The Green Scale: A New Digital Design and Analysis Tool for Sustainable Building

The University of Notre Dame
School of Architecture
Department of Aerospace and Mechanical Engineering
Center for Research Computing

Quantifying Truly Sustainable Design

Submitted for Consideration:
Faculty Research Support Program 2012
Regular Grant

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II. ABSTRACT

Inspired by rapid innovation in building technology and correlated advances in building energy performance, architects are turning to emerging technologies with unparalleled enthusiasm to achieve buildings aimed at greater ecological sustainability. Accordingly, prevailing discourse on "green" building design focuses almost exclusively on the capacity of advanced technologies to generate "sustainable" design solutions. Yet there currently exists no universally accepted method or tool capable of holistically measuring the broader impact of these technologies on the built and natural environment. But what are the costs—the consequences, even—of these novel and often experimental building materials and methods of assembly? And how are they currently evaluated and measured alongside the more common metric, 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 informed decision-making, inspire knowledgeable adoption of nascent technologies, and ultimately influence the design and execution of truly sustainable buildings?

Launched by PI-Buccellato in the fall of 2009, The Green Scale Research Project (GSRP) has begun to examine these questions through the development of a more accessible, efficient method of analysis of construction methods, materials, and principles of design; research that is simultaneously supported by and guiding the development of a novel digital design and analysis tool that will enable students and design professionals to empirically evaluate and compare the broadest possible impacts of their designs on the environment. **There currently exists no parallel interdisciplinary 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 GSRP methodology and prototype Tool being developed in collaboration with faculty in the College of Engineering and the Center for Research Computing is uniquely focused on generating specific, objective, quantifiable data capable of describing and comparing the broader implications of decisions made at the earliest stages of design—*and throughout the design process*—in order to positively influence the range of impact that those decisions may have on the environment.

Such a tool is necessary, not only to provide a more 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 *alongside* building energy use. Data collected from case studies generated as part of the GSRP reveal that 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; tools, like the prototype Green Scale Digital Design and Analysis Tool, have the potential to inspire change across the discipline and industry and influence the creation of a truly sustainable built world.

III. PROJECT DESCRIPTION

Current State of Knowledge

Buildings are our largest consumer of domestic energy and resources. In 2006, buildings accounted for 40 percent of domestic primary energy consumption and 72 percent of U. S. electricity consumption, a figure that is projected to increase to 75 percent by 2025[1]. Nearly 40 percent of domestic carbon dioxide emissions come from building services (non-industrial heating, cooling, and lighting)[2]. The construction industry is one of the largest exploiters of both renewable and non-renewable resources, like water and raw materials[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 truly staggering statistic when coupled with the following: as of 1995, an average of 170,000 new commercial buildings were constructed annually, while over the same time period, an estimated 44,000 commercial buildings were demolished[5]. Consequently, *what* we build, *how* we build, and what we build *with* are questions of growing domestic and global import.

Many argue that the need for efficient and durable buildings has never before been greater: that the challenges of our time – climate change, population growth, and dependence on fossil fuels – demand sweeping and highly sophisticated interventions, and further, that novel materials and methods necessarily lead to enhanced energy efficiency and optimized building performance. As energy use tied to the building sector continues to rise[6], much attention is focused on reducing 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 (i.e.: the USGBC's LEED Green Building rating system[7]). Accordingly, research, development, and the integration of emerging building technologies are rapidly 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.

In fact, the actual construction of some hyper-efficient buildings, by virtue of the design, fabrication, and the assembly of their particular component parts, can consume significantly more energy than what the most energy efficient building uses annually. Life cycle analyses[8] that took the embodied energy of building materials and methods into account have shown that embodied energy—or the combined energy consumed in the making of a building, including all of the energy

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[1] U. S. Department of Energy and Annual Energy Review 2007. *Building Energy Data Book.* DOE/ EIA-0384 (2007). Energy and Information Administration, U.S. Department of Energy (June 2008).
[2] 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.
[3] Dixit, M. et al, "Identification Parameters for embodied energy measurement," *Journal of Energy and Buildings:* Vol. 42 (2010).
[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] U. S. Department of Energy and Annual Energy Review 2007.
[7] The U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design (LEED) Green Building 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.
[8] One of the principal ways that we measure the ecological impact of our buildings is through Life Cycle Assessment (LCA), defined by SETAC as a process to evaluate the environmental burdens associated with a product, process, or activity; a process that should necessarily evaluate all stages of a product's life cycle, including the extraction and processing of raw materials, their transport, distribution, use, maintenance, and disposal (see also, ISO Standard 14040).

expended in the extraction of materials, their manufacture, transport, and assembly—can vary between 2 and 38 percent of the energy consumption of a conventional building over its lifetime (estimated 30 years). In the low-energy buildings studied—buildings designed with the express purposes of reducing energy consumption—embodied energy accounted for up to 46 percent of life cycle energy use, demonstrating that a reduction of energy use in operation does not always imply a reduction in net energy use[9]. So, in our endeavor to develop new technologies and materials that will make our buildings more efficient while at the same time attempting, ultimately, to use less energy, there exists a potentially significant—if not inversely proportional—relationship between material embodied energy and lifetime operating energy consumption[10]. Yet currently there exists no universally accepted method or tool capable of holistically measuring the broader impacts of advanced technologies on the built and natural environment[11] or, therefore, a tool capable of influencing truly informed decision-making related to the design and execution of sustainable buildings.

If we accept that sustainability means using building systems and materials that collectively have less of an impact on 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.

While there are various methods and practices focused on studying the operating side of the energy use equation, far less focus exists in education and practice on 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, not inconsequentially, the availability and use of existing metrics and analysis tools. At present, methods used to assess the potential ecological impacts of our buildings are fragmented across disciplines; material databases are incomplete[12]; and prevailing analysis tools lack the capability to accurately or uniformly quantify energy use tied to material extraction, production, transportation, and assembly *alongside* building energy use and fundamental site and climate-related factors. Industry-leading 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.

Metrics-based rating systems, like the LEED Green Building rating system, the Environmental Protection Agency's energy management-focused Energy Star Program[13], and the energy use standards set forth by the ASHRAE[14], among others, are not written to evaluate the overall impact of a building's design *and* its systems, nor—and perhaps most importantly—the

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[9] Paxti Hernandez and Paul Kenny, "Development of a methodology for life cycle building energy ratings," *Journal of Energy Policy 39* (2011): 3779-3788

[10] The Canadian Wood Council, "Comparing the Environmental Effects of Building Systems: a Case Study," *Wood the Renewable Resource* No. 4 (1997): 3.

[11] Ortiz, Castells, Sonnemann, "Sustainability in the construction industry: A review of recent developments based on LCA," *The Journal of Construction and Building Materials 23* (2009): 28-39.

[12] Kathrina Simonen, "Motivating Low-Carbon Construction: Opportunities and Challenges," Carbon Leadership Forum White Paper, University of Washington College of Built Environments, Department of Architecture. January, 2011.

[13] U. S. Environmental Protection Agency, Energy Star Program: http://www.energystar.gov/ (accessed November 2010).

[14] American Society of Heating, Refrigerating and Air Conditioning Engineers, ASHRAE Standard 90.1 -2007. ASHRAE, Inc. (2007).

broader impact of the technologies promoted to achieve certification or compliance; as in the case of many LEED certified 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[15]. And so while we aim for operating energy efficiency, many of these novel technologies—which are oftentimes experimental, require specialized knowledge and proficiency, and longer transit—may actually lead to *more* energy-intensive industrialization.

Clearly, a more integrated and practical approach is necessary, one that takes into meaningful consideration the broader impacts of an emerging building technology or system, and enables the user – student and practitioner, alike – to easily evaluate the potential gains of a building technology, material, or method (i.e., energy efficiency) against any costs associated with its development, production, and ultimate deployment in the built world.

Specific Objectives and Method

Launched by PI-Buccellato in the fall of 2009, the Green Scale Research Project (GRSP) is focused on developing a more accessible, efficient method of generating quantifiable data and analysis of building construction methods, materials, and principles of design. Data collected thus far from original case studies in which we analyzed and compared the materials and construction methods used in existing and proposed buildings 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 late-stage design optimization and post-occupancy validation. The GSRP contends that in order to effect real change in the way our buildings consume energy and resources and inspire widespread adoption of *truly* sustainable building practices, professionals across the design and building industry need access to enhanced decision-making tools that are capable of accurately evaluating the broadest possible ecological impacts of our buildings.

The Green Scale Research Project intends to fill this void with the development of the "Green Scale Digital Design and Analysis Tool for Sustainable Building", an easy-to-use building design and analysis tool that will enable users to quantitatively evaluate and effectively weigh the consequences of their design decisions at every step of the building design process. The current, operational prototype of the Green Scale Tool is a Java-based application (developed by the authors with support from the Office of the Vice President of Research, FRSP Initiation Grant 2011 and the Center for Research Computing) modeled after the GSRP calculation methodology. In ongoing beta tests within the GSRP team, the prototype tool has produced useful preliminary results and accelerated the research, but is in need of substantial further development before it can serve as an effective and useful tool for practitioners and educators.

The next generation Green Scale Tool will improve upon prevailing design analysis tools and inspire truly informed decision-making because it will have the capacity to:

1) measure and evaluate the "up-front costs", or material energy flows, *alongside* operating energy simulation;

[15] Buccellato, A, "Quantifying Sustainable Design: Select Case Studies." P*roceedings of the 2011 Building Enclosure Sustainability Symposium.* California Polytechnic University, Pomona: April 2011.

2) provide simultaneous quantitative comparison of multiple materials and methods, or the ability to evaluate and compare different ways of making at the granular, rather than the macroscopic level;
3) interface with industry-leading solids modeling and building design software, AutoCAD® and Revit®, enabling continuous, synchronized analysis throughout every step of the design process.

The GSRP will use industry standard Industry Foundation Classes/Xml (IFC) source code[16] to allow the Green Scale Tool to interface with widely used building design software. The Green Scale Tool will be capable of synchronized, whole building analysis *throughout* the design process, enabling the user to integrate evolving, design-specific data into a concurrent design process, including comparative material analyses and advanced energy use simulation models. Using our tool, students and design professionals will be able to use the GSRP methodology to quantitatively evaluate and compare the consequences of their design decisions **at every step of the building design process**—including environmental impact, material selection, thermal performance, durability, and building life-cycle costs. Prevailing simulation and analysis tools are largely focused on influencing operating energy use consumption and facilitate only periodic or late-stage design analysis. However, since up to 90 percent of the total life-cycle cost of a product is determined in the *design* stage[17], a tool, like the Green Scale, that can provide critical and timely access to comparative data means greater potential for the information to positively influence decisions made during—as opposed to after—the design process.

If awarded, the grant would support parallel advancement of the Green Scale model/methodology and the pilot Green Scale Tool using a spiral software development model. Presently, the Green Scale model/methodology and associated Tool provide a unique framework for utilizing prevailing, "known" methods of material analysis (i.e., embodied energy, thermal performance, building life-cycle costs, etc.) and according to available domestic material databases. In the next development cycle, we will make necessary refinements to the existing prototype; implement the Application Programming Interface (API) for the plug-in architecture for both the model/methodology and its interface to other software packages; and integrate additional measuring instruments to the hi-fidelity model, including the development of an enhanced building energy use simulation model. This model will use a lumped capacitance approach to more accurately determine the effects of building design on fluxes of mass, energy, carbon dioxide, and water concentrations, among other spatial and temporal variables, *alongside* design-driven material energy impacts.

After another testing phase, we will commence a final (under this grant) development cycle to further refine the Tool, implementing the hi-fidelity model from cycle 2 and executing the connection between the Green Scale plug-in architecture and AutoCAD® and Revit®, the software we are specifically targeting for initial interoperability[18]. And because of its modular design, the Green Scale Tool will be capable of incorporating additional, presently evolving methods for

[16] IFC is an object-based file format and a neutral and open specification developed by the International Alliance for Interoperability, IAI, to facilitate interoperability in the building industry; it is a commonly used format for Building Information Modeling (BIM) and is currently in the process of becoming the official International Standard ISO 16739

[17] Keoleian, G. A. and Menerey, D., "Life Cycle Design Guidance Manual". Environmental Protection Agency: Office of Research and Development. Cincinatti, OH (1993).

[18] In 2008, Autodesk sold an estimated 5.47 million seats (including upgrades) of their drafting software, AutoCAD®, one of several kinds of software used by the Architecture Engineering and Construction industry.

assessing environmental impact into future development cycles; for example: necessary advances in the databases that compile information on products and systems, like the U. S. Department of Energy's Life Cycle Inventory and the UK-based Inventory of Carbon and Energy (ICE)[19] database; and future development of Environmental Product Declaration (EPDs), EcoLabels, and tools that make these emerging mechanisms more fair and rigorous, like Product Category Rules (PCRs) [20].

Project Location and Timeline

The research and program development will take place jointly in The GSRP Lab (G21 Bond Hall), the Department of Aerospace and Mechanical Engineering (AME) and the Center for Research Computing (CRC), and will involve undergraduate and graduate Architecture students currently involved in The GSRP, undergraduate and graduate AME students, and critical collaboration with colleagues in Computer Science.

Collaboration as part of this grant would commence in the spring of 2012, in the context of my Special Research in Sustainable Design and Building Technologies course (ARCH 67611) and would involve, at minimum, two undergraduate or graduate-level research assistants from the School of Architecture, the introduction of a research assistant from AME, and an intern-level programmer from the CRC. Our work in the first year, Development Cycle 1, will focus on refinement of the current Green Scale model/methodology, incorporating ISO standard (IFC/Xml) interoperability protocol between the model and our targeted building design software, AutoCAD® and Revit®, and expanding the GSRP domestic-material database (aggregating data on material embodied energy, thermal performance, durability, etc.).

In year two, Development Cycle 2, we will continue to advance the Green Scale model/ methodology; specifically, in the development of an enhanced energy modeling component that will enable the Green Scale users to instantly see how changes to material selection, building location and orientation, and assembly design, etc. impact the thermal performance, annual energy use, building maintenance requirements, and estimated lifetime embodied energy. During this second year, we will also commence development of the plug-in architecture that will enable the Green Scale Tool to communicate with industry-leading building design and modeling software, AutoCAD® and Revit®. Preparation for deployment of the Green Scale Tool will begin within this cycle and continue in the next, final cycle (under this grant), during which we will conduct rigorous testing and validation of the developing model and graphical interface, both within the GSRP Team and in focus groups in academia and professional practice.

[19] G. Hammond and C. Jones, Inventory of Carbon and Energy (ICE) Version 1.6a (2008).
[20] Simonen, 2011.

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 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 Department of Aerospace and Mechanical Engineering, 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 broadest possible impacts of the way that we build on the environment.

Recent programs launched by the university, including a $6.5 million investment 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.

The future of the research underway – and our institution's unique ability to influence the creation of a truly sustainable built world – is in the full development and deployment of the Green Scale Digital Design and Analysis Tool for Sustainable Building. The University's support of this interdisciplinary research endeavor is manifold. If awarded, this grant will support broad interaction between faculty and students in the School of Architecture, the College of Engineering, and the Center for Research Computing; critical collaboration that will help the research achieve greater access to future funding sources outside of traditional architecture funding channels. Support of this cross-disciplinary collaboration within our institution will continue to inspire the adoption of structured research, like the GSRP, within the School of Architecture and other academic units. And finally – and perhaps most importantly – institutional support for the development of the Green Scale Tool allows the GSRP team to advance the research while maintaining critical control over the University's intellectual property, the source code; thereby protecting Notre Dame's ability to license the Green Scale Tool to industry-leading solids modeling and building design software companies, like AutoDesk (licensee of AutoCAD and Revit); and generate revenues that might further support this important research and the development of future allied interdisciplinary research initiatives, like a new Institute for the Study of Material Science and Advanced Building Technology at Notre Dame.

V. CURRENT & PENDING FUNDING SOURCES

PI-Buccellato

Current:
The Green Scale Research Project: Quantifying Truly Sustainable Design
Buccellato, A.
Initiation Grant, Faculty Research Support Program 2011
University of Notre Dame Office of the Vice President of Research
$10,000/ 1 year

Linked Experimental Ecosystem Facility – Notre Dame (LEEF-ND)
Lamberti, G. (lead), Buccellato, A., Lemmon, M., Tank, J. (2009)
University of Notre Dame Environmental Change Initiative
$1,270,000
(Project Designer, non-funded support to project)

Pending:
Environmentally Opportunistic Computing
Go, D. (lead), Buccellato, A., Brenner, P. (2011)
Wells Fargo National Environmental Grant Program 2011
Limited submission proposal/ internal competition winner (in review)
$90,000

The Green Scale: A New Digital Design and Analysis Tool for Sustainable Building
Buccellato, A. (lead), Paolucci, S., Vardeman, C. (2011)
Regular Grant, University of Notre Dame Office of the Vice President of Research
Faculty Research Support Program 2012
$98,538/ 3 years

The Green Scale: Developing and Deploying a New Digital Design and Analysis Tool for Sustainable Building
Buccellato, A.
Individual Grant, Graham Foundation
Inquiry Form/ initial proposal in review (9/2011)
$20,000/ 2 years

The Green Scale Digital Design and Analysis Tool for Sustainable Building
Buccellato, A. (lead), Duke, R., Parker, M., Vardeman, C. (2011)
McCloskey Business Plan Competition, Gigot Center for Entrepreneurship
University of Notre Dame, Mendoza College of Business
(Multiple Award Submission, in review)

Co-PI: Paolucci

Current:
Notre Dame Geothermal Ionic Liquids Research: Ionic Liquids for Utilization of Geothermal Energy
Brennecke, J.F., Maginn, E.J., McCready, M., Paolucci, S., Sen, M., Stadtherr, M.A., (2010)
U. S. Department of Energy
$951,500/ 2 years

Co-PI: Paolucci, continued

Pending:
Adaptive, Multi-scale, Integrated Models for Energy Efficient Design, Monitoring and Control of Building Systems
Antsaklis, P.J., Murphy, P.M., Paolucci, S., Sen, M. (2011)
National Institute of Standards Technology
$873,485/ 3 years

Verified and Validated Detailed Kinetics Modeling of a Hypersonic Combustor
Powers, J.M., Paolucci, S. (2011)
National Aeronautics and Space Administration
$699,180/ 3 years

Center for Shock Wave-processing of Advanced Reactive Materials
Kogge, P., Lumsdaine, A., Matous, K., Alexander Mukasyan, A., Paolucci, S., Powers, J. M., Son, S., Sterling, T., Tryggvason, G. (2011)
National Nuclear Security Administration ASC Alliance
$10,509,900/ 5 years

The Green Scale: A New Digital Design and Analysis Tool for Sustainable Building
Buccellato, A. (lead), Paolucci, S., Vardeman, C. (2011)
Regular Grant, Faculty Research Support Program 2012
University of Notre Dame Office of the Vice President of Research
$98,538/ 3 years

Co-PI: Vardeman

Pending:

HAMMAC – Heterogeneous Architectures using Molecular Modeling Algorithms for Computation
Izaguirre, J. (lead), Sweet, C.,Vardeman, C. (2011)
National Science Foundation, CISE Computing Research Infrastructure
$354,079/3 years

The Green Scale: A New Digital Design and Analysis Tool for Sustainable Building
Buccellato, A. (lead), Paolucci, S., Vardeman, C. (2011)
Regular Grant, Faculty Research Support Program 2012
University of Notre Dame Office of the Vice President of Research
$98,538/ 3 years

The Green Scale Digital Design and Analysis Tool for Sustainable Building
Buccellato, A. (lead), Duke, R., Parker, M., Vardeman, C. (2011)
McCloskey Business Plan Competition, Gigot Center for Entrepreneurship
University of Notre Dame, Mendoza College of Business
(Multiple Award Submission, in review)

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Dear Professor Buccellato,

Thank you for your submission of your proposals, "The Green Scale: A New Digital Design and Analysis Tool for Sustainable Building". The Review Panel carefully considered each of the proposals and made a recommendation to me about which of the proposals they felt best fit the criteria of this competition. I have accepted their recommendation.

I am pleased to inform you that your proposal will be funded at the level of $98,538 over three years as proposed. Please contact Michelle LaCourt in the Office of Research when you are ready to set up an account. In the text that follows, I have synthesized feedback from the panel with the help of review panel members. We hope that this feedback will help you to strengthen your research.

There was strong support for this project from the committee because it clearly endeavors to broaden the scope of sustainability studies, would raise the level of research within the Architecture School to a more scientific focus, and has obvious commercial applications. It is a very topical project, one that is strongly linked to the University's mission through green building and energy and waste management.

A big concern raised by the committee was about the potential for other funding sources. Acknowledging that it may be difficult for an architect to receive funding from an agency such as the NSF, it would seem there could be possible funding sources available from corporations, foundations, the EPA, and donors to the School of Architecture. A word of caution about approaching corporations for support in that they may require an ownership of your ideas.

The committee also recommends that you need to develop a business plan for how this will eventually be brought to commercial use. Is it a project for Innovation Park? More immediately, the committee suggests making more effort to publish your early findings and submit more papers to conferences to gain a wider audience for what you are doing.

I am pleased to pass along the good news. I wish you great success with your scholarship.

Sincerely,

Robert J. Bernhard
Vice President for Research