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Do sustainable buildings inspire more sustainable buildings?

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Abstract

Sustainable buildings offer numerous social benefits including improved health and productivity for occupants. This study adds to this growing body of knowledge to suggest benefits extend to influence occupant consideration for sustainability. In an undergraduate civil engineering senior “capstone” course, students were given a mock request for proposal to design a new campus building. Over the course of a semester students (n=120) worked in groups of four to develop detailed drawings including documentation for Leadership Energy and Environmental Design (LEED) certification of Silver or better. Class sections were randomly selected to work within a newly constructed LEED Gold building or a 60-year-old engineering building. Among these groups, students who worked in the LEED building were more likely to achieve a higher LEED score on their final project (p=0.04). Scores were less varied, more likely to meet the Gold standard and likely to include similar features as the building they were designing within. Students’ final grades were compared and found not significant (p=0.3). These results suggest working within sustainable buildings can influence design considerations for more sustainable buildings.

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1. Introduction

There are many benefits to sustainable buildings that include reduced energy and water consumption [1], higher occupancy rates [2], and improved physical (e.g., reduce colds and infections) and psychological (e.g., reduce fatigue) health [3]. Sustainable design combines technological advances like high performance ventilation systems to reduce respiratory illness [4] and more nuanced opportunities like overhead or desk lighting to reduce computer glare, which is attributed to headaches [5]. Considerations for building orientation and window placement can also

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have a dramatic impact. Windows that face green space enhance occupant comfort [6] and mental focus [7]. Incorporating these numerous approaches is estimated to improve productivity rates compared to conventional buildings by more than 20 percent [8].

The interface between building systems and occupants is also a critical aspect for sustainable design. The key is to balance energy strategies with form and function. Buildings that are energy efficient may reduce carbon emissions but if these buildings are less comfortable they can lead to negative associations with sustainability from occupants [9]. Building form can also affect occupant decision processes. Variation in ceiling height correlate with consumer purchases [10] and the type of office furniture can enhance or distract from workplace collaboration [11].

Design considerations for sustainability require making complex tradeoffs between environmental concerns, comfort, and well being. To help make these decisions, designers and engineers can use rating systems, like Leadership in Energy and Environmental Design (LEED), and others, to guide project team consideration for sustainability in site programming, building layout, and identifying energy efficiency goals [12]. LEED provides a metrics to compare alternative options and justify decisions. There are also external benefits for using LEED. Buildings labeled with LEED command higher occupancy rates and higher lease prices [13]. While the LEED rating system is not comprehensive of all aspects of sustainability these higher prices suggest commercial clients, and the public, value such rating systems, which substantiates using the metrics in the decision process [14].

Whether LEED is used for external reasons (e.g., signaling sustainability to others) or internal (e.g., perceived value for occupants) [15] increasing the designers motivation to achieve a high LEED score is likely to improve building performance. LEED buildings that achieve a mediocre score can vary dramatically in energy and water use performance but highly rated LEED buildings always perform better than conventional buildings [16].

More sustainable buildings that meet a high LEED score, compared to conventional buildings, provide social, economic, and environmental benefit. To encourage more highly sustainable buildings this research investigates if engineers are influenced by the physical space during the design process. Similar to how the physical space can enhance occupant comfort and mental focus, can the physical space influence engineers' design consideration for sustainability? Answering this question can help design engineers become more aware of their design choices. Understanding how the physical space influences their design decisions, those who are interested to incorporate or reach higher levels of sustainability can intentionally seek out these positive benefits of sustainable buildings.

1.1 Leadership in Energy and Environmental Design

In this study, the use of LEED buildings is to inspire occupants, in this case, engineers to consider more sustainable design when planning a new commercial building. LEED is used because of its wide application in industry. LEED awards points in five categories: Sustainable Sites, Water Efficiency, Energy and Atmosphere, Materials and Resources, and Indoor Environmental Quality. The Sustainable Sites (SS) category rewards decisions that integrate local and regional systems, that includes transportation services and natural systems for biodiversity. The Water Efficiency (WE) category addresses indoor and outdoor water use with increasing points for reducing consumption. The Energy and Atmosphere (EA) category approaches energy from both efficient design methods and renewable energy sources. The Materials and Resources (MR) category focuses on the life cycle of products awarding points for minimizing extraction, processing, transport, and disposal of building and construction materials. And Indoor Environmental Quality (IEQ) category rewards buildings that improve air quality and thermal and visual comfort.

2. Hypothesis

The hypothesis is the physical space during the design process will significantly impact engineers' consideration for sustainability. Designing a new building inside a highly rated LEED building will encourage engineering design teams to reach for similarly higher levels of performance. The null hypothesis is the physical space will have no measured affect on engineering design for sustainability. Sustainability is quantitatively measured using the LEED rating system for New Construction v3. An engineering team that reaches a higher LEED score is considered to have met a higher level of sustainability for the purposes of the study. Statistical significance is set to an alpha of less than 0.05.

Control and intervention groups of engineering students were chosen at random. The tested hypothesis is the physical space during design influences decision making and consideration for sustainability. The control group designed their building inside a typical engineering building similar to many buildings on college campuses built around the 1950's and the intervention group completed their initial design in a newly constructed LEED Gold building.

3. Methods

In an undergraduate civil engineering senior "capstone" course students were given a mock request for proposal for a new campus building. The proposal asked for the architectural, structural, and site design of a two to three story, 15,000 to 30,000 square feet, commercial or educational facility. The proposal required all civil aspects of the facility, including design of the structure, storm water impact analysis, drainage system design, site development work, grading and earth work calculations and cost estimates and schedules. The proposal excluded electrical and mechanical system design. Students also had to consider traffic flow and parking, handicap accessibility, county codes and university standards. A university standard that affected the project was all new facilities over 5,000 gross square feet and major capital renovations shall seek to acquire a LEED Silver rating at minimum.

Students were instructed to incorporate sustainability into the design and construction planning using the LEED checklist; and persuade the capstone stakeholders of the benefits of the LEED requirements. All projects had to reach the minimum 50 points or greater using LEED v3 rating system for New Construction (NC). Students were told to detail how they planned to meet the required credits and provide a list of references. Instruction was provided about LEED categories and examples of how to meet each credit. Students that met, for example, LEED NC credit *WE 1: Water Efficient Landscaping* provided a list of local plant species with specifications about each plant along with a local nursery that offers these species and the cost to include them in the project. Not all credits were as straight forward. Some credits were slightly modified for students to more easily evaluate. For instance, credit *EA 2: On-site Renewable Energy*, students used the energy consumption of a similar building in size and purpose already on campus as the baseline energy use of their proposed building.

Like credit *EA 2*, six other the LEED credits were slightly modified for students to more quickly evaluate their project design. For instance, teaching students and expecting them to complete an energy simulation of their building to meet credit *EA 1* exceeded the objectives for the course. Instead students were recognized for optimizing energy performance by increasing the R-value of insulation in the exterior walls, reducing the number of west facing windows, optimizing interior and exterior lighting, and including automatic light sensors.

The LEED section of the project was graded based on effort to meet the LEED requirements for Silver or better. A student who provided adequate explanation for all 50 credits achieved a similar class grade as a student who adequately met 60 credits. Similar to the university standard, there was no incentive to go beyond the minimum requirement. Projects were evaluated based on completeness. A student was only deducted points for not providing enough information to explain or illustrate how their project met a listed credit. Credits without sufficient detail were removed from the rating score card and not included for analysis.

Students worked in groups of four over 15 weeks to develop detailed architectural, structural and site drawings including documentation for LEED. One student from each group led a specific portion of the project. Each team included one student structural engineer, transportation engineer, storm water engineer, and cost and scheduling engineer. The team as a whole directed which LEED credits to pursue. The cost and scheduling engineering student coordinated with their team members to ensure these credits were represented on the team drawings and documentations.

Four faculty members provided instructional assistance through the 15 week course and reviewed each project twice, approximately at week 7 and 15. The final project deliverables were graded by the four faculty members as well as four industry professionals. In total, eight professional engineers reviewed the students design and documentations, including the LEED documentation. None of the industry panel were aware which teams were from the control or intervention group.

3.1 Design Process

In week one, student teams were given their initial proposal documents, course requirements and visited the project site. The building design had to meet size, height and use restrictions but the purpose was decided by individual teams. Building purposes ranged from restaurants to student study centers to alumni halls of fame.

In week two, a charrette was held to encourage teams to consider more sustainable design and construction methods. A charrette is typically a series of collaborative sessions to draft a solution to a design problem. Charrettes can traditionally last one to ten days of iterative design-review processes. In this experiment, a condensed half day charrette was held to quickly generate a design solution that integrated sustainability and incorporated all group member ideas. Consideration for sustainability meant passive solar design methods, building materials (e.g., white roof, porous paving systems), natural lighting, building technologies (photovoltaics, automatic windows for natural ventilation), and construction methods like reducing the disturbance of soil on the site and recycling programs. The topics that were included loosely followed the requirements for LEED because this was the university standard students were required to meet.

At the time of the charrette students had a concept for their building's purpose but had not started the design process. By the end of the half day charrette student teams left with conceptual hand drawings and a list of features for their building relevant to LEED credits.

3.2 Buildings: LEED or Non-LEED

The design charrette occurred in either Lowry Hall or Lee Hall. Lowry is listed on the National Register of Historic Places in South Carolina. The building was completed in 1958 with minimal upgrades since its completion. The building is similar to many buildings built in the 1950's across college campuses. It has a brick exterior façade, faded interior tile floors and yellowed tile walls. The furniture is typical of the 1950s. Individual desks are still bolted to the floor. Chalk boards and overhead projectors are in every room. The building provides limited natural light to the front of the building and there are problems regulating indoor air temperatures. Lowry was not designed to meet LEED standards.

Lee Hall completed construction in 2012 and currently holds the title for largest green roof in the Southeastern United States. Other features include controlled daylighting and natural ventilation. There are a total of 53 skylights each with automatic shading to regulate radiant heat. Windows span 30 feet and allow for 95% of the interior space to have outdoor views. Additionally, a closed loop 100 ton geothermal well cools the building with no mechanical refrigerant. This is the first building in the world to incorporate a radiant slab floor in a mixed humid climate. A large percentage of Lee Hall's site is covered with pervious material. These surfaces allow storm water to transfer into the ground instead of municipal treatment systems. Lee Hall achieved LEED Gold with 64 out of a possible 110 points.

3.3 Experimental Procedure and Analysis

In the fall and spring semester 30 teams (13 teams in the fall and 17 teams in the spring, 120 students) participated in the capstone course and experiment. Two charrettes were held at the beginning of each semester. One in Lowry and Lee. Teams were randomly assigned to each location. In total, 18 teams were assigned to Lee and 12 teams to Lowry. Charrettes were held the same week. Each group followed the same procedure and received the same materials. The only difference was the physical location of the charrette. Students in Lee were not aware which credits the building achieved. However, design aspects associated with LEED were apparent when inside the building. For example, daylight and views are noticeably greater than in Lowry. Students toured the building just prior to their charrette. Mechanical, pluming, and lighting systems were pointed out to the students during the tour. The student groups in Lowry did not see the sustainable design features apparent in Lee. The teams who completed their initial design in Lee spent the remaining 14 weeks in Lowry to complete their design.

LEED scorecards from each team were used to measure consideration for sustainability in design. Scorecards were grouped by location of the charette. A Mann Whitney U-Test was used to compare the distributions of certification levels (i.e. certified, silver, gold and platinum). Individual credits were assessed using an independent t-test, Mann Whitney U-Test and Chi-squared test. The independent t-test was used for credits with continuous variables. For instances, *EA 1* is a range of points possible between 0 and 19. The Mann Whitney U-Test was used for credits with an ordinal range within a ranked category. For example, a building design can achieve 0, 2 or 4 points for Water efficient landscaping (*WE1*). The Chi-squared test was used for the remaining credits with binary responses. For these credits the design team either achieves 1 or 0 points. As stated in the hypothesis, the expected results are design teams in Lee will achieve more LEED points, indicating that the physical space affects consideration for sustainability. Student grades were also assessed to control for possible significant difference in

LEED scores. An independent t-test was used to compare student final grades. Student design documents and LEED scorecards were reviewed at the preliminary phase (appox. week 7) and the final design (week 15).

4. Results

Sustainable buildings appear to inspire more sustainable building design. Students who completed their preliminary design in the newly constructed LEED certified Gold building outperformed students in the control group for achievement in sustainability. Mean scores averaged four points higher for the group in Lee, the LEED certified Gold building, compared to Lowry, the traditional building. Students in Lee median scores were eight points higher. The students in Lee were statistically more likely to achieve Gold certification than the other group (p=0.04) shown in Table 1. These students also had less variation in their total scores (SD=5) compared to students in Lowry (SD=10).

Outliers were considered and defined as a total score outside two standard deviations from the mean. One outlier was identified in each group. However, removing outliers increased the significant difference between groups (p=0.02). Table 1 includes these outliers to report the original results. By removing the outliers, the mean score for Lee is 61 points and Lowry 56 points. The standard deviation becomes 4 and 7 points, respectively.

Table 1. Designing in a LEED rated building increases design consideration for sustainability.

Building	Mean	Median	Stdv.	p-value
LEED	62	62	5.25	0.04
Non-LEED	58	54	10.29	

Students in Lee included similar building features as included in the building they were designing within. Credits related to energy, daylighting and the site were achieved at a higher rate. Credits listed in Table 2 are binary, meaning students either chose to incorporate them or not. This is different than credits like credit *EA 1: Energy Performance* where building designs can meet a range of points. The EA credits related to commissioning (*EA 3)* and verification *(EA 5*) are likely higher because more students in Lee included geothermal systems and incorporated passive design strategies compared to students in Lowry (a rate of 50% more however not all passive design strategies are represented in the LEED rating system therefore the increase in scores is not quite as high).

The building location was the same for all groups, yet, more students who designed their building in Lee included (*SS 4.1*) public transportation access documents in their final submittal. Sustainable Sites credits 6.2 and 7.1 include storm water control quality and heat island effect non-roof. Lee, the LEED Gold building, includes both onsite bio-swales and gravel hardscape (rather than asphalt or concrete). Students completing their design in Lee were slightly more likely to include these features in the SS 6.2 credit for storm water design quality control and 7.1 heat island effect non roof. Lee also includes outside views from more than 95% of the building. Students who designed their building in Lee were 20% more likely to incorporate daylight views (*IEQ 8.2*) compared to students in Lowry.

Table 2. Student teams were more likely to include LEED credits when designing from a LEED rated building.

Credit	Non-LEED	LEED	Increase
EA 3	75%	95%	20%
EA 5	0%	78%	78%
SS 4.1	0%	89%	89%
SS 6.2	17%	33%	16%
SS 7.1	33%	50%	17%
IEQ 8.2	8%	28%	20%

Credit *EA 2: Onsite renewable energy* ranges in score from 0 points (no renewable energy) to 7 points (13 percent renewable energy). An independent t-test was used to measure statistical difference in scores for this credit because points are nominal and normally distributed. Students in Lee were statically more likely (p=0.005) to include renewable energy. The mean score for Lee was 4 points, meeting slightly more than half the total possible points. Students from Lowry averaged 1 point.

Student grades were also considered and investigated to identify if a higher LEED score correlated with a high grade. There was no significant difference between groups (p=0.3). Students in Lowry averaged a final grade of 90% and students in Lee averaged a final grade of 87.5%. A difference in grade was not expected because a student that provides documentation for all LEED points but only achieves 50 points would score a similar grade as a student who equally provided documentation for 60 points. There was no incentive to meet a higher level of LEED points than the minimum required 50 for LEED Silver. Yet, the results indicate working inside a highly rated LEED building provides additional motivation to do so.

5. Discussion

Benefits of sustainable buildings for its occupants may extend to include positive implications for the design and decision process for sustainability. Results suggest sustainable buildings lead to more sustainable building design. Teams comprised of fourth year civil engineering students were more likely to design a building that met a higher LEED score when they completed their initial designs in a highly rated LEED Gold building. Team designs included building features similar to the building they were designing within. The increase in average score was only four points, however the difference in rankings (i.e. Silver, Gold, Platinum) was significant. The student engineering teams designing from the LEED Gold building were more likely to meet LEED Gold for their building compared to other design teams who met LEED Silver. Had the requirement to meet LEED Silver not been assigned the difference between groups may have been greater.

The teams who completed their initial design in the LEED Gold building spent the remaining 14 weeks in the traditional building. Had these teams spent the entire 15 weeks in separate buildings, the sustainable building or traditional building, a larger difference may have also been observed.

The highly rated sustainable building may have provided additional motivation to meet sustainability requirements. For example, credit *SS 4.1 Access to Public Transportations* is not dependent on building design but rather site location and therefore equally applicable to all groups. Yet, much fewer teams from the traditional building included documentation for this credit. Also, observing how a building is able to meet certain credits may lead to higher achievement. Credit *EA 2: On-site renewable energy* can be met by incorporating photovoltaic (PV) panels on the site. Teams that designed their building in the LEED Gold building, which is outfitted with electrical equipment for PV panels, were more likely to include PV panels in their design. Similarly, the teams designing in the LEED Gold building were more likely to meet credits for storm water quality control and reducing heat island effect, which were represented as a vegetated roof and porous hardscapes around the building.

The time spent on the charrette process and in the LEED Gold certified building was at most 5 percent of the total design time as indicated in Table 3 but appears to make a significant positive impact towards sustainability. The teams who received the intervention spent roughly four hours at the beginning of the semester in the LEED Gold building. The remaining minimum required time to complete the design was 56 hours (a 4-hour lab for 14 weeks). Approximately 225 hours by each team (4 students each for 56 hours). Hosting the charrette in a LEED Gold building with many visible sustainable design features likely led to students' recognizing such design features were possible to implement and this was observed in the LEED scorecard.

The charrette process was the same for each student team the only difference was the physical space. Other interventions may have also helped teams consider sustainability. For example, simply showing a presentation about a sustainable building may have had a similar effect. Or spending the entire semester in the LEED Gold building may have increased the measured affect even more. Designing within a highly rated building and witnessing the design features in person seemed more likely to influence design decisions than a presentation but spending the entire semester in the building, while possible for this experiment, is less likely to be applied in industry. Moving to a new space for consecutive weeks to complete a design is not likely but holding a brainstorming session or kick-off meeting might be possible.

Table 3. Less than 5% of design was spent in LEED rated building but significantly improved outcomes for sustainability.

Capstone	Total Hours for Design Charrette	Minimum Remaining Design Hours	Percent of Design Hours in LEED Building
Each Student	3	56	5%
Team Total	12	224	

Other methods could have been used to evaluate building design for sustainability but LEED was chosen as the assessment tool because it includes a large range of sustainability aspects and is used extensively by industry as a benchmark. Some design strategies like passive heating and cooling are poorly represented. A negative of using LEED for assessment are strategies like non-asphalt white roof and a vegetated roof are drastically different in design and cost but are represented under the same LEED credit for reducing heat island effect.

The student projects mimicked the real world design processes as closely as possible. The course was led by four faculty members with industry experience and judged by four industry professionals. However, this is still a limitation of the study. Students lack experience compared to professional engineers. This lack of experience may contribute to the influence of the LEED Gold building during design. These students are senior engineers and will be making similar decisions in industry within months of their final project and therefore the results are still important to report. Students' age ranged from 21-25. All students had less than one year of work experience. Other demographic information was not recorded.

Student skills, background, experience and interests likely varied and this is likely reflected in their projects. Students were able to pick their teams. So, team dynamics also could have influenced sustainability performance. However, choosing which team received the intervention was done at random and students that performed better on other course assessments like grades were not more likely to have a higher LEED score.

Student engineering teams designing a new building for campus were more likely to achieve a higher LEED score and include similar design features as the physical space around them. The results of this study extend the benefits of LEED and sustainable design further indicating that simply working in this type of building translates to a significant positive impact when occupants are in the design process. The physical space appears to influence our design decisions whether subconscious or not. Being aware of this can help those in the design process make better choices. If the physical space influences design consideration, simply moving the design process or kick-off meeting to a more sustainably designed building may help consider more sustainable design features in the future.

6. Conclusion

Students who completed their initial design in a LEED Gold building were more likely to meet LEED Gold than students who completed their design in a non-LEED building. Based on students' final design documents, students who completed their initial design in the LEED building were motivated to achieve more points than students in the non-LEED building. Students in the LEED building likely recognized that high levels of sustainability achievement and design practices (i.e., daylighting, onsite renewable energy, reducing heat island effect) are possible and led them to include these features in their drawings. Yet, after the experiment, students did not believe the physical space had an affect on their design or decision process.

The results from this empirical study suggest that simply holding a preliminary design meeting in a building that includes inspirational design features for sustainability may encourage design teams to reach for similarly high levels of sustainability performance. In this study, less than 5 percent of the design time was spent in the highly rated LEED Gold building but the impact was measurable 15-weeks later in the final design and documentation. A similar intervention could be replicated in industry as a brainstorming session or kick off meeting. If the results in the real world are similar to the study findings, simply changing the physical space of these meetings could have a dramatic impact for sustainability. These results can help design engineers become more cognizant of their design choices. Recognizing that the physical space influences their design decisions, those who are interested to incorporate or reach higher levels of sustainability can intentionally seek physical spaces to help in their efforts.

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