CASE STUDIES IN SUSTAINABLE DESIGN AND THE MOTIVATION FOR ENHANCED METHODS AND TOOLS TO MEASURE ENVIRONMENTAL IMPACT

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Graham Farmer and Simon Guy asserted in their 2001 article, "Re-interpreting Sustainable Architecture: The Place of Technology" that the emblematic issue in building design [arguably remains[1]] how to represent the epoch shift of the new millennium and the transition to a holistic, ecological worldview or zeitgeist (Farmer and Guy 2001). Hallmark enthusiasm in this, the era of "new sustainability", signified by novel, high-tech solutions designed to express our current, global condition and, in some cases, to actually mitigate them. However, while stretching the boundaries of material and systems technologies and building design *may* lead to more ecologically sustainable buildings, paradigmatic solutions are not *inevitably* eco-logical.

Environmental innovation and sustainability are ubiquitous terms in academic and practical discourse. Yet, differing approaches, fragmented priorities, and both technical and philosophical barriers remain to assessing the true ecological impact of our buildings. In many respects, the web of interrelated "priorities" – cultural, aesthetic, technological, sociopolitical, etc. – imitates the complex natural ecosystem that our buildings engage; as in nature, gains in one realm may, in fact, create losses in another. Regardless of the means – or the ends, though – our buildings must work harder and more effectively today than they have since the dawn of the thermostat – notwithstanding our evolving ideas of comfort and productivity in the modern age.

Despite the damning statistics[2], many continue to prioritize architectural form that expresses our heightened ecological consciousness over building performance. Just as Charles Jencks accepts that "good ecological building may mean bad expressive architecture," (Jenks 1995) surely the inverse can also be true. Expressive architecture is not *necessarily* good building. Contemporary, commemorative architecture is not automatically, inevitably ecological, is oftentimes at odds with the cultural values of individuals and place, and, perhaps most tangibly, may actually be more energy-hungry: as buildings become progressively more energy efficient, "the ratio of embodied energy consumption to lifetime operating energy consumption becomes more significant" (Canadian Wood Council 1997).

According to a study conducted at the Earth Institute at the University College Dublin, the embodied energy of materials used in a structure can constitute nearly half of the life-cycle energy use of a "low energy" building (Hernandez and Kenny 2010), particularly as the energy tied to the manufacture of energy-intensive building materials – most of which are manufactured off-site – accounts for 75 percent of the total energy embedded in buildings – and this number continues to rise (Ding 2004). What are the costs – the consequences, even – of novel and often experimental building materials and methods of assembly? And how effectively are they currently being measured and considered alongside anticipated building energy use? Are the prevailing systems of measurement adequate, the industry-leading tools comprehensive enough and readily accessible to students and practitioners of architecture to enable truly informed decision-making, inspire knowledgeable adoption of nascent technologies, and ultimately influence the design and execution of genuinely sustainable buildings?

The authors have begun to examine this question through the development of a more accessible, efficient method of quantitative analysis of construction methods, materials, and principles of design; research that is simultaneously supported by and motivating the development of a novel digital design and analysis tool which will enable students and design professionals to critically and empirically evaluate and compare the broader impacts of their design decisions at every step of the building design process. This paper will present a focused series of case studies involving certified "green" built projects, analyses of how they are currently assessed, and empirical materials and methods analyses conducted using the novel methodology and Tool:

How Green Is Gold?

Comparative analysis of Geddes Hall, a new, LEED[3] (Gold; 2008) certified institutional building

The Placebo Effect and LEED

Comparative analysis of Loyola University of Chicago's Information Commons (LEED Silver; 2007)

As energy use tied to the building sector continues to rise, most of our attention is focused on finding ways to reduce direct energy use by buildings, their occupants, and systems through advances in building technology and renewable energy sources, the adoption of environmental policy initiatives, and the implementation of various methods of assessment. Accordingly, research, development, and the integration of emerging building technologies, materials, and methods of construction are evolving in-line with goals to reduce the energy-carbon impact of the built world. But some of these new technologies may have surprising up-front costs and involve lesser-known impacts to the environment (beyond their potential to reduce long-term energy consumption), prompting many to wonder if we ought to be more rigorous in our assessment and adoption of new technologies, especially those that purport to achieve enhanced performance.

What current research – and the tools available to both research and practice – lacks is the ability to holistically measure and evaluate building practices, from the commencement of the design process, to the selection of materials, the methods of their assembly, and the long term implications of one's design *alongside* building energy use. As the paper will describe, data collected from case studies generated as part of this research reveal that despite prevailing certification methods, there exist quantifiable differences between newness – in terms of advanced building technologies and design – and effectiveness, underscoring the need for more accessible and effective methods and tools for measuring, evaluating, and promoting the execution of truly sustainable building design; and inspiring much-needed critical examination of contemporary "green" building practices, many of which may be, in fact, completely at odds with long term sustainability.

HOW GREEN IS GOLD?

Geddes Hall, the subject of the first[4] case study, was awarded LEED Gold certification for New Construction in July 2009, under LEED v2.2[5]. In its application for certification, the approximately 65,000 SF classroom and office building is predicted to achieve over 32% savings in energy and water annually. These systems-based efficiencies and the use of some regional and recycled materials earned the project 42 out of a (then) possible 69 LEED credits. Despite achieving LEED's penultimate green status, however, the project does not involve any green or renewable power source and did not achieve any available credits for day-lighting. Per the objective of our research, to quantify the broader impacts of specific decisions made at the outset of the design process, the intent of this particular study was to determine whether the building ultimately executed can maintain its claims of sustainability, and if so, what does this reveal about the prevailing systems of assessment?

The primary wall assembly[6] for the structure as-built, or the Subject Case (Figure 1a), is a standard brick-CMU cavity wall wrapping a structural steel superstructure, with a total material embodied energy of approximately 7,093.14 MBtu[7]. When compared to an alternative wall assembly of load-bearing, triple-wythe brick[8], the total mate-

Figure 1a. (image at top) Geddes Hall, completed July 2009; Figure 1b. (image above) Revit™ model of Alternative Design on the same site. Image credit: Authors.

rial embodied energy for the wall assembly drops to approximately 5,217.82 MBtu. Although some of the steel used in construction included partially recycled content, the energy cost of virgin steel, which must still be included in a net-energy calculation, is still more than 8 times that of brick; in this case, steel contributes to approximately 38% percent of the overall initial building energy cost.

Our study acknowledges that the side-by-side comparison of the Subject Case wall assembly and the alternative assembly is problematic, given that the building footprint and structural system (50+ foot spans between load bearing devices) cannot be readily substituted with lower-tech materials. Therefore, an additional alternative design study considered the effects of necessarily reducing building depth while maintaining the gross square footage of the Subject Case by creating a U-shaped footprint (Figure 1b). Although the change in surface-area-to-volume ratio increased both the amount of materials needed and the area for potential heat loss, the lower embodied energy content of the net materials resulted in a significantly lower initial building energy cost. Compared to the 14,411 MBtu of EE estimated for the entire existing building, the design and material alternative cost approximately 8,909 MBtu. The amount of energy saved up-front could power the entire building for two years and save more than $40,000 in operating energy cost.

Unpacking LEED

To achieve its LEED Gold Certification Geddes Hall accrued 42 points, 2 of which were earned for having a LEED Accredited Professional on the project and for selecting a site that was not previously designated as a wetland, farm, or public park. The project earned an additional 8 points for existing transportation amenities common to many college campuses. For its location within walking distance of various community resources, Geddes Hall earned 1 point, and 1 more for maximizing open space (which included the existing, adjacent University quadrangle; see Figure 2). An additional 2 points were achieved for maintaining green areas on-site which use water-efficient landscaping – which cover a fraction (less than 15%) of the designated building site – while manicured lawn covers the remaining open space. Re-designating existing parking for carpools and 'green' vehicles earned 2 more points, as well as 1 more for bicycle storage, changing rooms, and showers, the latter of which post-occupancy evaluations reveal have yet to be used since the building opened in 2009. All 10 of these points - or nearly ¼ of the total points awarded – are unrelated to the building design itself.

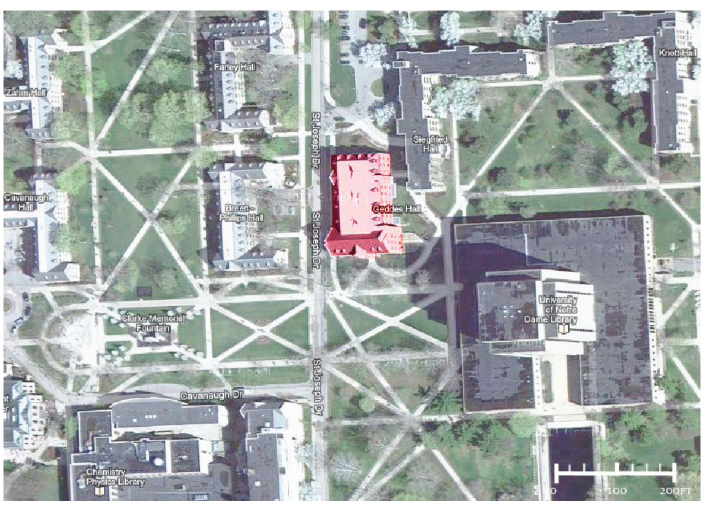

Figure 2. Site Plan of Geddes Hall (in red). Image: Google Maps, edited by Authors.

The majority of Geddes' LEED credits were achieved by employing advanced water and energy-saving mechanical systems. The project earned 7 of a possible 10 points for Optimizing Energy Performance[9], meaning that the design is projected to save around 32% more energy per year than the baseline model generated according to ASHRAE 90.1 2004[10] guidelines. This baseline model assigns walls and roof values of R12 and R16, respectively, and assumes a variable air volume system with hot water reheat. The proposed design (Subject Case building) simulates boiler and chiller performance for the campus power plant systems, while the baseline model assumes ASHRAE standard on-site boiler and direct-exchange chillers. The other differences between the baseline model and proposed design are the assembly R-values, which are actually R9 and R20 for the walls and roof (as designed), and a major reduction in volume for the fan and chiller systems[11]. Motion-sensored lighting and these enhanced mechanical systems are credited with an anticipated annual savings of 827 MBtu and 116,070 gallons of water through low-flow plumbing and conservative irrigation. Yet, given the difference in initial material embodied energy between the Subject Case and the Design Alternative, it would take almost 10 years for Geddes Hall as-built to save as much energy through the anticipated system-enhanced performance as the Design Alternative saved instantly through the selection of lower-energy materials and configuration. In addition, the Design Alternative could potentially utilize the same energy-saving mechanical systems, and perform even better, because of the potential to utilize natural daylight and ventilation throughout the building.

Geddes Hall doesn't appear to be modern, cutting-edge, or stereotypically sustainable – and yet it has achieved (what we have come to accept): qualified "green" status. What about a building that appears to be more advanced, uses more technologically advanced materials, methods, and systems?

THE PLACEBO EFFECT AND LEED

The focus of the second featured case study is the 70,000+ SF Richard J. Klarchek Information Commons, located on the eastern shore of Lake Michigan, in the heart of Chicago's Loyola University. Here architect Solomon Cordwell Buenz designed a pair of 150 foot glazed façades bound by pre-cast concrete-clad "bookends"; what has been characterized as a four-story glass box (Gonchar 2009). The broadest exposure of the existing, Subject Case building (Figure 4a) faces nearly due east, exploiting an (otherwise) unobstructed view of Lake Michigan.

Among the building's various novel design responses, the west-facing glass façade is a double-skin curtain wall with an average assembly R-value of 4.35 designed to engage and integrate many of the building's mixed-mode operating systems. The lakefront façade is a single-skin curtain wall with an average assembly R-value of 2.17. Included in its application for LEED status were the building's novel HVAC systems and energy conservation strategies, including higher than anticipated thermal performance, despite the fact that the average R-value for over 47 percent of the building – the glass curtain walls – is 3.26. And while post-occupation energy use exceeds ASHRAE's baseline (model referenced standard: ASHRAE 90.1-1999), the building's *actual* energy use is still notably higher than the design model (McLauchlan and Lavan 2010).

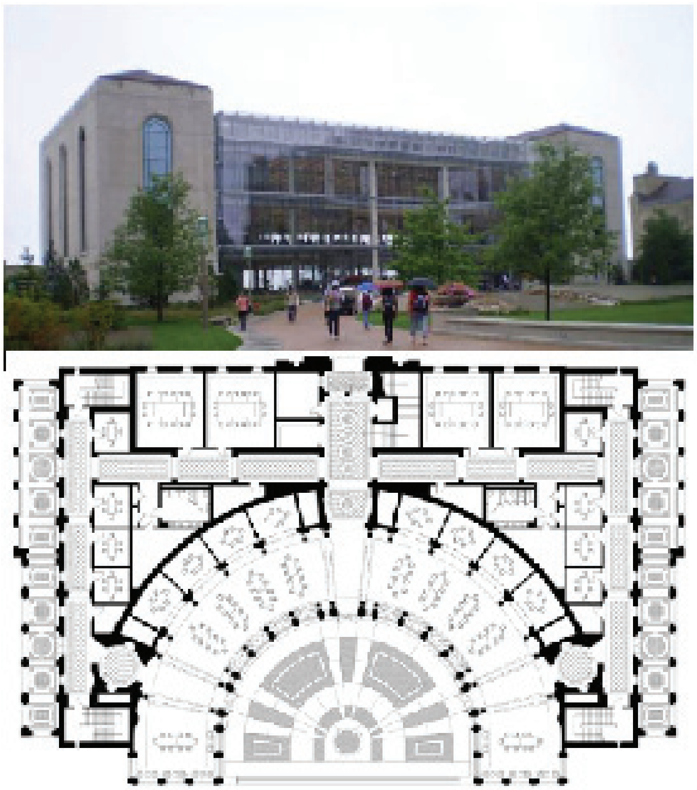

Figure 4a (image at top): Subject Case: Loyola University of Chicago's new Klarchek Information Commons (LEED Silver); Figure 4b (image directly above): Alternative Design Case Floor Plan. Images: John C. Mellor.

Our study of the IT Commons also included the evaluation of an alternative design (Figure 4b), a masonry structure of self-supporting limestone and brick façades (33 and 55 percent of the total façade surface area, respectively) in front of a single-wythe of structural reinforced concrete masonry. The average façade R-value for the Alternative Design Case, including punched openings (insulated glass; 13 percent of the total façade surface area), is 23.6. And while the total façade surface area of the Design Case is 10 percent greater than the total façade surface area of the Subject Case (44,605 SF: 41,034 SF) – by virtue of the alternative design's footprint (Figure 4b) – heat loss through the Subject Case's envelope is considerably greater: 462K BTU/hour versus 152K BTU/hour (calculated on a 15 degree day).

Beyond considering the thermal performance of the materials used, the estimated embodied energy (and water) involved in the execution of each Case was also studied. Due to incomplete information about the roof and floor assemblies of the Subject Case, and to maintain comparable side-by-side evaluations, the preliminary quantifications presented in this paper do not include the embodied energy calculations for the roof, floor, or foundation systems for either design. Conservative assumptions were made about the use of recycled aluminum in the subject building (20 percent recycled: 80 percent virgin), and the quantity of stainless steel cable, fittings, and connections in the curtain wall assemblies was estimated at 1000 lbs. The embodied energy calculation for the subject building does not include the 6,625 feet (or 1.25 miles) of silicone sealant used in the glass facades and joints between the precast panels.

While the existing façade has slightly less embodied energy than the alternative, 6027 mBTU versus 6526 mBTU, it is important to note two crucial influences: there is a 10 percent difference in total façade surface area between the two designs and the volume of brick masonry material calculated for the Alternative Design could be significantly reduced if a single-wythe brick veneer construction were employed in lieu of the multi-wythe self-supporting system included in our calculations (for durability). The use of recycled brick versus virgin material would also significantly reduce the net material embodied energy figure.

		Case Study	
		Loyola Commons	Geddes Hall
Category	Points Possible	Points Earned	
SS	14	2	10
WE	5	1	3
EA	17	11	7
MR	13	6	6
IEQ	15	9	11
ID	5	4	5
Total	**69**	**33**	**42**

Figure 5. Table comparing LEED credits earned by each project.

Unpacking LEED

The Loyola Information Commons earned 9 out of 10 possible points for Optimized Energy Performance – or a proposed 55% annual energy savings over the baseline model. Post-occupancy analysis revealed a significant omission in the baseline model calculations, the plug loads of approximately 300 personal computers and copy machines used in the purely digital research center. Annual energy consumption including these loads would reduce the savings initially anticipated and reported to the USGBC. The actual building performance is only 46% better than the baseline model, nearly 10% less efficient than anticipated. The plug load consumption, 1,692 MBtu/year, accounts for nearly one-third of the overall energy cost, a total 5,922 MBtu/year (McLauchlan and Lavan 2010).

The next largest credit allocation came from using low-emitting finish materials, employing carbon dioxide monitoring, and providing views for 90% of interior spaces. Remarkably, the project did not achieve the available credit for daylight in 75% of spaces, although nearly half of the façade is made of glass. Proper construction-waste management and materials sourced locally (only 20% of the gross budget) achieved an additional 4 points. The double glass curtain walls are utilized as thermal stacks that enable passive ventilation and can be combined with radiant cooling in the building's hybrid HVAC system. And yet, despite the operating benefits of these technologies, any gains must be evaluated alongside their net costs. The motorized sun shades, active day-lighting control, and mechanically operated windows all have associated material and operating energy costs that extend beyond the energy embodied in the multi-layer glass curtain walls that span nearly the entire east and west sides of the building.

THE STATE OF THE ART

According to the US's dominant system for assessing sustainable building practices, both Loyola Commons and Geddes Hall – demonstrably different structures - are models of sustainable design. So how well does this current system actually evaluate the ecological impacts of buildings constructed today? How effectively does it influence truly sustainable design practices? Just *how* green is a gold-rated building?

If submitted under the standards adopted in 2009 – the year it was completed – Geddes Hall would barely achieve LEED certification. The Loyola Information Commons, which achieved 33 out of 69 possible credits, was also certified under the previous version of LEED. Just under five years after its completion, the project could not be certified under today's LEED standard.

Today, systems and incentives to study the operating side of the energy equation far outweigh the means for measuring the up-front costs of the materials and methods used to achieve optimized building energy performance. This is related, in part, to rapid innovation itself, and the ability (and time) to test, measure, and track the performance of nascent technologies, and also the availability and use of existing metrics and analysis tools.

Currently, there is no universally accepted method or tool capable of holistically measuring the broader impacts of advanced technologies on the built and natural environment (Ortiz et al. 2009). Metrics-based rating systems, like LEED, the Environmental Protection Agency's energy management-focused Energy Star Program (US EPA 2010), and the energy use standards set forth by the ASHRAE (ASHRAE 2007), among others, are not written to evaluate the overall impact of a building's design and its systems, nor – and perhaps most importantly – the *broader impact of the technologies promoted to achieve certification or compliance*; as in the case of many LEED certified buildings, like those we presented here, that are able to achieve sustainable status despite being constructed primarily out of materials that are high in embodied energy and low in thermal performance.

These well-established guidelines undervalue the role of materials in whole-building impact analysis. For example, in the current LEED rating system, 58 out of a 110 possible points are available to be awarded if the design incorporates the use of advanced technologies such as photovoltaic cells or automated lighting systems. However, only 4 points are available for the reuse of an existing building and its interior non-structural components. A mere 4 points are additionally available if the design incorporates materials that are either salvaged or *incorporate* recycled content. In stark comparison, 5 points are awarded for designating priority parking for hybrid and fuel-efficient vehicles (while Well-to-Wheel studies indicate a range of thinking about the current net energy saving potential of these new technologies (DOE (a) 2011)). The category dedicated to Optimizing Energy Performance and atmosphere is worth 35 points alone; today, base LEED certification requires a minimum of 40 credits. The use of low-tech or passive materials and methods, like natural ventilation or the installation of native vegetation, may earn up to 14 points, but 12 of these points can alternately be achieved by utilizing advanced technologies. Yet material life-cycle analysis (LCA) is worth just one point, under a Pilot Credit in the Innovation in Design category (despite the long-standing and widespread practice of LCA in construction and other industries).

In addition, current life-cycle assessment practices are fragmented across disciplines, material databases are incomplete, and analysis tools lack the capability to accurately – or uniformly – quantify energy use tied to material extraction, production, transportation, and assembly *alongside* fundamental, site and climate-specific information and design decisions.

Prevailing digital modeling and whole building carbon analysis software, like Revit®, Ecotect®, Athena Impact Estimator®, Green Building Studio®, and programs developed by the U. S. Department of Energy (DOE-2) and the U. S. Department of Commerce (BEES 4.0) are not capable of accurately evaluating whole building impact related to material choice at the level of an individual component or unique assembly, but only according to very basic, limited palettes of predetermined assemblies, making informed choices about the adoption of emerging materials and technologies even more difficult. The Athena Impact Estimator® comes closest, as a calculation engine/ data analysis tool with some “spatial resolution” (Schaltegger 1997) capability, but lacks (according to the authors) critical proximity to the actual design process, or the ability to analyze and integrate evolving, design-specific data into a concurrent design process.

And despite advances in databases that compile information on products and systems, like the Inventory of Carbon and Energy (ICE) Database (Hammond and Jones 2008), and related enthusiasm for Environmental Product Declaration (EPDs), ECOlabels, and tools to make these mechanisms more fair and rigorous, like Product Category Rules (PCRs) (Simonen 2011), market-driven incentives do not yet currently outweigh barriers to voluntary product declaration (Heiskanen 1999). However, more ambitious, rigorous systems, like the Living Building Challenge (ILFI 2012) are evolving to address some of these ideas.

Advancing New Methods and Tools

In order to study our current means for measuring the ecological impact of the built world, Aimee P. C. Buccellato of the University of Notre Dame initiated the Green Scale Research Project (GSRP)[12] with the goal of generating quantifiable data and analysis of the implications of materials and methods used in building design and construction. Data collected from the case studies (Buccellato 2010 and 2011) produced as part of the GSRP demonstrate that there are critical aspects of sustainability, like proper siting and building orientation, material sourcing, fabrication, transportation, and maintenance that can – and should – be measured holistically *and throughout the design process*, as opposed to current practices of completed design optimization and post-occupancy validation.

In an effort to accelerate the research and meanwhile develop a more effective decision-making framework, the GSRP team began translating the methodology into a prototype digital design and analysis tool that enables the user to evaluate and effectively weigh side-by-side the use of specific materials and methods of assembly *simultaneously* with site and context-specific design decisions, from the very earliest stages of design. By reaching beyond polemics and positions still grounded on largely aesthetic or stylistic premises, the methodology and tool being developed by the authors intends to expand existing modes of inquiry and analysis, and aims, ultimately, to influence our ability to make truly informed design decisions – in order to positively influence the range of impact that those decisions may have on the built environment.

For example, by increasing access to design-driven data, we can more effectively assess whether or not technology-driven gains in one area, like reduced energy consumption, will lead to (potentially unaccounted for) losses in another area, like pollution. Such a Tool will help architects and building stakeholders better understand the up-front costs of novel building materials alongside anticipated energy use so that we can expand our ability to weigh the broadest impacts of our design and material decisions on the environment, throughout the design process.

In beta tests, the prototype GreenScale® Digital Design and Analysis Tool (preliminary patent filed) developed in collaboration with the University of Notre Dame's Center for Research Computing has produced useful preliminary results, but requires significant further development before it can serve as an effective and useful tool for educators and practitioners.

When completed, the GSRP will launch the novel graphic-user-interface and analysis platform to interface with industry leading solids modeling and building design software. Such a resource will expand current methods for quantifying the net environmental impact of our buildings, and will enable students and design professionals to use the GSRP methodology to influence informed decision-making at every step of the building design process—including material embodied energy, thermal performance, durability, and building lifetime costs.

ENDNOTES

1 Author emphasis
2 In 2006, buildings accounted for 72 percent of U. S. electricity consumption, a figure that is projected to increase to 75 percent by 2025 (DOE (a) 2008). Nearly 40 percent of domestic carbon dioxide emissions come from buildings (DOE (b) 2008). Debris generated as a result of the construction, use, renovation, and demolition of buildings in our country amounts to nearly 26 percent of all non-industrial waste produced annually (EPA 2009), a staggering statistic when coupled with the following: as of 1995, an average of 170, 000 new commercial buildings were constructed annually in addition to an estimated 44,000 commercial buildings that were demolished in the same period (US Dept. of Commerce 1995). Current studies suggest that it takes approximately 40 years for a new, energy efficient commercial building to begin realizing energy savings when the embodied energy involved in its construction is considered in conjunction with its operating energy consumption (NTHP 2008).
3 LEED, Leadership in Energy and Environmental Design, is a voluntary, third-party rating system developed by the U. S. Green Building Council (USGBC) (not a government agency) in 2000 as a resource for green building professionals.
4 This case study is the 4th in a series of on-going case studies underway at the University of Notre Dame as part of the Green Scale Research Project (GSRP).
5 Superseded in 2010; LEED 2012, the fourth version to-date, was anticipated in the spring of 2012.
6 Primary wall assembly, including fasteners and reinforcing materials; does not include window assemblies.
7 MBtu is the SI used to refer to 1,000,000 British thermal units
8 Total exterior wall assembly calculation includes a 2x4 wood stud interior wall
9 Refer to LEED v2.2 (2007), Energy and Atmosphere (EA) Category, Optimizing Energy Performance, EA Credit 1.
10 ASHRAE 90.1 2004, Table G is provided by the American Society of Heating, Refrigeration, and Air-Conditioning Engineers for the estimating building mechanical systems. It is the standard recommended by LEED v.2 to estimate baseline design energy usage for the EA1.1 credit, Optimize Energy Performance.
11 The fan supply volume for the proposed design is 24,291 cfm, compared to the baseline model of 32,396 cfm. Additionally, the fan systems included in the proposed design use 60% less

horsepower than the baseline model. The chilled water loop and pump parameters are also reduced from 179.3 tons in the baseline model to 89.3 tons in the proposed.

12 The Green Scale Research Project was initiated in 2009 and has involved over a dozen undergraduate and graduate researchers in departments across the University, including Architecture, Aerospace and Mechanical Engineering, Civil Engineering, and Computer Science Engineering.

REFERENCES

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 90.1 -1999* (1999): ASHRAE, Inc.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 90.1 -2004* (2004): ASHRAE, Inc.

American Society of Heating, Refrigerating and Air Conditioning Engineers. *ASHRAE Standard 90.1 -2007* (2007): ASHRAE, Inc.

Buccellato, Aimee P. C. "Responsibile Technology: The Green Scale Research Project." *Proceedings of the Creating_Making Forum.* (2010): 101-08. Print.

Buccellato, Aimee P. C. "Quantifying Sustainable Design: Select Case Studies." *Proceedings of the 2011 Building Enclosure Sustainability Symposium*. (2011): 127-35. Print.

Canadian Wood Council. "Comparing the Environmental Effects of Building Systems: a Case Study." *Wood the Renewable Resource No. 4 (1997):* 1-11. Print.

Ding, G. "The Development of a multi-criteria approach for the measurement of sustainable performance for built projects and facilities." PhD Thesis, University of Technology; Sydney, Australia: 2004.

Farmer, Graham and Simon Guy. "Re-interpreting Sustainable Architecture: The Place of Technology." *Journal of Architectural Education, 54-55* (2001): 140-48. Print.

Gonchar, J. AIA. "Case Study: Loyola Information Commons." *Green Source Magazine* (2009). On-line: http://greensource.construction.com/projects/0811_LoyolaUniversity.asp.

Hammond, Gregory and Jones, C. "Inventory of Carbon and Energy (ICE) Version 1.6a." (2008) Print.

Heiskanen, Eva. "Every product casts a shadow: but can we see it, and can we act on it?" *Journal of Environmental Science & Policy 2* (1999): 61-74. Print.

Hernandez, P. and Kenny, P. "From net energy to zero energy buildings: defining life cycle zero energy buildings (LC-ZEB)," *Journal of Energy and Buildings 42* (2010): 815-21. Print.

International Living Future Institute (ILFI). "The Living Building Challenge Standard, Version 2." Online: https://ilbi.org/lbc/standard. (Accessed March 2012).

Jenks, Charles. *The Architecture of the Jumping Universe: How Complexity Science is Changing Architecture and Culture.* London: Academy Editions, 1995.

McLauchlan, D. and Lavan, D. "Efficiency by the Book; Case Study: The Richard J. Klarchek Information Commons Building." *High Performing Buildings Magazine.* (2010) Online: www.hpbmagazine.org.

Ortiz, G., et al., "Sustainability in the construction industry: A review of recent developments based on LCA." *The Journal of Construction and Building Materials 23* (2009): 28-39. Print.

Sartori, I. and Hestnes, A. G. "Energy use in the life cycle of conventional and low-energy buildings: a review article." *Journal of Energy and Buildings 39,* Vol. 3 (2007): 249-257. Print.

Schaltegger, S. "Economics of Life Cycle Assessment: inefficiencies of the present approach." *Journal of Business Strategy and the Environment,* Vol. 6 (1997): 1-8. Print.

Simonen, K. "Motivating Low-Carbon Construction: Opportunities and Challenges." (Carbon Leadership Forum White Paper, University of Washington College of Built Environments, Department of Architecture, 2011).

The National Trust for Historic Preservation (NTHP). "A Cautionary Tale." *Preservation Magazine,* Vol. 60, No. 1 (2008): 19-26. Print.

U. S. Department of Commerce. "C-Series Reports." Manufacturing and Construction Division of the U. S. Census Bureau (1995). Print.

U. S. Department of Energy, Energy and Information Administration. "Building Energy Databook: DOE/EIA-0384(2007)." *U.S. Department of Energy and Annual Energy Review 2007* (2008).

U. S. Department of Energy, Energy and Information Administration. "Report: Emissions and Greenhouse Gases in the United States 2007: DOE/EIA-0573(2007)." (2008).

U. S. Department of Energy (a). "Fuel Technologies Program." Online: http://www1.eere.energy.gov/Hydrogenandfuelcells.(Accessed September 2011).

U. S. Department of Energy (b) "Building Tech-nologies Program." http://www1.eere.energy.gov/buildings/about.html. (Accessed September 2011).

U.S. Environmental Protection Agency. "Product Life-Cycle Assessment: Guidelines and Principles*:* EPA Report #68-CO-0003." (1991).

U. S. Environmental Protection Agency. "Buildings and their impact on the environment: a statistical study," (online: www.epa.gov.greenbuilding/pubs/gbstats.pdf. (Accessed April 2009).

U. S. Environmental Protection Agency. "Energy Star Program." http://www.energystar.gov/. (Accessed November 2010).

U. S. Green Building Council (USGBC). "Leadership in Energy and Environmental Design (LEED) Green Building Rating System." http://www.usgbc.org/LEED.