Funded Project Final Survey Report

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Co-investigator: Victor Gane

Project Title:
Improving Energy Efficiency of High-Rises through Requirements Driven Parametric Modeling

1. Project Description:

During a conceptual building design process, multidisciplinary teams define project objectives, create various alternatives, and try to understand their impacts and value. With non-parametric Computer Aided Design (CAD) methods designers produce on average only three alternatives, whereas with parametric CAD - thousands. However, with current parametric methods, CAD experts lack a comprehensive set of parameters to build and analyze multi-objective parametric models. Therefore the resulting models do not effectively encapsulate multi-objective value measures, such as building’s energy performance, construction cost, or space efficiency.

This research introduces the Design Scenarios Methodology (DS), which builds on research from Systems Engineering, Process Modeling, and Parametric Modeling. With DS, Enablers use Methods to create Elements using five interconnected models to define (1) project stakeholders and their objectives, (2) designer logic used to address objectives, (3) the connection between designer logic and computable models to generate alternatives, (4) the predicted impact and (5) value of the generated alternatives. We implemented DS as a web-based software prototype and tested it on an industry project. The results provide evidence that the DS method provides CAD experts with well-defined logic and parameters for addressing objectives and the process enables creating parametric alternatives with clear multi-objective values that potentially provide clients with building designs with improved multi-disciplinary performance.

Research Activities:

This research consisted of the following research activities:

- We developed a set of multidisciplinary metrics to benchmark current conceptual design process. We performed retrospective analysis of five high-rise projects designed by a leading international building design firm. To validate the case study findings, we surveyed industry leading building design professionals.

- The benchmarking study helped reveal process shortcomings in existing conceptual design process and motivate the needs addressed by this research. For example, we determined that mechanical engineers have limited contribution at the conceptual design stage, which negatively impacts the energy performance of the future design.

- We performed an extensive literature review in such fields as Design Theory, Quality Function Deployment, Requirements Engineering, Process Modeling, and Parametric Modeling to determine how existing theory/research addressed the identified needs.
• We developed the Design Scenarios methodology (DS) to address the current conceptual design process shortcomings and enable an evaluation and comparison of the novel process.

• In collaboration with a software engineer, we developed the Design Scenarios web-based software to enable testing the impact of DS on the conceptual design process performance.

• We applied the software on one industry case study – a high rise building designed by a leading building design firm.

**Major Findings:**

We present major findings in three journal papers:

• *Benchmarking Current Conceptual High-Rise Design Processes (Gane & Haymaker, 2010).* This paper presents an analysis of current conceptual design processes for high-rise buildings. We synthesize a method to document and measure these processes and use it to analyze data from several case studies and a survey of leading architectural and engineering design firms. We describe current high-rise conceptual design process in terms of the following: design team size, composition, and time investment; clarity of goal definition; number and range of design options generated; number and type of model-based analyses performed; and the criteria used for decision making. We identify several potential weaknesses in current design processes including lack of clarity in goal definition and a low quantity of generated and analyzed options. We argue that potentially higher performing designs are being left unconsidered, and discuss the potential reasons and costs.

• *Design Scenarios: Enabling Transparent Parametric Design Spaces (Gane & Haymaker, 2011)* This paper presents a novel methodology called Design Scenarios (DS) intended for use in conceptual design of buildings. DS enables multidisciplinary design teams to streamline the requirements definition, alternative generation, analysis, and decision-making processes by providing a methodology for building and managing requirements driven design spaces with parametric CAD tools. This paper motivates the need for the DS methodology thorough industry case studies, and establishes points of departure for the methodology through literature review. Next, the paper details the elements and methods in the methodology, describes its implementation into a software prototype, and provides an example to illustrate how DS can potentially enable multidisciplinary teams to generate and communicate larger and better performing design spaces more efficiently than with traditional methods.

• *Application of Design Scenarios Methodology to Evaluate the Effectiveness of Transparent Parametric Design Spaces (Gane, Haymaker, Fischer, Bazjanac, 2011)* Quality designs generally emerge from a conceptual design process that generates and communicates large design spaces of objectives, alternatives, impacts, and values. Parametric modeling is a popular means for generating large alternative spaces but it is difficult to use effectively when the other spaces are not well generated. We apply a framework for measuring design space clarity and quality to traditional non-parametric practice, and to two applications of parametric modeling, on high-rise projects. The framework reveals deficiencies in both the quality and clarity of the design spaces that building designers are able to construct using traditional and parametric methods. We describe a fourth industry case study illustrating the application of Design Scenarios developed to address these shortcomings. The case studies illustrate the potential for significant impact that parametric modeling can have on the overall conceptual design process performance, particularly when supported by methodologies to better generate and communicate design spaces.

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?
In the U.S. over 70% of the electricity, 40% of raw materials, and 12% of water consumption is attributed to buildings (USGBC, 2007). The situation is not improving – the lifecycle performance of many new buildings is below that of older buildings and often below code requirements (Turner and Frankel, 2008). While design costs (5-8%) are typically dwarfed by construction costs (60-80%) (Miller, 1993), the biggest impact and opportunities for lifecycle performance improvement are with decisions made during conceptual design, when the building’s orientation, massing, materials, components, and systems and their properties are proposed (Ellis and Torcellini, 2008). Current conceptual building design process starts with a limited set of architect and client-biased project requirements such as building space efficiency, budget constraints, gross area, etc. Such design process has little or no participation from the mechanical engineers who are experts in providing guidance on energy efficient design practices. Consequently, the architect-proposed designs are often post-rationalized by engineers and result in mediocre or poor lifecycle performance.

The Design Scenarios methodology (DS) requires starting the conceptual design process by determining the requirements of all stakeholders involved in a building design and construction project, including mechanical engineers. DS enables identifying key design parameters that impact the energy efficiency of a building design (e.g., building orientation, window height, shading device location and size) and translating such parameters into parametric Computer Aided Design (CAD) models used to generate multiple design alternatives. DS has proven to significantly impact both the design process by eliminating negative iterations and the quality of the generated designs by providing multidisciplinary design teams with a process of making objective decisions about alternatives that provide most value for a set of multidisciplinary project requirements that the conceptual design process started with.

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.**

Victor Gane, PhD was the Research Assistant on the project. Victor led the development of the Design Scenarios methodology and its implementation into a software prototype (in collaboration with a software consultant). Victor tested the application of the methodology on an industry project – a high rise in Jeddah, Saudi Arabia and determined its power and generality. Victor authored three journal papers and two conference papers on industry problem identification, methodology description, and methodology impact topics.

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

Victor Gane is currently seeking additional building and product design industry projects to apply the methodology and further quantify its impact on design process efficiency and resulting design multi-attribute quality.

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.**

N/A

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

N/A

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

Victor Gane is currently in the process of applying for a provisional patent with the Stanford Office of Technology Licensing to patent the process of translating multi-disciplinary project requirements into key design parameters.
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.*


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://stanford.edu/~vgane/research/stanfordstuff.html
www.designscenarios.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.*

In collaboration with a software engineering consultant, we developed the Design Scenarios web-based software application. The software was developed using Java script, Rubi on Rails, and MySQL database. The software consists of six inter-connected modules:

(1) **Product Administration** – project administrator adds and edit new projects and new users.

(2) **Project Setup** – project administrator creates project roles (e.g., client, designer, end user), assigns access rights to the Design Scenarios models, and assigns user(s) to roles.
(3) **Requirements Model** – project stakeholders aggregate multidisciplinary project constraints and goals and assign individual preferences to goals. The software generates a cumulative percentage importance score for each goal normalized to 100% (Figure 1).

*Figure 1: Requirements Model – project stakeholders create constraints and goals and assign preferences to goals*
(4) **Scenario Model** – designers decompose multidisciplinary goals and constraints into decision nodes with relationships and identify key design parameters addressing the multidisciplinary project requirements including energy performance (Figure 2).

*Figure 2: Scenario Model – designers capture their logic and parameters for addressing design requirements*
(5) **Parametric Process Model** – CAD experts link parameters to geometry and parametrically generate requirements-driven design alternatives (Figure 3).

*Figure 3: Parametric Process Model - Computer Aided Design experts translate designers’ logic into geometric models and parametrically generate design alternatives*
6) Alternatives Analysis Model – designers assign for each generated design alternative quantitative and qualitative impact scores determined from formal analysis for each project goal. The system generates a total value score for each design alternative, enabling designers to objectively select the best performing alternative (Figure 4).

<table>
<thead>
<tr>
<th>Goal</th>
<th>Alternative 1</th>
<th>Alternative 2</th>
<th>Alternative 3</th>
<th>Alternative 4</th>
<th>Alternative 5</th>
<th>Alternative 6</th>
<th>Alternative 7</th>
<th>Alternative 8</th>
<th>Alternative 9</th>
<th>Alternative 10</th>
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</thead>
<tbody>
<tr>
<td>Maximize unit exposure to water</td>
<td>65%</td>
<td>71%</td>
<td>72%</td>
<td>7%</td>
<td>85%</td>
<td>81%</td>
<td>72%</td>
<td>79%</td>
<td>82%</td>
<td>79%</td>
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<td>Minimize direct sunlight in units</td>
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<td>34%</td>
<td>64%</td>
<td>5%</td>
<td>49%</td>
<td>43%</td>
<td>10%</td>
<td>61%</td>
<td>86%</td>
<td>43%</td>
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<tr>
<td>Minimize water load</td>
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<td>43%</td>
<td>71%</td>
<td>8%</td>
<td>75%</td>
<td>91%</td>
<td>10%</td>
<td>64%</td>
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<tr>
<td>Maximize exposure to prevailing wind</td>
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<td>62%</td>
<td>65%</td>
<td>5%</td>
<td>54%</td>
<td>54%</td>
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<td>53%</td>
<td>60%</td>
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<tr>
<td>Street design</td>
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<td>9%</td>
<td>100%</td>
<td>93%</td>
<td>95%</td>
<td>80%</td>
<td>73%</td>
<td>60%</td>
</tr>
</tbody>
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Figure 4: Alternatives Analysis Model – designers assign impact scores

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.

N/A

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.

Victor Gane and John Haymaker presented the Design Scenarios methodology at both public and private institutions and events, a selection of which is listed below:


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.

Since 2006, Victor Gane collaborated with design teams in the Chicago, London, and San Francisco offices of Skidmore, Owings, and Merrill (SOM), a leading architecture engineering design firm. SOM provided Victor with access to test projects and company resources. Victor first benchmarked current, non-parametric conceptual design practice by actively engaging the design teams on five high-rise projects. He then tested the application of traditional parametric CAD (three high-rise test projects) and parametric CAD supported by Design Scenarios methodology (one high-rise test project).

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

N/A