception questions, we assume that Attitude responses were made with comprehensive thought of intuitional and deliberated reactions. In addition to a general prompt asking how the respondent would rate their attitude toward green roofs, the Attitudes section included two questions concerning how likely the respondent would support green roof installation in the future. Jungels et al. (2013) reported a Cronbach's alpha of 0.829 for the Attitudes section.

Socio-demographics—the final section—divided respondents into potentially different perception groups based on gender, age, educational attainment, status, and past and current living environments. The Socio-demographics section was based on Fernandez-Cañero et al. (2013). We made three adjustments. In addition to the options of "Male" and "Female," the ender prompt included a free-response box for individuals who "Prefer to self-describe" as well as the option to "Prefer not to respond." "Graduate degree" was added to the educational attainment prompt. Lastly, the status prompt was called "Occupation" in the Fernandez-Cañero study. The reponse options were adjusted for a more nuanced description of people on campus. For status, individuals could choose to classify themselves as "Student," "Faculty," Staff," or "Campus visitor." A "Department" prompt was included for students and faculty but was not used due to lack of responses from students. For each group subdivision, T-tests were run assuming unequal variances in Microsoft Excel to identify any statistical differences among socio-demographic groups.

The designed questionnaire had thirty-six questions—formatted as either Likert scale or multiple choice—and took less than five minutes to complete based on a small test group. The distribution of the questionnaire comprised two methods: Online and on-site paper. Though online distribution could gather more responses in a shorter time period, we recognized that testing on paper allowed reactions within sight of the green roof. There are many potentially confounding factors determining survey responses such that the online and on-paper responses were merged into a collective dataset. The formatted questionnaire was uploaded on Qualtrics—a web-based survey platform— and distributed to professors from each college on campus for online distribution. To reach the broad demographics of the university, ten professors from varying colleges were contacted. Two of the professors confirmed they had distributed the questionnaire. Paper copies were printed to be distributed by the researcher in the Greek-style theater, which is adjacent to and overlooking the green roof.

The on-site questionnaire response target was one hundred responses. The theater was reserved the last three weeks of classes during the Spring 2019 semester with the goal of using twelve one-hour blocks of time to collect responses. In accordance with Jungels et al. (2013), on-site questionnaires were distributed only on sunny to partly cloudy days to help eliminate any atmospheric influences on perception such as albedo discepancies. Individuals often sit in the theater on pleasant days to work on homework, eat lunch, or relax between classes. Individuals in the theater were approached and asked to participate in the study. The paper questionnaire was formatted as one sheet—front and back. A quick synopsis of the basics of the study was included on a separate page attached to the front with contact information for questions and concerns. This page could be removed by participants to save for any follow-up questions. This study was approved by IRB number 1902177442 (see Appendix A).

Weather conditions and class schedules restricted on-site distribution to three days (April 16, 19, and 22), or five one-hour blocks. April 16 and April 22 were both sunny days around 21 °C. April 19 was partly cloudy with temperatures from 12 °C to 14 °C. The surrounding days were overcast and sometimes rainy. Fifty responses were collected on-site. The number of reponses slightly increased each collection day (13, 17, and 22 responses, respectively) with no indication of fewer people on April 19 due to cooler temperatures. The respondents' distances from the green roof ranged between 30 m and 80 m, at which distance the vegetative make-up of the green roof cannot be discerned.

After collection, the paper questionnaires were inputted into Qualtrics using a separate directory from the online questionnaires to maintain flexibility between the two data subsets. The two data subsets were downloaded to Microsoft Excel for analysis. Three questionnaires less than 50 percent complete were discarded to keep response numbers similar for each question.

2.4 Sustainable Rating Systems Literature Review

The second objective of the UA study sought to outline the current emphases of sustainable rating systems in relation to green roofs and the synergies among the sustainable rating systems for green roof evaluation. LEED, SITES, and WELL were chosen for their prominence in the United States and for the pre-established relationships among each of them. All three sustainable rating systems are certified by Green Building Certification, Inc. (GBCI) and have been developed or adapted for ease of synthesis with each other and other rating systems. A review of documents posted by the United States Green Building Council (USGBC), the Sustainable SITES Initiative (SITES), and the International WELL Building Institute, as well as from collaborations between the organizations, provided the foundation for the union of the three sustainable rating systems for green-roof adorned buildings. LEED focuses on the built environment, SITES focuses on sustainable landscapes, and WELL focuses on the optimization of the human experience.

2.4.1 LEED

LEED was launched in 1998 by the USGBC. LEED projects can be registered as Building Design and Construction (BD+C), Interior Design and Construction (ID+C), Operations and Maintenance (O+M), Neighborhood Development (ND), Homes, Cities and Communities, LEED Recertification, and LEED Zero (USGBC, 2020).The green roof in the UA study crests a building certified under LEED v2009 BD+C: New Construction guidelines (USGBC-Hillside, 2020). LEED has since been updated and so this review will focus on the latest version of LEED for BD+C—LEED v4.1 BD+C—to ensure the most recent developments within LEED are considered. LEED BD+C can be further specified into New Construction, Core and Shell, Data Centers, Warehouses and Distribution Centers, Hospitality, Schools, Retail, and Healthcare. The different types of buildings have significantly different demands, so there is discrepancy in how credits are allocated among the types. For the purpose of this study, the most common allocation of credits will be considered representative for all project types. Discrepancies in the allocation of credits for Healthcare and Core and Shell projects occur most often (USGBC, 2020).

LEED has a possible 110 credits (Table 1). The credits are distributed among nine categories: 1) Integrative Process, 2) Location and Transport, 3) Sustainable Sites, 4) Water Efficiency, 5) Energy and Atmosphere, 6) Materials and Resources, 7) Indoor Environmental Quality, 8) Innovation, and 9) Regional Priority (USGBC, 2019). A green roof may contribute to credits in Sustainable Sites, Water Efficiency, or Innovation (

2.4.4 *Synergies*

In addition to the impact of green roofs on certification, sustainable rating systems can impact each other. LEED, SITES, and WELL each have an independent process to certification. However, existing certification infrastructure can expedite the process. The USGBC has created documents detailing the interchangeability of credits in LEED and SITES. Furthermore, LEED and WELL projects can supplement accreditation when paired with other sustainable rating system certifications due to Innovation credits. In pursuit of synergies among LEED, SITES, and WELL, these relationships were reviewed.

Firstly, the site boundary of a project seeking LEED and SITES certification must align. Some credits can fully substitute between LEED BD+C and SITES v2. Meeting either the LEED prerequisite Outdoor Water Use Reduction or the SITES Water P3.2 Reduce Water Use for Landscape Irrigation automatically qualifies a project for both credits if no permanent irrigation occurs on site. The LEED credit for Heat Island Reduction and the SITES credit Soil + Vegetation C4.9: Reduce Urban Heat Island Effects are also interchangeable. Other credits can only be applied in one direction due to one sustainable rating system having more stringent qualifications for the credit. Achieving the LEED Sustainable Sites Rainwater Management credit can qualify for both Water C3.3: Manage Precipitation On-Site and Water C3.3: Manage Precipitation Beyond Baseline credits .

Table 2). Construction of a green roof could also contribute to Materials and Resources and Regional Priority credits, but the contribution is not performance-based and therefore not considered in this study.

Most of the credits to which a green roof contributes in LEED are in the Sustainable Sites (SS) section. Green roofs that restore native vegetation or other vegetation adapted to the region that provide habitat can qualify for two points (SS Credit 2). A physically accessible green roof that has an area greater than or equal to 30% of the area of the building site can qualify for an Open Space credit (SS Credit 3). The Rainwater Management credit provides one point for retaining or treating the 80th percentile event of regional rainfall, two points for the 85th percentile event, and three points for the 90th percentile event (SS Credit 4). Because a site must retain or treat 100% of a storm event, an individual green roof rarely will have the ability to achieve SS Credit 4 without other stormwater management features to retain or treat water that does not fall on the rooftop of the site. A green roof can singularly achieve the Heat Island Reduction criterion if the green roof is 75% the size of all paved areas on site (SS Credit 5). In the Water Efficiency (WE) section, the Outdoor Water Use Reduction criterion requires a threshold reduction in water use from a baseline value for LEED certification, but water management beyond the threshold value can count for up to two points (WE Credit 1). If the landscape requires no irrigation, then two points are earned. If water use is reduced 50% from the baseline, one point is earned. The last credit achievable from green roof installation is in the Innovation section. The Innovation section applies to sustainable practices being applied on site that are not specifically credited in another section. A green roof could provide pollinator habitat (Colla, et al, 2009) or meet a regional priority such as Portland's Ecoroof Incentive (City of Portland, 2020) to receive a credit in the Innovation section. The Innovation section could also recognize the site receiving multiple sustainable rating system certifications (USGBC, 2020). A green roof can contribute to up to eleven credits in LEED, which moves a project in LEED from Certified to Silver or Silver to Gold.

Table 1. Summary of LEED BD+C v4.1, SITES v2, and WELL v2 certification requirements. Note: WELL uses a scoring system scaled 5 to 10. The values in the table represent the equivalent number of credits required to achieve a level of certification.

Rating System	Level of Certification	Points Requirement
	Certified	40-49

LEED (110 points possible)[a]	*Silver* *Gold* *Platinum*	50-59 60-79 80-110
SITES (200 points possible)[b]	*Certified* *Silver* *Gold* *Platinum*	70-84 85-99 100-134 135-200
WELL (110 points possible)[c]	*Silver* *Gold* *Platinum*	41-64 65-88 89-100

[a]*LEED Reference Guide to Building Design and Construction* (USGBC, 2019)
[b]*SITES v2 Rating System for Sustainable Land Design and Development* (SITES, 2014)
[c]WELL Scoring (IWBI, 2020)

2.4.2 SITES

SITES was launched in 2007 through a collaboration of the United States Botanic Garden, the Lady Bird Johnson Wildflower Center at The University of Texas at Austin, and the American Society of Landscape Architects. This review will focus on SITES v2 (SITES, 2014). Of SITES's ten Guiding Principles, the first one is to never degrade the environmental processes of an area. SITES v2 was developed with the concept of ecosystem services as its framework for quantifying the environmental benefits of a site. The healthy ecosystem on a site will provide a set of services, such as water filtration, carbon storage, and habitat for diverse organisms. SITES encourages new development, first, to preserve, then to conserve, and lastly to regenerate any of these pre-existing ecosystem services in the post-development site.

There are 200 possible credits in the SITES rating system (Table 1). The credits are distributed over ten categories: 1) Site Context, 2) Pre-Design Assessment + Planning, 3) Site Design – Water, 4) Site Design – Soil + Vegetation, 5) Site Design – Materials Selection, 6) Site Design – Human Health + Well-Being, 7) Construction, 8) Operations + Maintenance, 9) Education + Performance Monitoring, and 10) Innovation or Exemplary Performance (SITES, 2014). As with LEED, the focus of this study is on credits pertaining to green roofs and connections to other sustainable rating systems.

Synergies between SITES and LEED allow several of the SITES credits listed in

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In addition to the impact of green roofs on certification, sustainable rating systems can impact each other. LEED, SITES, and WELL each have an independent process to certification. However, existing certification infrastructure can expedite the process. The USGBC has created documents detailing the interchangeability of credits in LEED and SITES. Furthermore, LEED and WELL projects can supplement accreditation when paired with other sustainable rating system certifications due to Innovation credits. In pursuit of synergies among LEED, SITES, and WELL, these relationships were reviewed.

Firstly, the site boundary of a project seeking LEED and SITES certification must align. Some credits can fully substitute between LEED BD+C and SITES v2. Meeting either the LEED prerequisite Outdoor Water Use Reduction or the SITES Water P3.2 Reduce Water Use for Landscape Irrigation automatically qualifies a project for both credits if no permanent irrigation occurs on site. The LEED credit for Heat Island Reduction and the SITES credit Soil + Vegetation C4.9: Reduce Urban Heat Island Effects are also interchangeable. Other credits can only be applied in one direction due to one sustainable rating system having more stringent qualifications for the credit. Achieving the LEED Sustainable Sites Rainwater Management credit can qualify for both Water C3.3: Manage Precipitation On-Site and Water C3.3: Manage Precipitation Beyond Baseline credits .

Table 2 to be met if the corresponding LEED credit is met (see Section 2.4.4 Synergies). Here, the focus will be on the specific criterion that a green roof would have to meet to achieve SITES credit. A green roof may contribute to a combined three prerequisites and credits (SITES, 2014). All SITES projects to be able to retain the 60th percentile rainfall event using infiltration, evapotranspiration, and reuse methods (Prerequisite 3.1 Manage Precipitation On-site). As with the LEED Rainfall Management credit, additional points are earned in SITES for retaining more extreme rainfall events: retaining the 80th percentile event receives four points, the 90th percentile event receives five points, and the 95th percentile event receives six points (Credit 3.3 Manage Precipitation Beyond Baseline). A project will most likely require additional stormwater controls to retain and treat precipitation that does not fall on the rooftop.

One of the most significant differences between LEED and SITES is SITES projects can earn points if stormwater features are visually and physically accessible (Credit 3.5 Design Functional Stormwater Features as Amenities). In the Soil + Vegetation category, a green roof can aid the awarding of points through two credits. Projects that maintain appropriate biomass on a site can earn points (Credit 4.8 Optimize Biomass). Post-development vegetation should be native to the region and have a similar biomass density index (BDI) as pre-development vegetation. The biomass credit is awarded on a six-point scale as a function of terrestrial biome of the site and the change in BDI between pre- and post-development. An additional Soil + Vegetation credit worth 4 points can be achieved if a green roof has an area equal to or exceeding 50% the area of the total roofed area and total paved area (Credit 4.9 Reduce Urban Heat Island Effects).

Whereas environmental performance SITES credits are similar to LEED credits, SITES includes Human Health + Well-Being credits that are similar to WELL. A green roof that provides a quiet, visually and physically accessible green space, as well as vegetation viewable from at least half of the common spaces of a building for regularly occupied buildings can earn points toward SITES certification (Credit 6.4 Support Mental Restoration). Overall, a green roof can contribute to 23 SITES credits. Twenty-three credits in SITES can move a project from Certified to Silver, from Silver to Gold, and nearly from Gold to Platinum.

2.4.3 WELL

WELL was launched in 2014 by the International WELL Building Institute. This review will focus on the most recent update from 2018 WELL v2 (IWBI, 2019). Like SITES, WELL lists foundational principles to guide how WELL develops. According to its mission statement, WELL aims to provide the greatest benefit to the greatest number of people using feasible strategies that are evidenced-based and technically robust (IWBI, 2018).

WELL has 110 possible credits (Table 1). The WELL scoring system differs from LEED and SITES. To normalize the scoring systems for comparison, the WELL preconditions and optimizations were backcalculated from the scoring system. The credits of WELL are divided into 11 categories: Air, Water, Nourishment, Light, Movement, Thermal Comfort, Sound, Materials, Mind, Community, and Innovations. WELL requires all projects to achieve at least two credits in each category but also prevents a project from pursuing more than twelve credits in an individual category (IWBI, 2018). Green roofs have a limited capacity to affect WELL certification. Green roofs may impact the precondition Access to Nature (M02|P), as well as the optimizations Restorative Spaces: Part 2 (M07|O) and Enhanced Access to Nature (M09|O).

The precondition Access to Nature ensures a project uses at least two of the following four natural elements in its design: 1) Plants, 2) Water, 3) Light, and 4) Nature views. The next credit—Restorative Spaces—requires an area designated for mental restoration through relaxation and contemplation. This area should be between 7 m^2 and 74 m^2 depending on the occupancy size of the project building. A variety of sunlit and shaded seating, sound masking features, and a design creating a private respite are recommended for the space. The optimization Enhanced Access to Nature requires a project to fulfill two of four criteria ensuring building occupants easy physical and visual access to green or blue spaces (i.e., open water). A green roof can contribute to two of these criteria. First, WELL requires a site to have at least 25% of its exterior area dedicated to accessible green spaces, in which 70% of the area is vegetation or other natural elements. This exterior area must have tree canopies. Second, WELL requires visibility of natural elements for 75% of the workstations or classroom seats in the project building (IWBI, 2018).

For recognizing multiple sustainable rating system certifications, WELL qualifies the Green Building Rating System Optimization into its Innovation category. A green roof does not offer as significant of impacts for WELL certification as it does for LEED and SITES certification but can contribute up to three credits.

2.4.4 Synergies

In addition to the impact of green roofs on certification, sustainable rating systems can impact each other. LEED, SITES, and WELL each have an independent process to certification. However, existing certification infrastructure can expedite the process. The USGBC has created documents detailing the interchangeability of credits in LEED and SITES (USGBC, 2016). Furthermore, LEED and WELL projects can supplement accreditation when paired with other sustainable rating system certifications due to Innovation credits. In pursuit of synergies among LEED, SITES, and WELL, these relationships were reviewed.

Firstly, the site boundary of a project seeking LEED and SITES certification must align. Some credits can fully substitute between LEED BD+C and SITES v2. Meeting either the LEED prerequisite Outdoor Water Use Reduction or the SITES Water P3.2 Reduce Water Use for Landscape Irrigation automatically qualifies a project for both credits if no permanent irrigation occurs on site. The LEED credit for Heat Island Reduction and the SITES credit Soil + Vegetation C4.9: Reduce Urban Heat Island Effects are also interchangeable. Other credits can only be applied in one direction due to one sustainable rating system having more stringent qualifications for the credit. Achieving the LEED Sustainable Sites Rainwater Management credit can qualify for both Water C3.3: Manage Precipitation On-Site and Water C3.3: Manage Precipitation Beyond Baseline credits (USGBC, 2016).

Table 2. Credits for LEED, SITES, and WELL to which a green roof may contribute. In the SITES section, P = Prerequisite and C = Credit. In the WELL section, P = Precondition and O = Optimization.

Green Roof Credit	Points Possible
LEED v4.1	
Sustainable Sites	
SS Credit 2 Protect or Restore Habitat	1-2
SS Credit 3 Open Space	1
SS Credit 4 Rainwater Management	1-3
SS Credit 5 Heat Island Reduction	1-2
Water Efficiency	
WE Prerequisite Outdoor Water Use Reduction	
WE Credit 1 Outdoor Water Use Reduction	1-2
Innovation	
Green Rating System, Biodiversity	1
Total Possible	11
SITES v2	
Water	
P3.1 Manage precipitation on site	Prerequisite

C3.3 Manage precipitation beyond baseline *C3.5 Design functional stormwater features as amenities*	4-6 4-5
Soil + Vegetation *C4.8 Optimize biomass* *C4.9 Reduce Urban Heat Island effects*	 1-6 4
Human Health + Wellbeing *C6.4 Support mental restoration*	 2
Total Possible	23
WELL v2	
Mind *M02|P Access to Nature* *M07|O Restorative Spaces (Part 2)* *M09|O Enhance Access to Nature*	 Prerequisite (1) 1 1
Innovation *I05|O Green Building Rating System*	 1-5
Total Possible	8

In addition to interchangeable credits among the sustainable rating systems, LEED and WELL have credits encouraging certification from multiple sustainable rating systems as mentioned in each rating system section (Figure 2). The Innovation in Design Credit in LEED exists to give projects flexibility during certification. Providing specific environmental credits not in the LEED list can be achieved through Innovation in Design. If achieving multiple sustainable rating system certifications enhances the environmental quality of the building, an Innovation in Design Credit could be achieved. WELL more explicitly includes a credit for achieving multiple sustainable rating system certifications through the Green Building Rating System Optimization in the Innovation category. SITES contains no credits for synthesis with other sustainable rating systems. In 2015 a course titled “Green Building System Synergies: LEED-SITES-WELL” was presented at the Greenbuild International Conference and Expo and is since listed as credit-providing for USGBC members (Greenbuild, 2015). However, the course was not accessible to the researcher.

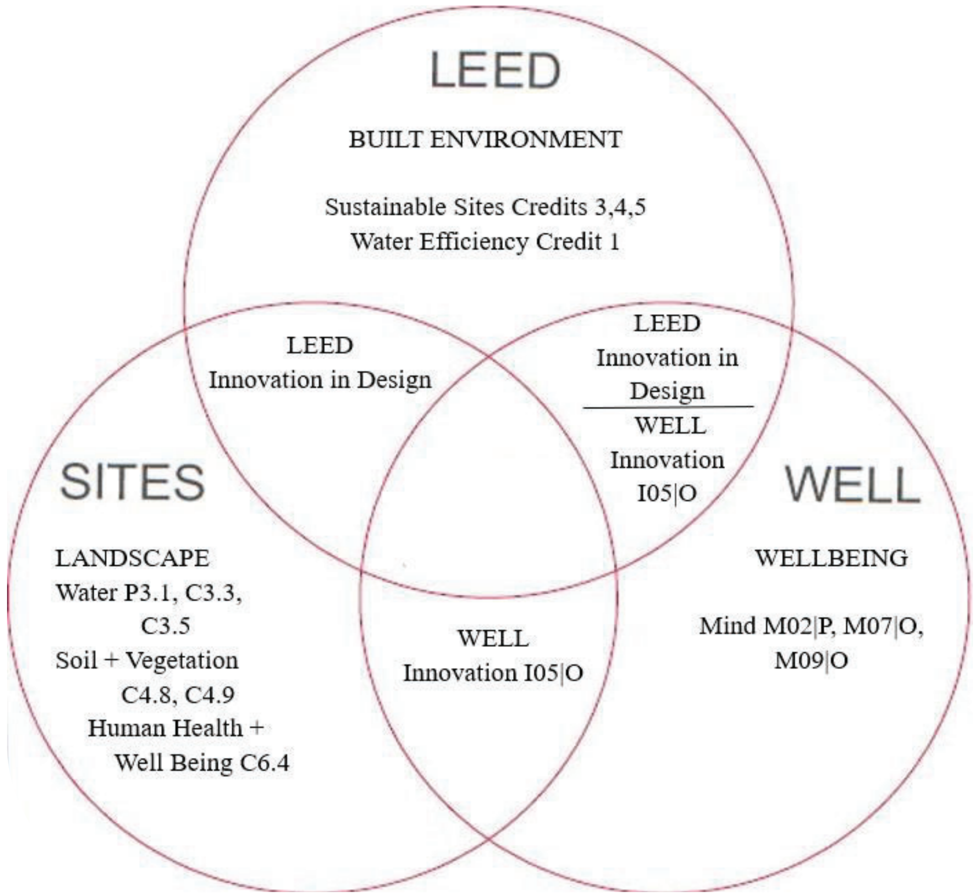

Figure 2. The credits each sustainable rating system may apply to green roof impacts or may synergize with other sustainable rating systems. LEED provides a sustainability index for the built environment; SITES provides a sustainability index for landscape design; and WELL is an index for categorizing the impact of the built environment on human wellbeing. LEED and WELL both have credits that are earned when a project achieves additional sustainable rating system certifications.

2.4.5 Current Hillside Green Roof Design

For its Silver LEED certification, Hillside Auditorium achieved fifty-three credits (USGBC-Hillside, 2020). The design of the green roof on Hillside Auditorium contributes to four credits. The green roof meets two credits in the Sustainable Sites category due to its area proportional to the entire development (SSc5.2 Site Development – Maximize Open Space, SSc7.2 Heat Island Effect – Roof). The vegetation of the green roof was chosen to reduce the consumption of potable water for irrigation by 50%, which achieves two points for the Water Efficient Landscaping Credit 1. The green roof of Hillside Auditorium does not meet the criteria to achieve either of the rainwater management credits (SSc6.1 Stormwater Design – quantity control, SSc6.2 Stormwater Design – quality control). Quantity control can be achieved either through a design storm approach or through a percentile storm approach and is based on keeping post-development runoff flows equal to or less than pre-development runoff flows. Quality control requires capture and treatment of 90% of the average annual storm with best management practices (BMPs). Since the project was certified in 2014, it followed v2009 guidelines, some of which have been updated in v4.1.

The main relevant differences between v2009 and v4.1 stem from the reorganization of credits with some change in stringency. In LEED v4.1 the urban heat island credits are combined into one credit worth two points (LEED v2009 SSc7.1 and SSc7.2 Heat Island Effect to v4.1 SSc5 Heat Island Reduction). Combining the requirements of the older LEED v2009 credits into a single LEED v4.1 credit ensures the site of the project is uniformly designed to mitigate the urban heat island effect and not skewed toward roof or nonroof measures. The corresponding water efficiency credits experienced no change in criteria, but the value of the credit was reduced from 4 points to 2 points (WEc1 Water efficient landscaping to WEc1 Outdoor Water Use Reduction). The unattained rainwater management credits have been condensed to a single credit that focuses on retaining rainwater (SSc6.1 and 6.2 to SSc3 Rainwater Management). The updated credit was also made more achievable by lowering the percentile storm the project must retain to achieve credit. The minimum percentile that achieves credit is now the 80% storm instead of the 95% storm as was the previous requirement.

The Hillside Auditorium project did not pursue certification in SITES or WELL, so the current value of the green roof for each of these latter sustainable rating systems must be postulated. SITES and WELL both require physical and visual access to green spaces to meet wellbeing credits. In the current state of the green roof, no WELL credits are achieved beyond the precondition. The roof provides no secluded space for mental restoration, nor is the roof advertised as accessible to the occupants of the building. Some SITES credits may be achieved due to the overlapping nature of several of the SITES and LEED credits. The SITES Manage Precipitation on-site prerequisite and Reduce the Urban Heat Island effects credit are most likely achieved. The original planting layout may have achieved the Optimized

Biomass credit in SITES, but the current lack of variety may keep the green roof from contributing to that credit now. However, improvements are possible.

The two most important characteristics of a green roof for meeting the credits available in LEED, SITES, and WELL are size-related. A green roof that has a proportionally large area compared to the developed site directly achieves credits from LEED and SITES and creates the opportunity to achieve credits from WELL. In the vertical dimension, the thicker media of an intensive green roof has greater potential for water retention, as well as its ability to support a greater diversity of vegetation. A challenge with a thicker media is the additional roof effective loading capacity required to support it, which can increase capital costs. Intensive green roofs are most likely to achieve credits for all three sustainable rating systems because they are most easily designed for human interaction.

3. Questionnaire Results

The perceptions questionnaire for the UA study compiled 114 responses. The population of the UA study comprised more individuals identifying as female (58.6%, *Table 3*). Every respondent was over 18 and had at least a high school education. The population was largely from eighteen to twenty-five years old (82.9%), and 89.2% were students. While most individuals of the population grew up in an “Urban” environment (56.8%), nearly a third marked “Rural” (32.4%), and the rest grew up in a “Forested” environment (10.8%). Current living environment was overwhelmingly “Urban” (89.2%), most likely due to the number of students who grew up in a “Rural” environment and have moved to Fayetteville to attend classes. The fact many respondents consider Fayetteville, AR (pop. 86,751), an urban living environment should be noted.

Table 3. Socio-demographics of UA Study

Characteristics of the sample (Sample size, *N* = 114)					
Gender		Age		Educational Attainment	
Male	40.5%	*less than 18*	0.0%	*Highschool or less*	0.0%
Female	58.6%	*18-25*	82.9%	*Some college*	64.9%
Prefer to self-describe	0.0%	*26-40*	9.9%	*Bachelor's degree*	22.5%
Prefer not to respond	0.9%	*more than 40*	7.2%	*Graduate degree*	12.6%

Status		Childhood Living Environment		Current Living Environment	
Student	89.2%	*Urban*	56.8%	*Urban*	89.2%
Faculty	5.4%	*Rural*	32.4%	*Rural*	9.0%
Staff	4.5%	*Forested*	10.8%	*Forested*	1.8%
Campus visitor	0.9%				

The aesthetic preferences of the UA study do not significantly vary from the results of Jungels, et al. (2013) except in "The green roof improves the appearance of the building" (Table 4), which more UA participants supported. In both studies the General Aesthetics Reactions received the greatest support indicating respondents believe the roof blends well with the surrounding landscape and improves the appearance of the building. It is important to note Hillside Auditorium always has had a green roof, so respondents' agreement with the statement "The green roof improves the appearance of the building" must be based on an abstract conception of the building without a green roof created in each respondents' mind. In the Specific Aesthetic Reactions section, respondents in both studies felt most strongly that the green was "Fresh, innovative" and was not "Out of place, strange." Similar results were reported for both studies in the Specific Aesthetic Reactions section.

Table 4. Comparison of Aesthetic Results.

Aesthetic Reactions		UA Study			Comparison Study			
	n	Mean	Std. dev.	Mode	Mean	Std. dev.	Mode	Source
General Aesthetics Reactions								Jungels et al. (2013), n = 145
The green roof blends well with the surrounding landscape	114	4.11	1.19	5	3.99	0.97		
The green roof improves the appearance of the building	114	4.17	1.13	5	3.64	1.02		
Specific Aesthetic Reactions (To what extent do you feel the green roof is:)								
- *Dull, unattractive*	113	1.69	0.88	1	1.87	0.97		
- *Fresh, innovative*	113	3.81	1.00	4	3.65	1.01		
- *Full, lush*	113	3.37	0.98	3	3.23	1.03		
- *Messy, overgrown*	113	2.12	1.01	2	2.14	0.95		
- *Bare, sparse*	113	2.15	0.95	2	2.01	0.96		
- *Out of place, strange*	112	1.37	0.63	1	1.73	0.91		
- *Clean, tidy*	113	3.28	0.88	3	3.23	1.13		
- *Beautiful, vibrant*	114	3.50	1.11	4	3.24	1.08		

The results of the UA study demonstrated some ambiguity from the participants (Table 5). The participants of the UA study indicated uncertainty in whether green roofs “Have high installation cost” or “Have a high consumption of water for irrigation.” Respondents also agreed most strongly with the statements “Help to manage the stormwater runoff” and “Increase biodiversity in urban areas.” The preconception “Cause problems for people with allergies” received the least support in the UA study (2.55 out of 5.00), which is notable due to the strong agreement demonstrated by the Fernandez-Cañero, et al. (2013) study (3.89 out of 5.00). Preconceptions of the costs and benefits of green roofs differ between the UA study and Fernandez-Canero, et al. (2013). Fernandez-Cañero, et al. (2013) reported significantly more support for the statements “Have expensive maintenance costs,” “Provide a new green space for recreational use,” “Have high installation cost,” “Reduce air pollution,” “Mitigate the heat island phenomenon in the city,” “Cause problems for people with allergies,” and “Create problems of dampness.” Overall, the participants of the Fernandez-Cañero, et al. (2013) study were more willing to rate each statement away from the middle value of three.

Table 5. Comparison of Preconceptions.

Preconceptions (To what extent do you feel that green roofs:...)		UA Study			Comparison Study			
	N	Mean	Std. dev.	Mode	Mean	Std. dev.	Mode	Source
Have expensive maintenance costs	114	2.56	1.00	3	3.48	1.01	4	Fernandez-Canero et al. (2013), n = 450
Act as a barrier against noise	114	3.46	0.84	3	3.70	1.02	4	
Provide a new green space for recreational use	114	3.46	1.22	4	4.22	0.85	5	
Encourage the proliferation of insects and rodents	114	3.46	1.03	4	3.63	1.01	4	
Help to manage the stormwater runoff	114	4.08	0.84	4	3.84	0.85	4	
Improve thermal insulation of the building	114	3.93	0.84	4	4.28	0.68	4	
Have high installation cost	114	2.99	1.03	3	3.63	1.01	4	
Reduce air pollution	114	3.87	0.88	4	4.39	0.68	5	
Increase longevity of the roof membrane	113	3.25	0.79	3	3.28	1.02	3	
Mitigate the heat island phenomenon in the city	114	3.66	0.95	3	4.18	0.85	5	
Achieve greater energy efficiency in the building	114	3.82	0.91	4	3.77	1.02	4	
Cause problems for people with allergies	114	2.55	1.04	3	3.89	1.01	4	
Increase biodiversity in urban areas	113	4.12	0.79	4	4.30	0.68	4	
Make it possible to cultivate vegetables, fruits, and ornamental plants	114	3.99	0.92	4	3.71	1.19	4	
Have a high consumption of water for irrigation	114	2.91	1.03	3	3.29	1.01	4	
Create problems of dampness	114	2.64	0.90	3	3.33	1.18	4	

The “Attitudes” section of the questionnaire was meant to capture the general perception of the green roof by the respondents. As seen in Table 6, the UA study reported greater support for green roofs than the Jungels et al. (2013) study.

Table 6. Comparison of Attitudes.

Attitudes		UA Study			Comparison Study			
	N	Mean	Std. dev.	Mode	Mean	Std. dev.	Mode	Source
Attitude	110	4.56	0.57	5	3.90	1.16		Jungels et al. (2013), n = 145
The benefits of green roofs outweigh the costs	111	4.31	0.68	4	3.94	0.87		
I would like to see money spent on building more green roofs	111	4.33	0.79	5	3.91	0.92		

The advantages and disadvantages from the Preconceptions section have some ambiguity (Table 7). Green roofs have three common classifications (extensive, semi-intensive, intensive) due to the differences in structural design and vegetation potential. The three types (extensive, semi-intensive, and intensive) of green roofs vary in the extent of agreement with the literature for each statement. The Preconceptions statements apply universally to intensive green roofs. Extensive green roofs are more likely to have maintenance costs of equal cost to conventional roofing. Extensive green roofs are also more likely to provide the advantages listed at reduced levels. Literature considering semi-intensive green roofs was not as prevalent as literature considering intensive and extensive green roofs, but what literature was found supported each statement. No green roof literature was found on allergies, so studies discussing green spaces were used as a surrogate. For ease of analysis, the extent of agreement was considered negligible, so all statements were classified as true. Furthermore, an understanding of the differences among the green roof types may have indicated a prior familiarity for a respondent, but this understanding should not have altered the answers of the respondent.

Table 7. Summary of studies supporting the "Preconceptions" section of the questionnaire.

Preconception	**Source**	**Extensive**	**Semi-intensive**	**Intensive**	**Green Spaces**
Have expensive maintenance costs	Porsche & Köhler (2013)	Agree		Agree	
	Carter & Keeler (2008)	Disagree			
Act as a barrier against noise	Porsche & Köhler (2013)	Agree	Agree	Agree	
	Pittaluga et al. (2011)	Agree	Agree		
Provide a new green space for recreational use	Oberndorfer et al. (2007)	Disagree		Agree	
	Fernandez-Canero et al. (2013)	Disagree		Agree	
Encourage the proliferation of insects and rodents	Li & Yeung (2014)		Agree		
Help to manage the stormwater runoff	Porsche & Köhler (2013)	Agree		Agree	
	Carter & Keeler (2008)	Agree			
	Oberndorfer et al. (2007)	Agree	Agree	Agree	
	Li & Yeung (2014)	Agree	Agree	Agree	
Improve thermal insulation of the building	Porsche & Köhler (2013)	Agree	Agree	Agree	
	Carter & Keeler (2008)	Agree			
Have high installation cost	Porsche & Köhler (2013)	Agree	Agree	Agree	
Reduce air pollution	Carter & Keeler (2008)	Disagree		Agree	
Increase longevity of the roof membrane	Porsche & Kohler (2013)	Agree	Agree	Agree	
	Carter & Keeler (2008)	Agree			
	Oberndorfer et al. (2007)	Agree	Agree	Agree	
Mitigate the heat island phenomenon in the city	Oberndorfer et al. (2007)	Agree	Agree	Agree	
	Carter & Keeler (2008)	Disagree			
	Li & Yeung (2014)	Agree	Agree	Agree	
Achieve greater energy efficiency in the building	Oberndorfer et al. (2007)	Agree	Agree	Agree	
Cause problems for people with allergies	Andrusaityte et al. (2015)				Agree
	Erdman et al. (2015)				Agree
Increase biodiversity in urban areas	Carter & Keeler (2008)	Disagree			
	Li & Yeung (2014)		Agree		
Make it possible to cultivate vegetables, fruits and ornamental plants	Oberndorfer et al. (2007)	Disagree		Agree	
Have a high consumption of water for irrigation	Oberndorfer et al. (2007)	Disagree		Agree	
Create problems of dampness					

For each demographic question, two-tailed T-tests were used to determine statistical differences. The only two groups who showed significant statistical differences were the *familiar* and *unfamiliar* groups (*Table 8*). Respondents who were classified as *familiar* agreed more strongly with the statements "The green roof improves the appearance of the building," "The benefits of green roofs outweigh the costs," and "I would like to see money spent on building more green roofs." Two of the three statements that were statistically different were in the Attitudes section suggesting the *familiar* group has a more positive paradigm for green roofs.

Table 8. Comparison of green roof perceptions between familiar *and* unfamiliar *respondents. P-values less than 0.05 represent a significant statistical difference between the subgroups.*

	Familiar, *n = 22*			Unfamiliar, *n = 93*			α = 0.05
General Aesthetics Reactions	Mean	Std dev.	Mode	Mean	Std dev.	Mode	p-value
The green roof blends well with the surrounding landscape	4.24	1.00	5	4.08	1.23	5	0.879
The green roof improves the appearance of the building	**4.62**	**0.59**	**5**	**4.06**	**1.20**	**5**	**0.003**
Specific Aesthetic Reactions (To what extent do you feel the green roof is…)							
- Dull, unattractive	2.05	1.02	2	1.61	0.82	1	0.078
- Fresh, innovative	4.14	0.85	4	3.74	1.01	4	0.068
- Full, lush	3.33	1.06	3	3.38	0.97	3	0.854
- Messy, overgrown	2.10	1.00	2	2.13	1.02	2	0.885
- Bare, sparse	2.29	0.90	2	2.12	0.96	2	0.458
- Out of place, strange	1.38	0.59	1	1.36	0.64	1	0.900
- Clean, tidy	3.19	0.87	3	3.30	0.89	3	0.595
- Beautiful, vibrant	3.48	1.17	4	3.51	1.10	4	0.917
Attitudes							
- Attitude	4.75	0.44	5	4.52	0.58	5	0.059
- The benefits of green roofs outweigh the costs	**4.60**	**0.50**	**5**	**4.24**	**0.70**	**4**	**0.011**
- I would like to see money spent on building more green roofs	**4.75**	**0.44**	**5**	**4.24**	**0.82**	**5**	**0.0003**

4. Design

4.1 Project Description

Hillside Auditorium is currently registered as LEED Silver. The green roof reasonably contributes to 5 credits in LEED v4.1 to reach this level. We will now analyze a series of redesign concepts for the green roof to maximize LEED, SITES, and WELL credits (Table 2). A fourth redesign concept will consolidate elements from each of the emphases into a final recommendation for Hillside Auditorium. The effects of the green roofs on the upper and lower tiers of Hillside Auditorium will be considered in the total impacts of green roofs on certification, but these locations will not be altered and should have a constant benefit to each of the emphases. Though the middle tier of Hillside Auditorium is described as an extensive roof, the substrate thickness (15-cm) and the variety of plants (grasses, shrubs, a small tree) supported now suggest the roof could support a greater range of features, such as seating or more expansive shrubbery.

There are some constraints to how much the green roof can be altered. A thicker substrate may provide for a greater variety of plants, such as trees, and for more reliable rainwater retention and treatment. However, unless the areal extent of the green roof is equal to the area of the project site, not all the precipitation that falls on the site can be retained or treated by the green roof. Therefore, rainwater management credits that are not earned in the current state of the green roof will not be earned without the addition of other stormwater controls on the site. SITES and WELL both have mental restoration credits with criteria requesting the vegetation be visible from the occupants of the building. The SITES Human Health + Wellbeing credit is unachievable due to the design of Hillside Auditorium that prohibits a view of the roof from the lecture hall. This credit was not pursued in the SITES emphasis since it was deemed out of reach. The WELL Enhanced Access to Nature credit can still be achieved but out of the four possible criteria that could be met, only two can possibly be met with alteration to the green roof on Hillside Auditorium. Additionally, the Optimize Biomass credit of SITES requires evaluation using the reference guide of SITES, which is behind a paywall, so the nuance of how to account for points in the credit is not known.

4.2 Redesign Concepts

The redesign concepts were generated from close consultation with the requirements of credits outlined in Table 2 and are presented in Figure 3. For the designs, convenience was also a consideration. Outside the inner fenced area, a safety harness is required by the campus Facilities Management. To decrease the hassle of maintenance, it is important to select hardier plantings that have a reduced maintenance timeline. For this reason, each emphases only has a monoculture of little bluestem (*Schizachyrium scoparium*) outside the rooftop fence. All the emphases include physical access to the green roof, which may require structural reinforcement. Calculations for the extent of this reinforcement have not been performed for this study.

For LEED (Figure 3a), improvements stem from establishing public access to the green roof, which is encouraged by a series of pavers leading to an assortment of tables within the fenced section of the roof. Small, flowering shrubs such as azure sage (*Salvia azurea*) and Hubricht's bluestar (*Amsonia hubrichtii*) add seasonal colors and texture to the green roof. Including a seasonal mix of native species such as little bluestem (*Schizachyrium scoparium*) and butterfly milkweed (*Asclepias tuberosa*) could cultivate a pollinator habitat (TWC, 2020). A small area of a variety of grasses has been included outside the rooftop fence to help cultivate this habitat.

The *SITES Emphasis* resulted in a design similar to LEED (Figure 3b). However, where the design for *LEED Emphasis* only sought to provide spaces for human occupation, the *SITES Emphasis* strove to create a landscape that people could visit. More than three times as many shrubs were included in the *SITES Emphasis* aimed at providing multiple layers of canopy and more biomass. Individuals visiting the green roof under *SITES Emphasis* should feel as though they are entering a botanical garden. Tables were intentionally nestled next to the shrubs of the roof. A medley of flowering shrubs could emphasize the aesthetic qualities present on the roof and reinforce the concept the green roof is a stormwater feature that serves as an amenity.

The *WELL Emphasis* (Figure 3c) requires the most radical change. The "Enhance Access to Nature" credit requires the green roof to have a tree canopy, which requires significant thickening of the media and structural reinforcement. The Restorative Spaces credit requires a secluded space for relaxation. This space has been created on the green roof with trees and shrubs. A table and a bench have included in this place of respite to encourage a variety of uses for relaxation and contemplation. A trail of pavers extends throughout the entire fenced area of the green roof and ends at a small gathering area with another table and bench near the center of the roof. This area creates a sunlit place of respite.

The fourth redesign concept compiles thought processes from each of the weighted emphases (Figure 3d). The fourth desgin began with foundation of *LEED Emphasis* and considered features from the other two emphases. The grass medley with species such as butterfly milkweed outside the rooftop fence was kept to provide additional pollinator habitat away from human seating. With consideration of the *WELL Emphasis,* the scattering of seating ranges from a place of respite secluded against the wall of the upper tier to a place of gathering in the middle the green roof. From the *SITES Emphasis,* the amount of shrubs was increased by 50% both to create the place of respite and provide a feel of a landscape versus that of a rooftop. Some enhancements were considered prohibitively radical. The tree canopy of *WELL Emphasis* was discarded, so that the substrate would not require substantial thickening. The final redesign concept has 50% less shrubs from the *SITES Emphasis* in consideration of irrigation requirements.

4.3 Score Evaluation

Evaluating the score of each design reveals little variation in scoring to what a green roof further can contribute on Hillside Auditorium (Table 9). The significant point totals from rainwater management in LEED and SITES cannot be achieved solely by the green roofs. The roofed portion of the site is approximately 80% of the total site area, so if the green roofs retained or treated 100% of the water that fell on the roof, LEED could achieve one point from the rainwater management credit.

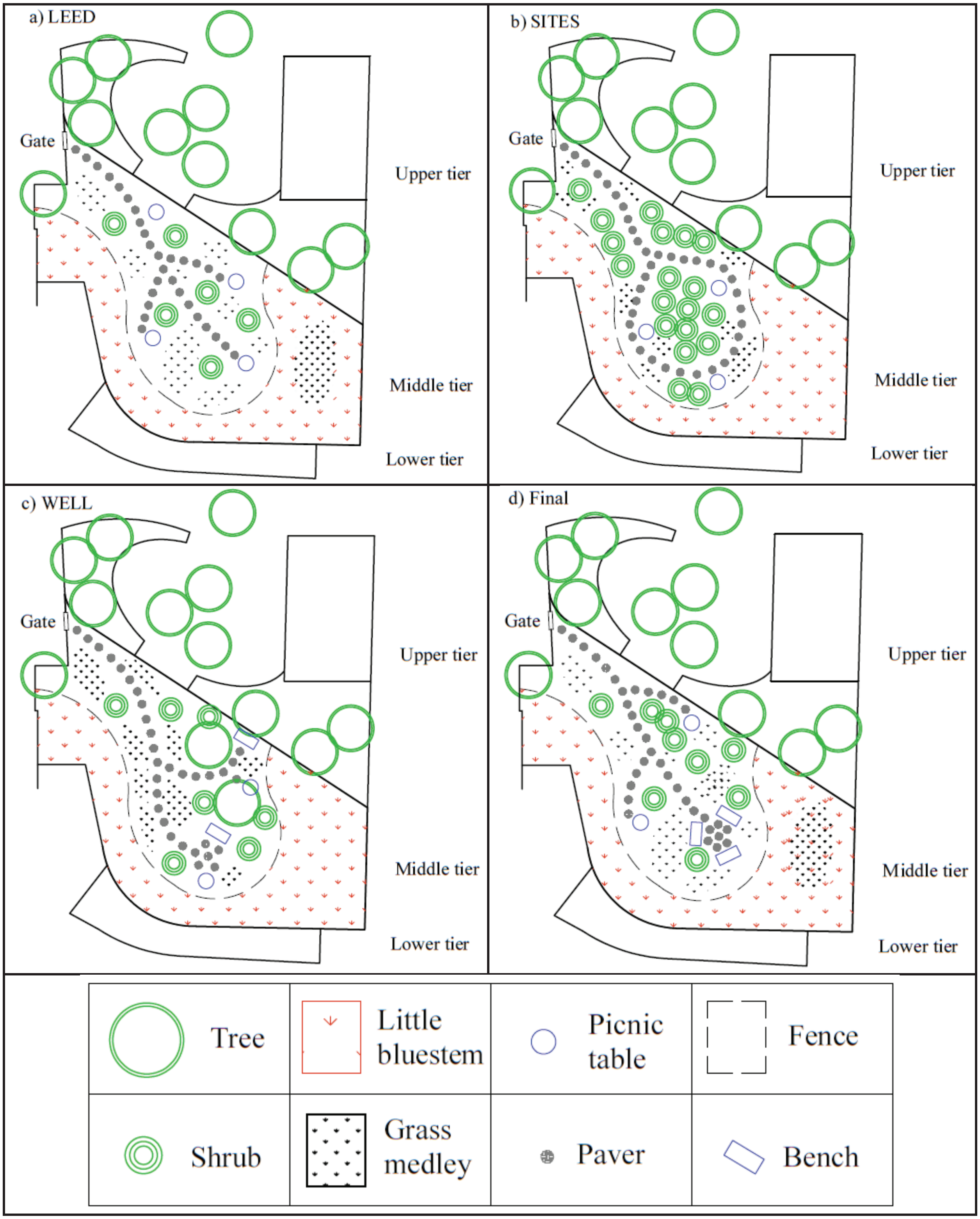

Figure 3. Hillside Auditorium middle tier green roof redesign concepts with a) LEED, b) SITES, and c) WELL emphases with a d) Final redesign concept melding features of the emphases. The emphasis of the design is indicated in the top left corner of each layout. Layouts were created in AutoDesk AutoCAD 2018.

The increase in points LEED experiences is minimal. The additional point gained stems from increasing the habitat on the green roof for urban wildlife through vegetation selection. Even this credit may not be achievable when balanced with the Open Space credit that encourages human use in the space. LEED achieves the most points under *LEED Emphasis* and does not improve or detract from SITES and WELL certification. Under *LEED Emphasis*, plants are chosen based on their hardiness and require little to no irrigation. The alternative emphases introduce a greater range of plants that will require some irrigation to support.

Evaluation of the *SITES Emphasis* is difficult due to the ambiguity of the Optimize Biomass credit. In theory, the *SITES Emphasis* should have the greatest range of plant biodiversity and therefore should gain more points from this credit than the other emphases. The SITES credits known to be achieved are a result of the area of the green roof and that the green roof is the only stormwater control on Hillside. Without a more nuanced understanding of the Optimize Biomass credit, the advantages and disadvantages of the *SITES Emphasis* are difficult to evaluate.

Without additional infrastructure in pursuit of WELL certification, the achievement of two more credits is not cost-effective. To achieve those two more credits, the substrate must be thickened to be able to support trees, which also requires structural reinforcement and a taller wall around the roof to hold the extra substrate media. Emphasizing WELL lowers the amount of points LEED achieves and does not improve the number of points SITES achieves. WELL certification is not feasible for Hillside Auditorium.

The final design does not increase the amount of points earned for any of the sustainable rating systems. Despite this lack of improvement toward certification, the final design represents a more holistic approach than any individual emphasis does. Since the green roof design is enhancing the benefits of the green roof, it may be important to display the specific impacts of the green roof in addition to advertising any sustainable rating system certification.

Table 9. Summary of the credits achieved under each redesign emphasis. Current scores for SITES and WELL as well as scores for redesign concepts are estimated. The prerequisite for WELL contributes to the WELLness score, but the prerequisites for LEED and SITES do not contribute to scoring.

Rating System		Emphasis of Redesign			
LEED v4.1	Current	LEED	SITES	WELL	Final
Sustainable Sites					
Protect or Restore Habitat	0	2	2	0	2
Open Space	1	1	1	1	1
Rainwater Management	0	0	0	0	0
Heat Island Reduction	2	2	2	2	2
Water Efficiency					
Outdoor Water Use Reduction (Prereq)	Prerequisite	P	P	P	P
Outdoor Water Use Reduction	2	2	1	0	1
Total Achieved	5	7	6	3	6
SITES v2					
Water					
Manage precipitation on site	(Prerequisite)	P	P	P	P
Manage precipitation beyond baseline	(0)	0	0	0	0
Design functional stormwater features as amenities	(5)	5	5	5	5
Soil + Vegetation					
C4.8 Optimize biomass	?	?	?	?	?
C4.9 Reduce Urban Heat Island effects	(4)	4	4	4	4
Human Health + Wellbeing					
C6.4 Support mental restoration	(0)	0	0	0	0
Total Achieved	(9+?)	9+?	9+?	9+?	9+?
WELL v2					
Mind					
Access to Nature	(Prerequisite – 1)	P – 1	P – 1	P – 1	P – 1
Restorative Spaces (Pt. 2)	(0)	0	0	1	0
Enhance Access to Nature	(0)	0	0	1	0
Total Achieved	(1)	1	1	3	1

5. Discussion

5.1 Questionnaire Administration

The development of the questionnaire was based on the Jungels and the Fernandez-Canero studies. The UA study reported generally similar but slightly more positive perceptions and attitudes toward the green roof than the Jungels study. Some factors may have led to this discrepancy. The Jungels study reported all their respondents were between 6 and 15-meters from the green roof of interest

(Jungels, et al., 2013). Respondents in the UA study were much further away from their respective green roof. While participants may have had a better grasp of how the green roof fits into the surrounding landscape, the wide range of distances from the green roof may have confounded the more nuanced aspects of the Specific Aesthetics section. Other factors of concern are upon completion of the questionnaire, some respondents revealed they had never noticed the green roof before, which does remark on how well the green roof blends into the surrounding landscape. The Greek-style theater is enveloped by green space, which the green roof extends onto the roof of the Hillside Auditorium. Other participants asked where the green roof was located or when it would be installed after they had completed the questionnaire. Future studies may plan to eliminate these latter studies from the final analysis, or first have respondents indicate their whether they know of the green roof under study; however, the complexity of also including an online questionnaire where respondent experience with the green roof could not be known encouraged the inclusion of all completed questionnaires.

Some further issues arise from statement specificity. As mentioned in the aesthetics results, Hillside Auditorium always has had a green roof, so respondents have no reference for how the green roof may improve or detract from the appearance of the building. This ambiguity in reference could impact the precision of responses. Future studies may want to focus on buildings who have been retrofitted to have green roofs. Surrounding environment is also important for contextualization of a green roof. The green roof on Hillside Auditorium is located on a landscaped college campus in a low-density college-town. Many respondents indicated their current living environment as urban (89.2%, from Table 4), but Fayetteville is hardly urbanized. Instead of using “Urban,” “Rural,” and “Forested” as response options for living environment, perhaps an indication of the population of a respondent’s living environment could provide more clarity of the most familiar living environment to them.

5.2 Questionnaire Analysis

As with any questionnaire asking respondents to self-report thoughts (Schwarz & Oyserman, 2001), we assume each prompt was understood and interpreted similarly by the entire respondent population but recognize the potential for questionnaire prompts to approached in varying manners by the respondents. The UA study recorded favorable perceptions and attitudes toward the green roof on Hillside Auditorium. The aesthetic of a building affects the perception of the building and the perception of the greater neighborhood of a building. As green infrastructure projects such as green roofs become more common in response to climate change-exacerbated environmental concerns, an understanding of the perception of the green infrastructure is important to help guide the development of green infrastructure design. Fernandez-Cañero et al. (2013) concluded people like well-maintained green spaces best. The UA study reveals congruency with the surrounding landscape is also coherent with favorable viewing.

5.3 Questionnaire Results into Sustainable Rating Systems

Beyond the aesthetics of a green roof, it is important for the purposes of this study to analyze the feasibility of constructing a green roof that can achieve a multiplicity of credits available. Many credits in WELL and some in LEED and SITES require physical accessibility, which is more common for intensive green roofs. The variety of vegetation available to intensive green roofs also creates a more dynamic area for human occupation. A roof with trees allows for a mix of shaded and sunlit areas, and shrubbery arrangements can create pockets of space. The mental restoration credits of SITES and WELL depend on the creation of these secluded, peaceful places of respite. Balancing well-maintained places of comfort for humans without rendering the green roof an ineffective stormwater control and heat island mitigator is critical for synergizing LEED, SITES, and WELL.

When installing a green roof in pursuit of LEED, SITES, and WELL certification, it is easier to design the green roof into new construction plans than to retrofit an existing green roof. As demonstrated by the redesign concepts in Section 4, retrofitting a preexisting roof is not conducive to earning additional credits. This obstacle is due to a couple of factors. Location of the green roof may affect rainwater retention and visual accessibility. A significant piece to achieving credit in all three certification systems depends on substrate depth. Substrate depth dictates what amount of water can be retained and increases the variety of plants available to the green roof design. Designing a green roof with foreknowledge of the location of windows for interior viewing and flow of the watershed on the site can help maximize wellbeing and water management credits.

Though intensive green roofs are more likely to achieve the multiplicity of criteria available in LEED, SITES, and WELL, extensive green roofs serve several advantages. Extensive green roofs are cheaper to install, require less maintenance, and have more flexibility (Fernandez-Cañero, et al., 2013). Though the three sustainable rating systems could encourage more sustainable development, not quite achieving a credit is better than not attempting to achieve a credit. In the latest LEED updates, the threshold for achieving water management credits was lowered to encourage projects to attempt to achieve the credit. A scoring system that acknowledges small improvements toward sustainable development without sacrificing the integrity of the more developed projects could be considered for universal application. Such a system would require all development projects to be scored for an accurate representation of the spectrum of development projects.

However, while the results indicate respondents are supportive of investment in green roofs, it is unclear if respondents would react favorably to installing a green roof at their home. Though the UA study and other studies suggest individuals appreciate the aesthetics of green roofs, this aesthetic value may be context dependent (Smith & Boyer, 2007). This study fails to address perceptions of green roofs in the residential sphere. An analysis of LEED for Homes projects could elucidate the prevalence of cataloging green practices at residences. Further research into green roofs in residential sectors will be necessary to determine how receptive people are to green roofs in private spaces. Combining the environmental and social benefits cataloged by sustainable rating systems with literature touting the aesthetic quality of green roofs creates an arena in which green roof installation may increase.

Another step to introducing the multiple benefits of green roof installation could be the creation of educational signage on existing green roofs. The UA study reports a significant difference in attitudes toward green roofs between those who are familiar with green roofs and those who are not (Table 8). The Hillside Auditorium is well-suited to have a sign drawing attention to the green roof. A sign could not only draw the eyes of passersby to the green roof and share the characteristics of the green roof but could also discuss the major advantages and disadvantages of installing a green roof in general.

6. Conclusion

Respondents indicated favorable perceptions and attitudes toward the green roof on Hillside Auditorium. However, the advantages and disadvantages of green roofs are not well known. People who were classified as *familiar* comprised only 19% of the respondents but were significantly more likely to support green roof installation (Table 8). Perhaps more important to public perception of green roofs than their aesthetic is educating the public about green roofs (Figure 4).

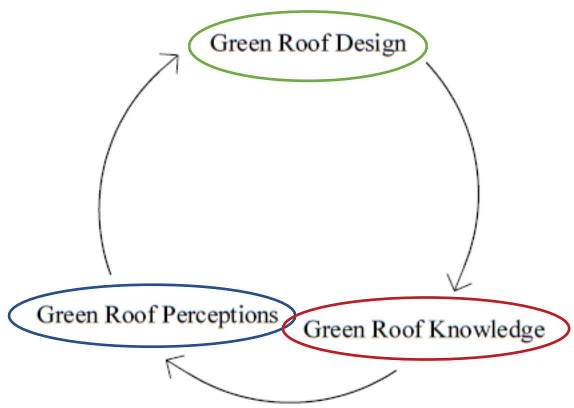

Figure 4. Demonstration of the possible positive feedback loop. Cultivating green roofs with good aesthetics may lead to more green roofs, which would increase green roof knowledge. Green roof knowledge has been reported to correlate positively with green roof perceptions (UA Study), which could lead to more green roof design.

Green roofs can positively impact LEED, SITES, and WELL projects, though the impact of a green roof on WELL projects is limited. It is important to note a green roof installation mostly impacts LEED and SITES projects through the same types of credits. About half of the credits for LEED (5 of 11) and SITES (10 of 23) are earned through stormwater management effects and urban heat island reductions and may be redundant. The environmental similarities of LEED and SITES with the wellbeing credit similarities between SITES and WELL suggests that pursuing LEED, SITES, and WELL certification for projects with green roofs is not necessary from a holistic standpoint. A project achieving LEED and WELL certification would have environmental and social measures considered. However, achieving all three sustainable rating systems would give some plausible indication of which credits were earned during the certification process. Furthermore, the similarities mean a green roof installation for a LEED or WELL project would also jumpstart a SITES project.

There are several challenges to redesigning a green roof layout. Preexisting access and a thicker media enable some redesign to occur on Hillside Auditorium. Thickening the media of the green roof on Hillside could help retain greater percentile storms and earn LEED and SITES credit, but without additional ground stormwater measures, rainwater management credits are out of reach. Cultivating a variety of native plants on the green roof could earn Protect and Restore Habitat credit in LEED through biodiversity initiatives and Optimization of Biomass credit in SITES. Enabling public access to the green roof with areas of refuge could also earn LEED and SITES credit and jumpstart the WELL certification process for Hillside Auditorium. The most crucial aspect of the roof for improvement is the effective loading capacity to allow for a range of vegetation and ensure the green roof can support continuous human interaction. If the roof cannot support the additions, then redesigning the roof will not achieve many more credits.

Applying a synergistic model of sustainable rating system certification is more feasible for intensive green roofs than for extensive green roofs. While extensive green roofs can meet several LEED and SITES credits, an intensive green roof design will be necessary to maximize credits in those sustainable rating systems and to achieve credits in WELL.

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Appendix A

The following three pages are a copy of the questionnaire distributed on-site that is IRB approved.

Evaluating Human Perception of a Green Roof

Kanaan Hardaway, Biological and Agricultural Engineering undergraduate

khardawa@uark.edu

Dr. Benjamin Runkle, Assist. Professor, Biological and Agricultural Engineering

brrunkle@uark.edu

This study intends to measure social performance of the green roof on Hillside Auditorium. If you have any questions about the project, contact me or my mentor through the information listed above. I am a student working under an Honors Research Grant in collaboration with a group measuring the environmental health of the green roof on Hillside Auditorium. Your participation through this questionnaire will teach me more about common knowledge of the impact of a green roof. The study consists of a questionnaire that should take about five minutes.

There are no known risks in the study. There is no direct benefit, but your participation helps further the knowledge of sustainable and resilient urban development. Any information you provide will be maintained in a secure manner. Your responses to the questionnaire will not be attached to your identity in any way or form and will be kept confidential to the extent allowed by law and University policy. You are free to refuse to participate in this research project or to withdraw your consent and discontinue participation in the project at any time without penalty or loss of benefits to which you are otherwise entitled. *My completion of this questionnaire implies my consent to participate in this research.*

If you have questions or concerns about your rights as a research participant, please contact Ro Windwalker, the University's IRB Compliance Coordinator, at 479-575-2208 or irb@uark.edu.

This study has been approved by IRB number 1902177442.

Questionnaire

Preferences Please indicate your response with an X or √.

General Aesthetic Reactions

Please indicate your level of agreement with the following statements:	strongly disagree	disagree	neither agree ~~or~~ disagree	agree	strongly agree
The green roof blends well with the surrounding landscape					
The green roof improves the appearance of the building					

Specific Aesthetic Reactions

To what extent do you feel that the green roof is:	very little	little	somewhat	much	very much
Dull, unattractive					
Fresh, innovative					
Full, lush					
Messy, overgrown					
Bare, sparse					
Out of place, strange					
Clean, tidy					
Beautiful, vibrant					

Preconceptions

To what extent do you feel that green roofs:	strongly disagree	disagree	neither agree ~~or~~ disagree	agree	strongly agree
Have expensive maintenance costs					
Act as a barrier against noise					
Provide a new green space for recreational use					
Encourage the proliferation of insects and rodents					
Help to manage the stormwater runoff					
Improve thermal insulation of the building					
Have high installation cost					
Reduce air pollution					
Increase longevity of the roof membrane					
Mitigate the heat island phenomenon in the city					
Achieve greater energy efficiency in the building					
Cause problems for people with allergies					
Increase biodiversity in urban areas					
Make it possible to cultivate vegetables, fruits and ornamental plants					
Have a high consumption of water for irrigation					
Create problems of dampness					

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Attitudes

Based on your knowledge of green roofs please indicate your general attitude toward them:	very unsupportive	unsupportive	neither supportive nor unsupportive	supportive	very supportive
Attitude					

To what extent do you agree that:	strongly disagree	disagree	neither agree or disagree	agree	strongly agree
The benefits of green roofs outweigh the costs					
I would like to see money spent on building more green roofs					

Sociodemographics

Please indicate the following				
	Male	Female	Prefer to self-describe	Prefer not to respond
Gender				
	Less than 18	18-25	26-40	More than 40
Age				
	Highschool or less	Some college	Bachelor's degree	Graduate degree
Educational attainment				
	Student	Faculty	Staff	Campus visitor
Status				
Department (if applicable)				
	Urban	Rural		Forested
Childhood living environment				
	Urban	Rural		Forested
Current living environment				

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