The Green Scale Research Project

The University of Notre Dame School of Architecture

Quantifying Truly Sustainable Design

Submitted for Consideration:
Faculty Research Support Program 2011
Initiation Grant

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II. ABSTRACT

Today, prevailing discourse on "green" building practices centers on a presumed corollary between sustainability and advanced building technologies – or the perceived dependence on the latter to achieve the former. As a result, research and discussions about achieving sustainability and greener building methods generally focus on the capabilities of modern technology to generate "sustainable" design solutions. And yet, currently there exists no universally accepted method or tool capable of holistically measuring the broader impact of these advanced technologies on the built and natural environments. What are the *true* costs – the consequences, even – of these novel and often experimental building materials and methods of assembly? And how might they be measured in order to expand our ability to make informed design and material decisions, leading ultimately to the creation of truly sustainable buildings?

The Green Scale Research Project (GSRP), launched in the fall of 2009, has begun to examine this question through quantitative analysis of construction methods, materials, and principles of design through a series of original case studies focused on measuring, evaluating, and comparing purportedly "green" materials and methods of assembly alongside their traditional predecessors. The aim of the project is to generate specific, objective, quantifiable data capable of describing and comparing the broader implications of decisions made at the earliest stages of design in order to positively influence the range of impact that those decisions may have when our buildings become manifest in the built world.

Preliminary, primarily manual analysis of the data collected from the case studies underway reveals that there exist quantifiable differences between newness – in terms of advanced building technologies and design – and effectiveness: As in the case of many LEED certified[1] buildings 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. However, current modeling software and available databases are unable to generate certifiable comparisons between existing buildings and design and material alternates germane to the research. This research necessitates the ability to evaluate and compare different ways of making at the granular, rather than the macroscopic level, which is neither supported by present technology, practice, nor broader academic discourse. Ultimately, the future of the research – and our institution's ability to influence the creation of a truly sustainable built world – is in the development of a dynamic digital modeling tool that will enable users (students, practitioners, developers, etc.) to empirically evaluate the full impact of their design decisions on the built and natural environs. It is hoped that this research can provide greater access to information and the necessary tools to make us all better stewards of the environment and better educators about how sustainability is measured and can be achieved.

[1] LEED or Leadership in Energy & Environmental Design, established by the U.S. Green Building Council, is promoted as an "internationally recognized green building certification system" that provides third-party verification that a building or community has been designed and constructed using strategies aimed at optimizing energy efficiency, minimizing water use and carbon emissions, and improving indoor air quality and resource consumption. For complete information about the rating system and certification requirements: www.usgbc.org.

III. Project Description

Current State of Knowledge

In 2006, buildings accounted for 72 percent of U. S. energy consumption, a figure that is projected to increase to 75 percent by 2025[2]. Nearly 40 percent of domestic carbon dioxide emissions come from buildings[3]. 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[4], 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 during the same time period[5]. 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[6] involved in its construction is considered in conjunction with its operating energy consumption[7]. Consequently, what we build, *how* we build, and for whom we build are questions of growing domestic and global import.

Many argue that the demand for efficient and durable buildings has never before been more critical: that the challenges of our time – climate change, population growth, and dependence on fossil fuels – demand sweeping and highly sophisticated interventions, and that novel materials and methods necessarily lead to enhanced energy efficiency and optimized building performance. The green building industry, driven by incentives like the USGBC's LEED rating system[8], focus much of their efforts on minimizing a building's carbon footprint by optimizing operating energy consumption. Meanwhile, the actual construction of some hyper-efficient buildings, by virtue of the design, fabrication, and the assembly of their particular component parts, can consume exponentially more energy than what the most energy efficient building uses annually. As result, in our endeavor to produce new technologies and materials that will make our buildings more efficient while at the same time attempting, ultimately, to use less energy, there emerges a significant – if not inversely proportional – relationship between embodied energy consumption and a building's lifetime operating energy consumption[9].

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[2] According to the United States Department of Energy. See the "Building Energy Databook 2006." US Department of Energy and Annual Energy Review 2007. DOE/ EIA-0384(2007). Energy Information Administration, U. S. Department of Energy: June 2008.
[3] From the report, "Emissions of Greenhouse Gases in the United States 2007." DOE/ EIA-0573(2007). Energy Information Administration, U. S. Department of Energy: December 2008.
[4] See the study by the U. S. Environmental Protection Agency, "Buildings and their Impact on the Environment: A Statistical Summary." www.epa.gov.greenbuilding/pubs/gbstats.pdf. U. S. Environmental Protection Agency. April 2009.
[5] From the "C-Series Reports." Manufacturing and Construction Division of the Census Bureau, U.S. Department of Commerce. 1995.
[6] Embodied Energy as defined as the combined energy consumed in the making of a building, including all of the energy expended in the extraction of materials, their manufacture, transport, and assembly.
[7] From an article in Preservation, a publication of the National Trust for Historic Preservation, entitled: "A Cautionary Tale." Published in the January-February edition, 2008.
[8] The U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) rating system measures the design and implementation of "green building strategies" aimed at optimizing energy consumption, minimizing water use and carbon emissions, and improving indoor air quality and resource consumption. See their website: www.usgbc.org for information on the 100 point rating system and certification criteria.
[9] From the study, "Comparing the Environmental Effects of Building Systems: a Case Study". Wood the Renewable Resource No. 4. The Canadian Wood Council 1997. p.3.

However, if we accept that sustainability means using building systems and materials that collectively have *less* of an impact of the environment, then by principle, the use, manufacture, and implementation of these systems and materials should be of *less* consequence to the environment than any gains to be had in their utilization.

And yet, we continue to promote the advancement of novel technologies and high-tech optimization to generate change in the unsustainable world that we have created. Ironically, such a trajectory may, in fact, lead to a future of global standardization, cultural ennui – and ultimately *more* industrialization. How have we come to prioritize these novel technologies – many of which are experimental, requiring specialized knowledge and proficiency, and longer transit – while overlooking more immediate, accessible, and responsible solutions? ***And at what cost?***

Presently, there is no universally accepted method or tool capable of *holistically* measuring the broader impact of these advanced technologies on the built and natural environments[10]. Metrics-based rating systems, like the U. S. Green Building Council's (USGBC) Leadership in Environmental and Energy Design (LEED) green building rating system, the Environmental Protection Agency's energy management-focused Energy Star Program, and energy use standards set forth by the American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE), among others, are not written to evaluate the overall impact of a building's design *and* its systems, nor – perhaps most importantly – the full ramifications of the technologies promoted to achieve certification or compliance. For example, in the LEED rating system, 58 out of 100 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 include recycled content. The use of low-tech or passive methods, like natural ventilation or the installation of native vegetation, may earn a building up to 14 points, but 12 of these points can just as easily be achieved by utilizing "high-tech" alternatives[11].

Similarly, prevailing digital modeling and whole building carbon analysis software, like Revit®, Ecotect®, Athena Impact Estimator®[12], 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 design related to material choice at the level of an individual component or unique assembly, but only according to a very basic, limited palette of predetermined (and by and large contemporary, non-traditional) assemblies[13]. Nor are the

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[10] In terms of operating energy and also the infrastructure related to research and development, manufacturing, transportation, distribution, and assembly – collectively understood as material embodied energy – material life-cycle, and maintenance

[11] Based upon an analysis of the current LEED rating system (v 3.0; USGBC: 2009) currently underway by Mary Myers (BArch 2011), Senior Research Assistant, The Green Scale Research Project (GSRP).

[12] Of the programs tested by The GSRP Team and those listed, Athena is the closest model digital framework, but is not capable of dynamic modeling, analysis, and offers very limited material choices and building site analysis locations.

[13] This observation is based upon our experience using these programs to gather data and analysis related to the four case studies underway as part of The GSRP.

programs currently available able to integrate aggregated design-specific data or outcomes into a concurrent design process.

Related research in this area, including other, similar case study-based quantitative comparisons, experimental, and theoretical studies are varied, but based largely on comparative digital modeling and field experimentation focused on measuring the thermal performance – and related operating energy efficiency – of individual building components, assemblies, and standard building enclosures (roof and wall systems) [14]. In some cases, these studies utilize available energy modeling software to assist in making cost ($) and material life-cycle-based decisions related to retrofitting existing structures[15] and, in other cases, as tools to estimate potential energy use savings involved in new construction[16]. However, these studies are not focused on – nor capable of, at this point – accurately quantifying additional energy use related to material extraction, production, transportation, and assembly *alongside* fundamental, site and climate-specific design decisions.

The ability to empirically evaluate the broader impact of materials, methods, and principles of design on the built and natural environment is further encumbered by the lack of a comprehensive and up-to-date domestic database for material embodied energy[17] and, equally, a tool capable of effectively correlating the particular *genus loci* of a building site, the origins of the materials used, and consequently, the total embodied energy involved in the execution of a building. Additionally, the reliability of available energy modeling programs and the standards and rating systems that adopt them have come under widespread scrutiny for their ability to accurately and reliably measure site, climate and building system-specific performance.[18]

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[14] Studies such as those undertaken at the Oak Ridge National Laboratory and described in the report by J.Kosny, T. Petrie, D. Gawin, P. Childs, A. Desjarlais, and J. Christian of the Buildings Technology Center, Oak Ridge National Laboratory, "Thermal Mass – Energy Savings Potential in Residential Buildings" (http://ornl.gov/sci/roofs+walls/research/detailed _papers/thermal/ index.html); and those published by Robert Adam, Atelier 10, et al., "Energy and Environmental Assessment: A study of the energy performance of two buildings with lightweight and heavyweight facades." April 2008 Executive Report (on-line). pp. 1-5, and "Sustainability and Traditional Architecture", On Green Architecture and Urbanism Council Report VII: Proceedings of The Congress for New Urbanism. Alexandria, Virginia (2007). pp. 14-15.

[15] Accounts of these techniques can be found in an article by John Cluver and Brad Randall in the APT Bulletin, the Journal of the Association for Preservation Technology, "Saving Energy in Historic Buildings: Balancing Efficiency and Value." Vol. 41. No. 1, 2010. pp. 5-12; and another by Mike Jackson, "Embodied Energy and Historic Preservation: A Needed Reassessment." APT Bulletin. Vol. 36. No. 4. pp. 47-52.

[16] Emily Leving's study "The Quandary of Quantification: Verifying the Climate Impact of Sustainable Design" (Internal Report published by the Tulane Office of Environmental Affairs, 2008) articulates this type of study and also summarizes the usefulness of available technologies to measure and verify carbon emission savings of new construction; again, primarily focused on operating energy use and not comprehensive energy consumption.

[17] Material embodied energy and water data collected for our case studies has largely been taken from the Inventory of Carbon & Energy (ICE v.1.6; 2008) generated by Geoff Hammond and Craig Jones at the University of Bath, UK, and a related database being generated by Professor Shahin Vassigh at the College of Architecture & Arts at Florida International University.

[18] As in the recent class-action suit launched against the USGBC's LEED rating system for alleged fraud, false advertising, deceptive trade practices, and unfair competition: http://www.environmentalleader.com/2010/10/15/usgbc-sued-over-false-advertising-fraud; and other articles related to concerns over the veracity of claims made by buildings certified under the rating system, like "Some Buildings Not Living Up To Green Label." Mireya Navarro for The New York Times. August 31, 2009.

Specific Objectives and Method

There currently exists no parallel research effort focused on empirically evaluating and comparing *known*, durable systems of construction and materials alongside high-tech and in many cases experimental solutions. The Green Scale Research Project (GSRP) is uniquely focused on generating comparative data on existing buildings, particularly those that purport to be sustainable. The data generated enables valuable comparative analysis of the broader implications of decisions made at the earliest stages of design and the range of impact of that those decisions may have on the built and natural environs. To this end, the GSRP method involves quantitative analysis of construction methods, materials, and principles of design through original case studies focused on measuring, evaluating, and comparing purportedly "green" materials and methods of assembly alongside their traditional predecessors.

Preliminary data collected from the four case studies[19] generated as part of this research 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 from the outset of the design process*, as opposed to current practices of completed design optimization and post-occupancy validation. Due to the limitations of available design and analysis software and domestic materials databases, the research is presently reliant upon – and limited in scope by – manual data collection, which can be validated, versus digitally generated data and analysis, which is difficult to qualify, the results of which are often incongruent with manually-collected results. Accordingly, the scope of the research is currently limited to the analysis of primary building systems: foundation, wall, roof, and openings in those systems and the evaluation of certain material properties, like thermal performance and general (non-localized) embodied energy and embodied water.

Therefore, the future of this research and its ability to expand current methods for making informed design and material decisions is in the development of a dynamic digital modeling tool that will enable the user to accurately evaluate and effectively weigh the use of specific materials and methods of assembly simultaneously with site and context-specific design decisions from the very earliest stages of design, leading ultimately to widespread adoption of *truly* sustainable building practices.

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[19] The first case study involves the quantitative analysis of the new (2007) 70,000 square foot Richard J. Klarchek Information Commons at Loyola University in Chicago, a primarily glass and steel structure (over 50% of its total surface area is glazed) that received LEED Silver certification, compared to an alternate design and construction of the same building using traditional principles of design, materials, and methods of construction. The second case also studies an existing building that involves novel technology as the primary wall system, in this case, cast concrete logs, compared to the design and construction of the same structure using regionally-appropriate, traditional methods of construction and assembly: timber logs and customary light wood framing. The third and fourth cases involve existing historic structures that are under threat of demolition and seek to empirically evaluate the value of maintaining and re-using existing, durable building stock versus the demolition and subsequent construction of a new building. The two buildings involved in these studies are an historic adobe flour mill in northern New Mexico (only three of its kind remain) and an early 20th century masonry church, St. Gerard's RC Church, in Buffalo, New York that is slated to be dismantled, transported, and reconstructed in a suburb of Atlanta, Georgia.

Such a tool is necessary, not only to provide a reliable and accessible quantitative methodology, but to inspire much needed critical examination of contemporary "green" building practices, many of which may be, in fact, completely at odds with long term sustainability. 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 on the environment associated with building operation, efficiency, maintenance, and the overall lifespan of the project. The four case studies underway – and the challenges encountered by the research team – expose the kinds of questions that research in this area should be seeking to answer, and meanwhile emphasize the need for more effective methods and tools for measuring, evaluating, and promoting the execution of truly sustainable building design, tools that have the potential to inspire change across the discipline and industry.

Project Location and Timeline

If awarded, the grant would support continuation of the case studies currently underway as part of The GSRP and would specifically initiate the development of a dynamic modeling and analysis tool. The research and program development will take place in The GSRP Lab (G22 Bond Hall) and will involve both undergraduate researchers currently involved in The GSRP and critical collaboration with colleagues in the College of Engineering, both in the Department of Aerospace and Mechanical Engineering and Computer Sciences.

Collaboration between The GSRP Team and colleagues in engineering and computer sciences would begin in the spring of 2011. Such collaboration would occur within the context of my Special Research in Sustainable Design and Building Technologies course (ARCH 67611) and would involve, at minimum, two undergraduate research assistants from the School of Architecture, and the introduction of a research assistant from the Computer Sciences (undergraduate or graduate). Our work this spring would focus, initially, on refining and evaluating the data collected from case studies currently underway in addition to continued analysis and validation of existing software and databases, followed by the development of a strategic plan to outline necessary upgrades to lab equipment. Early in this phase, we would arrange consultation with a visualization specialist within the University's Center for Research Computing (CRC) to establish our baseline equipment needs and the appropriate type of platform to support the development of the novel graphic-user-interface (GUI)/ dynamic modeling and analysis tool prototype.

Development of the prototype GUI framework would commence in the summer of 2011, and would involve one (to two) undergraduate research assistants from the School of Architecture and one research assistant, preferably graduate-level, from the Computer Sciences. Development of the prototype would continue through the fall of 2011, and would likely involve both undergraduate research assistance in the context of my Special Research Course and also paid consultant(s) from the CRC. Internal prototype testing and refinement would begin in the spring of 2012, again in the context of my Special Research Course, in anticipation of and preparation for federal grant solicitations (National Science Foundation, Department of Energy) in the fall of 2012.

IV. DISCUSSION

The University of Notre Dame is well-positioned to become *the* leading voice in the pursuit of truly responsible building technology and sustainability. We are the only Institution in the country – and one of few in the world – that vigorously promotes the study of traditional methods of construction, materials, and principles of design – many of which we can establish[20] are inherently durable and sustainable ways of making. Owing to the unique qualifications and research interests of the faculty of the School of Architecture and the exceptional social and environmental consciousness of our student body, we are the only institution currently engaged in this kind of critical evaluation of contemporary methods of construction in order to quantify the broader impacts of the way that we build on the environment.

Recent programs launched by the university, including a $6.5 million investment over the next two years towards campus-wide energy conservation measures, and research initiatives specifically focused on issues surrounding environmental change make clear the university's commitment to our calling as Catholics: to live our faith in the protection of one another and all of God's creation. The environmental challenges that are shaped by the built environment are far reaching and have fundamental moral and ethical dimensions that can no longer be ignored. Research focused on the proper stewardship of our natural resources associated with environmentally responsible design and building practices will extend our ability, as a Catholic institution, to contribute a new (and better) pedagogy of sustainability, which is further supported by the following imperative: our ability to generate solutions for the very serious environmental issues that we face absolutely depends upon our ability to critically evaluate and *substantiate* prevailing claims of sustainability.

In order for this research to be transformative in its impact on the built and natural environments, the work currently underway at the University of Notre Dame School of Architecture must be greatly expanded to fill the void that currently exists in the empirical evaluation of building performance, materials, methods, and principles of design, which is the ability to effectively quantify the broader impacts of our buildings on the built world in the earliest stages of design and execution. Our unique ability to quickly and effectively fill this void is in the development of dynamic digital modeling and analysis tools to support and improve current research and validation methods. In its annual Environmental Sustainability Program, the National Science Foundation identifies that advancements in modeling such as life cycle assessment, materials flow analysis, input/output economic models, and novel metrics for measuring sustainable systems are important research areas[21]. An Initiation Grant dedicated to the development of a prototype dynamic modeling program will enhance our ability to compete for grants from Federal Agencies like the US Department of Energy, National Science Foundation, and also private Foundations, like the Aldo Leopold Foundation, to support the full development of the modeling program, its distribution, and subsequent adoption by the academy and industry at large.

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[20] Per the case studies underway in The GSRP and other related studies (previously noted).
[21] See the solicitation: NSF, Environmental Engineering & Sustainability, PD 10-7643, November 2010.

V. BUDGET

Research Assistance, Summer 2011:	
Undergraduate/ School of Architecture (1) $10.00/ hour; 30 hours/ week; 8 weeks	$2,400.00
Graduate Student/ Computer Sciences (1) $ 15.00/ hour; 30 hours/ week; 8 weeks	$3,600.00
Consulting Fees, Computer Research Center: $40.00/ hour; 8 hours/ week; 8 weeks	$2,560.00
(Potential) Equipment Upgrades/ Software	$1,440.00
	$10,000.00

VI. CURRENT & PENDING FUNDING SOURCES

Notre Dame Environmental Change Initiative (ND-ECI) – ExPaND, led by Professors David Lodge and Gary Lamberti
Member, Steering Committee focused on the design and execution of the EXPAND facility master plan (non-funded support to project)

Capitalization funds received to establish and support The Green Scale Research Project:
$6,000.00* (total, to-date; winter 09-current) from the Office of the Dean, School of Architecture

* Includes purchase of computer equipment, proprietary software, undergraduate research support (2 summer research assistants: $4,000 total), and research travel (for myself and six undergraduate students to Buffalo, New York as part of a case study currently underway to quantify plans to move an early 20th century masonry church 900 miles to Atlanta, Georgia.)

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CC: Michael Lykoudis, Dean, School of Architecture
Sunny K. Boyd, Associate Vice President for Research
Heather Boyd, Research Development Program Director
Michelle LaCourt, Business Manager, Office of Research

DATE: January 5, 2011

SUBJECT: FY2011 Faculty Research Scholarship Program (FRSP) Initiation Grant

Thank you for your recent submission to the FY2011 Faculty Scholarship Research Program Initiation Grant Program entitled, "The Green Scale Project: Quantifying Truly Sustainable Design". All proposals were prioritized, then read and evaluated carefully according to the criteria in the guidelines.

I am pleased to inform you that your project has been selected for funding at the requested amount of $10,000. The award is effective on January 1, 2011 and will continue for one year. A one year, no-cost extension may be approved if there has been satisfactory progress or growth of the project. Michelle LaCourt will establish your account number and notify you via email soon.

Acceptance conditions:

1. Conform to established practices and procedures concerning sponsored program activity
2. Travel must adhere to the University Travel, Entertainment, and Business Expense Policies and Procedures
3. Summer salary for faculty – up to one-ninth of academic year salary maximum
4. Graduate research assistant summer stipends only
5. Act in accord with the policy that all permanent equipment and supplies purchased under the FRSP Initiation Grant is the property of the University unless otherwise specified when the grant is approved.
6. Submit a final report to the Office of Research no later than three months after the end date of the award (~March 31, 2012). The report should include:
   - Any publications or manuscripts resulting from the award
   - Reference to any subsequent proposals or applications (e.g., fellowship applications, grant applications) resulting from the FRSP Initiation Grant award to any outside agency or foundation

Congratulations! I am pleased to support this project. I wish you great success with your scholarship.