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The Need to Measure the Guidance Afforded by Design Strategies

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THE NEED TO MEASURE THE GUIDANCE AFFORDED BY DESIGN STRATEGIES

Abstract and Introduction from Caroline M. Clevenger's Ph.D. Dissertation

ABSTRACT:

Performance-based design processes are explorations guided by objectives and analyses of alternatives. Historically, building design teams have relied on precedent-based strategies to guide limited and informal exploration. Today they use more advanced strategies to guide more systematic and extensive explorations. I define design Guidance as the relative impact of strategy on exploration for a given challenge. As strategies are implemented or proposed, the need arises to measure and compare the Guidance provided by competing strategies on different challenges to support their selection and improvement. Design theory lacks precise definition and metrics for design processes and the Guidance achieved. This research addresses the questions:

How can we measure the Guidance of a design process? More specifically, how can we assess the challenges addressed, strategies implemented, and explorations executed?

I use building energy-efficiency as the domain of the study. The larger opportunity is to provide greater Guidance across objectives. Through case studies, I identify the problem. Through literature review I synthesize a framework and set of metrics. I develop the Design Exploration Assessment Methodology (DEAM) to support the comparison of Guidance across design processes. Using laboratory testing with professional designers, I evaluate explorations afforded by six strategies with respect to two challenges (renovation and new construction of a mid-rise office building). Experimental findings suggest to the order of design strategies' ability to improve exploration from worst to best is: random guessing, tacit knowledge, point analysis, combined point and trend analysis, trend analysis alone, and full analysis. These results question the proposition that more data provide better Guidance. I conclude by adding process cost to my metrics and assessing the value of information generated by various strategies relative to challenge.

The contributions of this research are the metrics, DEAM, and the evaluation of design processes. I provide evidence that Guidance can be quantitatively assessed. I demonstrate power by measuring and comparing Guidance of strategies on a challenge. I demonstrate generality across a range of strategies and challenges. Initial findings show advanced strategies support better exploration and suggest further development of such strategies. The value of information generated, however, varies. This work motivates further research to provide greater understanding of the relative value of individual strategies to specific challenges.

Keywords: Design Theory, Process, Guidance, Challenge, Strategy, Exploration, Sustainable Design, Energy, Building

INTRODUCTION:

Arguably, all design is performance-based exploration guided by objectives and analysis of alternatives. Design Guidance is the relative impact of strategy on exploration for a given challenge. Historically building design has involved few formally defined objectives and alternatives, and relied on precedent-based analysis for guidance (Watson & Perera, 1997). Today, faced with increasing and more complex objectives and alternatives, Architecture, Engineering and Construction (AEC) teams look to computer simulation to guide exploration. However, practice today primarily relies on precedent or point-based analysis to support manual design iteration (Gane & Haymaker, 2007), (Flager & Haymaker, 2007), (Maile et al., 2007), (Clevenger et al, 2009).

Design challenges facing project teams continue to increase in complexity as industry demands higher performance (AIA, 2007). Design teams are being asked to balance multiple, potentially competing objectives (Ross & Hastings, 2005) while sifting through a potentially vast number of interrelated variables (Clark, J.A., 2001). To address increasingly complicated challenges, design teams are looking to use more advanced strategies to define objectives, generate alternatives, analyze performance, and make decisions. As design processes emerge, consisting of complicated challenges, advanced strategies, and sophisticated explorations, design teams need a method to assess the Guidance provided. This research develops, implements and evaluates a method to effectively measure exploration and compare Guidance in design processes. I use energy-efficiency as the domain of the study. The larger opportunity is to provide greater Guidance across a range of objectives. To this end, I address the questions:

How can we measure the Guidance of a design process? More specifically, how can we measure the challenges designers address, the strategies they implement, and the explorations they execute?

I began my research by assessing whether the strategy of precedent-based design or "point-based" performance verification typically provides sufficient Guidance to meet recent energy performance objectives. To model its effectiveness, I conducted a simple survey of 46 industry leaders averaging over 15 years of AEC experience on September 11, 2008. The survey tests how well tacit knowledge guides industry experts in a simple design challenge with the goal of energy efficiency. Among those surveyed were: 13 architects, averaging over 21 years of experience and 4 mechanical engineers, averaging over 26 years of experience, all working at firms of national prominence. The participation of experts in the survey is meaningful since they should be the ones with the ability to recognize underlying principles understood by industry (Cross, N. 2004). The survey asked each practitioner to do the following (see Figure 1):

Consider a "typical" two story rectangular 36,000 sf office building in a cold climate; assume an open, flat site. To the best of your ability, rank the following decisions from least to most important in terms of impact on energy savings

- Changes to wall construction (example 2'x4' construction vs. concrete)
- Changes to windows area (example small windows vs. large windows)
- Changes to glazing properties (example clear vs. spectrally-selective)
- Changes in Heating, Ventilation and Air Conditioning (HVAC) system type (example Constant Volume vs. Variable Air Volume)
- Changes to building orientation (example rotate the building on site)
- Changes to building geometry (example relatively square vs. long and rectangular)
- Changes to lighting design (upgrade efficiency for same lighting level)

In preparation, I performed a full analysis of all combinations of decision variables using an Energy-Plus (Crawley et al, 2001) model. I then ranked the impact of each variable using industry standard options (i.e., R-11 vs. R-19 insulation). Rank of variable impact is shown from left to right in Figure 1. Results of the survey are similar across participants; whether architects or engineers with significant or minimal experience: using tacit knowledge alone, professionals are generally able to correctly identify the variable with the most impact (in this case, window area). Professional estimates, however, quickly deviate from simulation results for variables with lesser impact. After identifying the variable with the most impact, the mean and standard deviation of industry professional estimations approaches random guessing regardless of population!

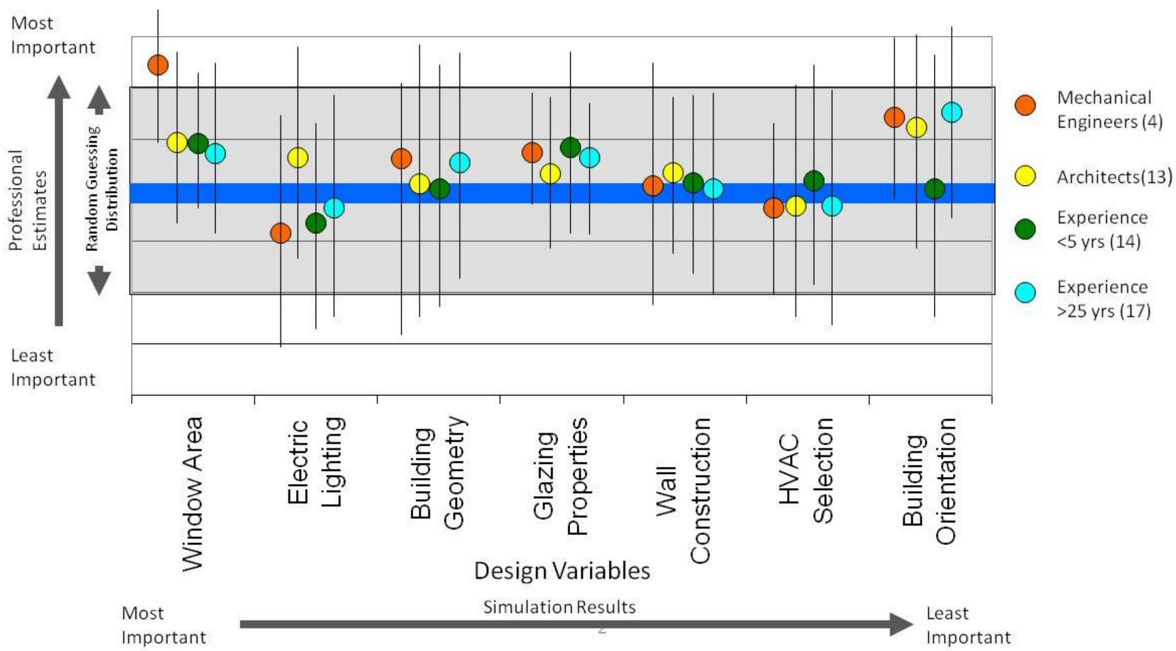

Figure 1: Survey results of professionals asked to use tacit knowledge in a simple design exploration. Each dot shows mean and standard deviation of rank of variable impact on energy efficiency as estimated by participant populations. The blue line represents the mean, and the grey area represents the standard deviation of random guessing. Results indicate a lack of consistency among industry professionals' estimates and suggest that precedent-based design does not provide significant Guidance when seeking energy efficiency.

These survey results suggest industry professionals have highly inconsistent assumptions about the variables impacting energy-performance regardless of experience level, design background, or familiarity with climate. While the survey has a relatively small sample size, results are consistent with other research that suggests that professionals lack the tacit understanding necessary to guide energy efficient decision-making in modern design projects (Papamichael & Protzen, 1993). Researchers generally agree that building science underlying whole building performance presents a complex, "wicked problem" with many challenges to modeling and rationalization in both theory and in practice (Cross & Roozenburg, 1992). Maximizing whole building energy performance requires understanding and successfully modeling stochastic, dynamic, continuous event-based systems (Maile, 2007), and human capacity to intuit such systems are bounded (Papamichael & Protzen, 1993). In conclusion, I observe that precedent-based design strategies are ill-prepared to meet today's challenges involving energy efficiency. The level of complication and variation in challenge (climate, orientation, building occupancy etc.) undermines the ability of even seasoned professionals to intuit efficient designs without more advanced strategies to guide them.

I next investigated the design strategy of performance verification or "point-based" analysis to assess its effectiveness to meet today's energy efficiency challenges. My case study documented professional energy analysis performed in 2006 during schematic design of a 338,880 sf Federal Building with 10 floors and a parking sub-basement sited in a mixed (hot cold), dry climate at an elevation of 4,220ft. Design analysis occurred over a period of 27 months. At the beginning of the project, the client set an annual energy usage target of 55 kBtu/sf/yr. A total of 13 energy simulation runs were generated during 5 rounds of energy modeling. Figure 2 represents the alternatives simulated and the associated estimates of annual energy savings (kBTU/sf/yr) with regard to a professionally generated baseline building.

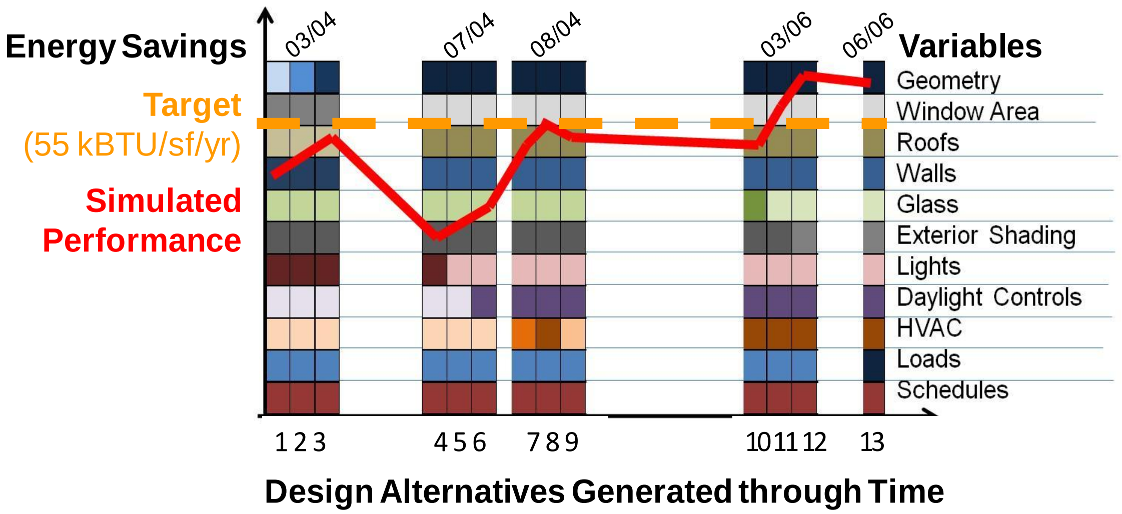

Figure 2: Graphical representation of a professional exploration during schematic design. Variables are listed on the right. Alternatives are shown as vertical stacks of specific combinations of options (represented by different colors). Changes to options for each alternative are shown by adjacent horizontal color changes. Estimated energy savings are shown with the red line. The dashed orange line shows target energy savings. The figure suggests that the professional energy modeling performed on this project supported a slow, disjointed, unsystematic and relatively ineffective exploration of building performance.

From this case study, I observe that only 13 out of a possible 12,288 design alternatives were analyzed (~0.1%). Average iteration time for an energy analysis during the project was approximately 2.1 months. Design improvements were relatively unsystematic with only the last two alternatives meeting the performance target. In conclusion, I observe that the “point-base” verification strategy provided only limited Guidance toward maximizing energy efficiency. If both precedent-based processes and current practice “point-base” strategies do not meet expectations, industry requires a new paradigm.

To meet current shortcomings in performance-based design, industry and research are investigating several strategies: among them, building optimization (Wetter, 2001; Christensen et al, 2006), Trade-space analysis (Ross & Hastings, 2005) and Process Integration Design Optimization (Flager et al, 2009). All strategies have an associated process cost. However, it is difficult for designers and researchers alike to assess the Guidance in exploration and ultimate value of such strategies. Specifically, little research exists to test the Guidance provided by a strategy relative to challenge addressed. Without such information designers are left to guess which strategy will have the greatest value and what the payback will be.

A research opportunity emerges to develop a method to measure and compare existing and emerging performance-based Design Processes. Designers need to be able to quantitatively characterize challenge, strategy and exploration to facilitate performance-based design process improvement. Review of literature reveals a lack of consistency in terms and concepts used in design theory. In this research, I define terms to facilitate clarity and consistency. I address my research questions in the following three chapters. Figure 3 illustrates the contributions of and the relationship between of these chapters.

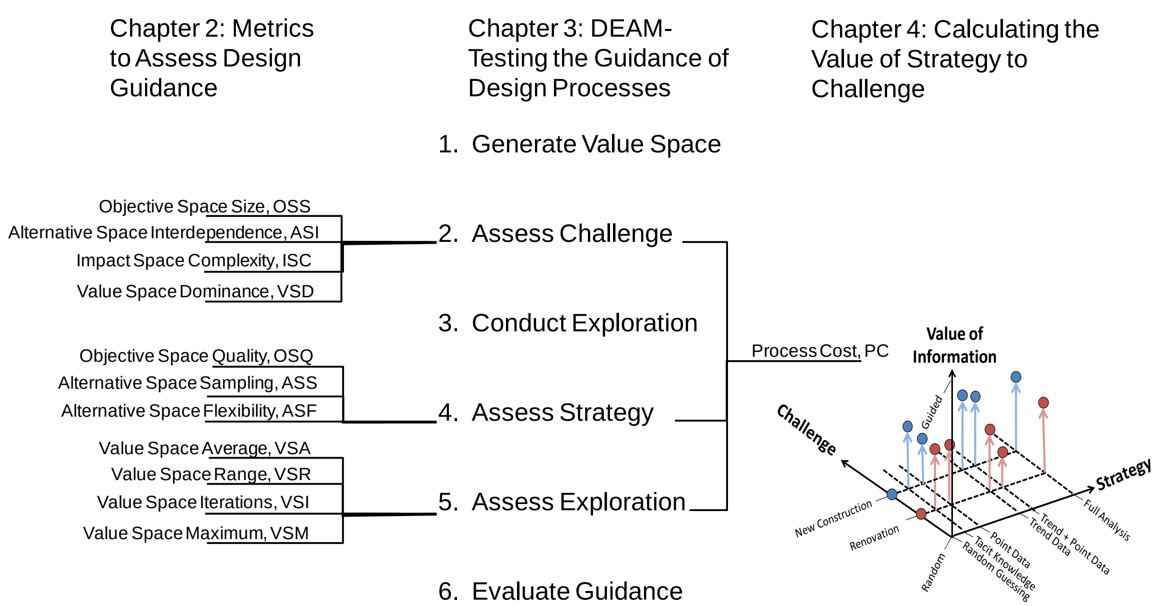

Figure 3: A summary of the relationships and contributions of this research. I synthesize a set of metrics for quantifying Design Processes (Chapter 2), and the Design Exploration Assessment Methodology (DEAM) (Chapter 3) to support the evaluation and comparison of Guidance afforded. The power and generality of DEAM is demonstrated by the ability to measure the Exploration enabled by applying six Strategies across two Challenges and to determine the Value of Information generated (Chapter 4).

In *Chapter 2: Metrics to Assess Design Guidance,* I lay the foundation for my research by precisely establishing definitions and metrics for performance-based Design Processes. These metrics provide a method for characterizing the challenge, strategy and exploration embodied. The contribution is the synthesis from literature of a framework of definitions and metrics to enable systematic and quantitative evaluation of the Guidance afforded by a given Design Process.

In Chapter 3: Design Exploration Assessment Methodology: Testing the Guidance of Design Processes, I develop and implement a Design Exploration Assessment Methodology (DEAM). I present the results of a laboratory experiment where I study the Explorations performed by professionals who implement six strategies, across two challenges. I rank the strategies tested according to their ability to guide exploration as follows: random guessing, tacit knowledge, combined point and trend analysis, point analysis, and trend analysis alone. The results are surprising: more data does not always help the designer. I discuss possible explanations, and conclude with a discussion on the strengths and weaknesses of DEAM.

In Chapter 4: Calculating the Value of Strategy to Challenge, I perform further computer experimentation to show that design challenges vary non-trivially. I introduce a new metric for the process cost of strategies. I use empirical data to calculate and compare the value of information generated by individual strategies across challenges. This work illustrates that that the optimal selection of strategy varies relative to challenge and motivates further development of advanced strategies.

AEC today is falling short of its potential to generate high performance designs. Precedent-based and even point-based strategies prove inadequate. Evolving and emerging advanced strategies create the need for methods to measure the Guidance they enable for specific Challenges. This research illuminates the multidimensional relationships between challenge, strategy and exploration. It provides evidence that Guidance can be assessed. The power of this research is to demonstrate that DEAM is an effective method to measure and compare the Guidance provided by various strategies for energy efficient design. The generality is that DEAM works across various design challenges and strategies, and is not domain specific. Initial findings support the development and selection of advanced strategies since they are shown to provide better Guidance economically. The value of information generated by Strategies, however, varies across Challenges. This finding makes different strategies more or less effective relative to the challenge addressed. This research motivates further work to develop greater understanding of the relationships and relative value of individual strategies to specific challenges.

REFERENCES

AIA. (2007). National Association of Counties Adopts AIA Challenge of Carbon Neutral Public Buildings by 2030.

Christensen, C., Anderson, R., Horowitz, S., Courtney, A., Spencer, J. (2006) BEopt™ Software for Building Energy Optimization: Features and Capabilities. NREL/TP-550-39929. Golden, Colo.: National Renewable Energy Laboratory.

Clevenger, C., Haymaker, J., (2009). Framework and Metrics for Assessing the Guidance of Design Processes, *The 17th International Conference on Engineering Design*, Stanford, California.

Clevenger, C., Haymaker, J., (2010a). Metrics to Assess Design Guidance, CIFE Technical Report 191, Stanford University, http://cife.stanford.edu/online.publications/TR191.pdf. Submitted to *Design Studies*.

Clevenger, C., Haymaker, J., Ehrich, A. (2010b). Design Exploration Assessment Methodology: Testing the Guidance of Design Processes, CIFE Technical Report 192, Stanford University, http://cife.stanford.edu/online.publications/TR192.pdf. Submitted to *Journal of Engineering Design.*

Clevenger, C., Haymaker, J., (2010c). Calculating the Value of Strategy to Challenge, CIFE Technical Report 193, Stanford University, http://cife.stanford.edu/online.publications/TR193.pdf. Submitted to *Building and Environment Journal.*

Clarke, J. A. (2001). Energy Simulation in Building Design (2 ed.): Butterworth-Heinemann

Crawley, D. B., Lawrie, L. K., Winkelmann, F. C., Buhl, W. F., Huang, Y. J., Pedersen, C. O., et al. (2001). EnergyPlus: creating a new-generation building energy simulation program.

Cross, N. (2004). Expertise in design: an overview. *Design Studies*, *25*(5), 427-441.

Cross, R., & Roozenburg, N. (1992). Modeling the design process in engineering and architecture. *Journal of Engineering Design, 3*(4).

Dorst, K., & Cross, N. (2001). Creativity in the design process: Co-evolution of problem-solution. *Design Studies*, 22, 425-437.

Flager, F. and Haymaker, J. (2007). “A Comparison of Multidisciplinary Design, Analysis and Optimization Processes in the Building Construction and Aerospace Industries,” 24th *International Conference on Information Technology in Construction*, I. Smith (ed.), pp. 625-630.

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

Gane, V., and Haymaker, J. (2007). “Conceptual Design of High-rises with Parametric Methods,” *Predicting the Future, 25th eCAADe Conference Proceedings*, ISBN 978-0-9541183-6-5 Frankfurt, Germany, pp. 293-301.

Gero, J. S. (1996). Creativity, emergence and evolution in design. *Knowledge-Based Systems*, 9, 435-448.

Maher, M. L., Poon, J., & Boulanger, S. (1996). Formalizing design exploration as co-evolution: A combined gene approach. Advances in Formal Design Methods for CAD.

Maile, T., Fischer, M. & Bazjanac, V., 2007. Building Energy Performance Simulation Tools – *a Life-Cycle and Interoperable Perspective.* CIFE Working Paper WP 107, Stanford University.

Papamichael, & Protzen. (1993). The limits of intelligence in design. *Proceedings of the Focus Symposium on Computer-Assisted Building Design Systems 4th International Symposium on Systems Research, Informatics and Cybernetics*.

Ross, A. M., & Hastings, D. E. (2005). The tradespace exploration paradigm. INCOSE 2005 International Symposium.

Shah, J., Vargas-Hernandez, N., & Smith, S. (2003). Metrics for measuring ideation effectiveness. *Design Studies, 24*(2), 111-134.

Watson, I., & Perera, S. (1997). Case-based design: A review and analysis of building design applications. *Journal of Artificial Intelligence for engineering Design, Analysis and Manufacturing AIEDAM, 11*(1), 59-87.

Wetter, M. (2001) GenOpt "Generic Optimization Program," *Seventh International IBPSAConference, Rio de Janeiro, Brazil.* (http://www.ibpsa.org/bs_01.htm).