Precourt Energy Efficiency Center

Funded Project Final Survey Report - WZAAC

Principal Investigator(s): John Haymaker, Martin Fischer

Project Title:

An integrated conceptual design process for energy, thermal comfort, and daylighting

1. Project Description:

The life-cycle energy, thermal comfort, and daylighting performance of buildings is substantially determined in the early stages of the design process. Performance-based analysis methods supported by product models have little opportunity to inform these early stage design decisions because current tools and processes do not support the rapid generation and analysis of alternatives. The goal of this research is to reduce the time required to complete such design iterations. We anticipate that this will allow design teams to formally investigate the energy, thermal comfort, and daylighting performance of many more alternatives during the conceptual design phase leading to improved built environments. The method we investigated is multidisciplinary design optimization (MDO), and how it can be support the workflow from a parametric building information model (BIM) to an energy and daylighting simulation engine.

Research Activities:

1. Develop an MDO workflow from a parametric BIM tool to an energy and a daylighting simulation engine via an interoperable, open data model.
2. Implement the workflow in an MDO environment that allows for the use of advanced optimization techniques.
3. Develop an information architecture within the MDO workflow to support flexible problem formulation and dynamic attribution. The researchers' method is called the CAD-Centric Attribution Methodology for Multidisciplinary Optimization (CAMMO).
4. Enable the MDO workflow to run using parallel and distributed computing.
5. Test the process on several industry case studies to determine generality, scalability, and power.
6. Publish research results.

Major Findings:

Our research has shown that applying MDO to CAD-centric energy and daylighting simulation is feasible on a large scale within the time constraints of conceptual design using parallel and distributed computing resources. The high level technical implementation is called ThermalOpt, a methodology for automated BIM-based multidisciplinary thermal simulation intended for use in multidisciplinary design optimization (MDO) environments. ThermalOpt mitigates several technical barriers to BIM-based multidisciplinary thermal simulation found in practice today while integrating and automating commercially available technologies into a workflow from a parametric BIM model (Digital Project) to an energy simulation engine (EnergyPlus) and a daylighting simulation engine (Radiance) using a middleware based on the open data model Industry Foundation Classes (IFC). ThermalOpt includes methods for: automatically converting architectural models into multiple consistent

thermal analytical models; integration/coordination of analysis inputs and outputs between multiple thermal analyses; reducing simulation times; and generating consistent annual metrics for energy and daylighting performance. ThermalOpt can improve design process speed, accuracy, and consistency, and can enable designers to explore orders of magnitude larger design spaces using MDO environments.

Our research also found that the accuracy and cost-effectiveness of such an MDO process is highly dependent on designers' ability to structure the optimization problem for specific challenges, particularly when specifying how building attributes and their associated geometry are configured for an optimization process. To fit current workflows efficiently, designers need flexible CAD-centric attribution methods for MDO environments. These methods are not addressed in the literature, or defined in available methods. Our research fills these gaps with the CAD-Centric Attribution Methodology for Multidisciplinary Optimization (CAMMO). The authors have demonstrated the potential power and generality of CAMMO with two industry case studies.

2. How have the results from this project contributed to the solution of energy efficiency challenges? How is it likely to contribute to solutions in the future?

The results of our research have demonstrated that multidisciplinary design optimization (MDO), a process which has been used heavily in the automotive and aerospace industries, can be applied to the architecture, engineering, and construction (AEC) industry for CAD-centric energy and daylighting simulation on a large scale and within the time constraints typical of building conceptual design. The application of these methods will enable design teams to explore much larger design spaces than is currently possible, and in a much more systematic and efficient manner. This improved design exploration will ultimately lead to more efficient, high-performance built environments. Many design firms are just now investigating the potential of such processes to improve their design capabilities, and our research has provided a "roadmap" of how to integrate such methods into their current workflow. We anticipate methods such as ours funded by PEEC will become standard practice for leading practitioners in the AEC industry within the next 5-7 years, and even sooner for a small handful of design firms.

3. What undergraduate or graduate students, as well as Post-Doctoral fellows, were involved this project. How were they involved? *Please list their name, classification and a short description of their involvement.*

Prasun Bansal (MS student): Prasun assisted in writing code for the original EnergyPlus wrapper. The results of the research were published in 2009.

Forest Flager (PhD Candidate): Forest assisted in the in the use of Phoenix Integration's Model Center for this research, as well as the installation and management of CIFE's HPC cluster.

Benjamin Welle (PhD Candidate): Ben was the key graduate research assistant on this project.

4. Will you be continuing work on this project? How and with whom? Please include any comments.

We have recently received funding from Autodesk to expand our current research by building software wrappers for the BIM tools Autodesk Revit Architecture and Autodesk Project Vasari. These wrappers will enable these CAD/BIM tools to be tested within our MDO environment and large parametric studies to be run using EnergyPlus and Radiance. This project will commence in March 2012 and last for approximately 6 months. Benjamin Welle will be the key researcher and the research will take place as post-graduate research.

5. Are you seeking or have you received additional funding as a result of this project, or for continued work on this project? *Please list the amount you are seeking/have received, source of the additional funding and a short description.*

Yes. We received additional funding in 2009 for the amount of $25,000 from the following proposal:

Haymaker, J., Kroo, I., Flager, F., Welle, B. (2009). "Improving Multidisciplinary Optimization Methods in AEC." CIFE SEED Proposal 2009.

Also, we received $22,000 in funding from Microsoft to help purchase a high-performance computing (HPC) cluster for CIFE, which has been, and continues to be, used to support this research. Additional, funding has been obtained for "extensions" to this research, and the projects are listed in the next section.

6. Has this project generated any other projects? *Please describe*.

Yes. This project has generated the following project: "Improving the Cost-Effectiveness and Scalability of Multidisciplinary Design Optimization (MDO) for Daylighting Simulation using Artificial Intelligence, Distributed Computing, and Uncertainty Analysis." This project was funded by the CIFE Technical Advisory Committee, and the proposed research is a direct result of PEEC-funded research.

This project has also generated the following project: **"**Development of Revit/Visari Plugin using gbXML for CIFE MDO Platform". This project was funded by Autodesk, and is a direct result of PEEC-funded research. This project will be conducted as post-doctoral research for Benjamin Welle.

7. What patents, if any, have you received or applied for?

We have yet to apply for any patents. However, we plan to begin the process with OTL to patent the IFC Plugin, Radiance Plugin, and EnergyPlus Plugin over the next several months.

8. Please list all academic and non-academic (Op-Eds, news magazines, etc.) publications and conference presentations as well as articles in progress that came about as a result of this project. May we post these on the PEEC website? *If so, please list the URL or provide a pdf version*.

REFEREED JOURNAL PUBLICATIONS

Flager, F., Welle, B., Bansal, P., Soremekun, G., Haymaker J. (2009). "Multidisciplinary Process Integration and Design Optimization of a Classroom Building." *ITcon,* Vol. 14, 595-612.

Welle, B., Haymaker, J., and Rogers, Z. (2011). "ThermalOpt: A Methodology for Automated BIM-Based Multidisciplinary Thermal Simulation for use in Optimization Environments." *Building Simulation: An International Journal,* Vol. 4, 293-313.

JOURNAL PAPERS RECENTLY SUBMITTED

Welle, B., Haymaker, J., Fischer, M., Bazjanac, V. (2011). "CAD-Centric Attribution Methodology for Multidisciplinary Optimization (CAMMO)." Submitted to *Advanced Engineering Informatics.*

JOURNAL PAPERS UNDER PREPARATION

Welle, B., Rogers, Z., Fischer, M. (2012). "BIM-Centric Daylight Profiler for Simulation (BDP4SIM): A Methodology for Automated Product Model Decomposition and Recomposition for Climate-Based Daylighting Simulation." To be submitted to *LEUKOS.*

CONFERENCE PROCEEDINGS

Welle, B. and Haymaker, J. (2011). "A Knowledge-Based Approach to Problem Formulation for Product Model-Based Multidisciplinary Design Optimization in AEC." Proceedings of the Association for the Advancement of Artificial Intelligence (AAAI) Spring Symposium: Artificial Intelligence and Sustainable Design, Stanford, CA, pp. 106-112.

INVITED CONFERENCE PRESENTATIONS

Welle, B. (2010). "Multidisciplinary Optimization (MDO) for BIM-Based Passive Thermal Simulation." EcoBuild America, Washington, DC.

Welle, B. (2010). "BIM2SIM: A Technology Update." ASRHAE Winter Meeting, Orlando, FL.

Welle, B. (2009). "Sustainabimegration: Where it's at and where it needs to go." CBE Technical Advisory Meeting, Berkeley, CA.

Welle, B. (2009). "Current State of the Integration of BIM and Building Performance for Sustainability". The Congress on the Future of Engineering Software (COFES), Scottsdale, AZ.

Welle, B., and Soremekun, G. (2008). "Improving Multidisciplinary Building Design: Geometry, Structural, Thermal, and Cost Trade-Off Studies using Process Integration and Design Optimization." SimBuild, Berkeley, CA.

INVITED LECTURES

Welle, B. (2007-2010). "Energy, Daylighting, and CFD Simulation and Analysis." CEE211-Multidisciplinary Modeling and Analysis and CEE215-Goals and Methods of Sustainable Building Design, Stanford.

Welle, B. (2009). "BIM and Energy Simulation." CEE214-Modeling Product, Processes, and Organizations in the AEC Industry, Stanford.

Welle, B. (2009). "Current State of BIM and Energy Simulation." CE470-Building Information Modeling and Integrated Practices, USC.

All publications and presentations that may be posted to the PEEC website have a link to the pdf.

9. Provide a URL address for any websites that provide more information for interested parties on your research project, including photos and videos. We will add this information to your project summary on the PEEC website.

http://zeroemissiondesign.com/

10. Have you developed any specific products, (such as databases, physical collections, educational aids, software, etc), as a result of this project? *If so, please list along with a short description*.

Yes. We have developed "wrappers" or "plugins" around the freely available energy simulation engine EnergyPlus, the freely available daylighting simulation engine Radiance, and to import and post-process IFC files out of the BIM tool Digital Project. Details of the software implementations can be found in our recently published journal article: *ThermalOpt: A Methodology for Automated BIM-Based Multidisciplinary Thermal Simulation for use in Optimization Environments."*

11. Were any undergraduate or graduate courses generated as a result of this project? *If so, please list the course title and a short description.*

None.

12. Have you provided any information regarding your research to any public or private institutions (e.g., legislative briefing, government panel, congressional testimony, corporate presentation) or any public or private institution asked you for information regarding your research? *If so, please list the organization, date and a short description.*

This research has been presented at various conferences and academic lectures. For details, see response to question #8.

13. Have you partnered or worked with businesses, governmental agencies, NGOs, or other public or private organizations in connection with your project? If so, what role have they played? *Please list the institutional name, type of institution and a short description of the partnership.*

General Services Administration (GSA) (type: federal agency, public): GSA is the largest building owner in the world and designs, constructs, and operates all the federal facilities in the US. The GSA has provided two case

studies this research: a retrofit of the GSA headquarters and the first net-zero energy building for GSA, a border station in New Mexico.

Microsoft (type: private business): Microsoft has contributed funding for a high-performance computing (HPC) cluster at CIFE which is being used for our research. Additionally, we have recently negotiated a low rate for accessing their Windows Azure cloud computing platform for this research.

Lawrence Berkeley National Lab (type: public lab): As a guest researcher at LBNL, Building Technologies Department, Benjamin Welle has recently started the process of accessing the HPC cluster at the lab to support validation of his research case studies.

Daylighting Innovations (type: private business): Zack Rogers at Daylighting Innovations has worked as a contractor for this research developing components of the Radiance Plugin.

Phoenix Integration (type: private business): Mike Haisma and Grant Soremekun at Phoenix Integration have worked as a contractor for this research developing components of the EnergyPlus Plugin and developing general MDO strategies.

AEC3 (type: private business): Matthias Weise at AEC3 has worked as a contractor for this research developing components of the IFC Plugin.

Autodesk (type: private business): We have recently received funding from Autodesk to expand our current research by building a software wrapper for the BIM tool Autodesk Revit Architecture.

14. What public education activities have you undertaken in conjunction with this project?

Conference presentations (open to the public) and development of a research website.