Parametric Analysis versus Intuition

Assessment of the effectiveness of design expertise

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This paper explores through professional case studies how design solutions produced by expert teams compares to those developed through systematic parametric analysis. While the expert intuition of either single designer or teams helps to rapidly identify relevant aspects of the design problem and produce viable solutions, it has limitation to address multi-criteria design problems with conflicting objectives and searching for design alternatives. On the other hand, parametric analysis techniques in combination with data analysis methods helps to construct and analyze large design spaces of potential design solutions. For the purpose of this study, the specifications of geometric features and material properties of the building envelopes proposed by the expert design teams define the base line to measure the extent of the performance improvements of two typically conflicting objectives: Daylight quality and energy consumption. The results show consistently significant performance improvement after systematic optimization.

Keywords: *Performance Analysis, Parametric Analysis, Design Space, Design Expertise, Optimization*

INTRODUCTION

This study compares the performance of the intuitive design decisions of expert designers relative to the results of systematic design exploration and optimization processes. Literature describes design expertise as the set of knowledge and skills acquired through professional practice that play an essential role in intuitive rapid design responses (Cross, 2004; Lawson & Dorst, 2009; Schön, 1983). Until recently, the complexity and vastness of design spaces, and the time required to produce and quantitatively analyze design solutions, meant that intuition based on design expertise was necessary to drive a fast-paced professional design process. However, when making decisions that impact building performance, to what extent can designers rely on intuition based on experience to make those decisions? How can we verify such as effectiveness? Emergent computational tools and frameworks (Bernal, Haymaker, & Eastman, 2015; Haymaker et al., 2018) offer means to deeper explore the above questions since they allow analyzing large number of design alternatives in short period of time. For the purpose of this study, we analyzed sample case studies leaded by expert professional design teams. We modelled and quantified the differences in performance between professional design teams intuitive design process, and the outcomes of a systematic optimization process. The intent is to illuminate the role, and motivate more research in leveraging design space exploration tools in performance-based architectural design practice.

Literature on design cognition identifies at least six degrees of expertise: novice, beginner, competent, expert, master, and visionary. However, designers begin to show the ability to produce intuitive responses from the expert level (Dreyfus, 1997). In practice, this expertise is usually distributed among design team members. While some designers are just competent in some areas, they can be expert in others. These experts can recognize the problem, select the relevant aspects to focus on, reference new problems to recognizable problems and previous solutions (Dorst, 2007), generate possible alternatives (Lawson, 2004), co-evolve a problem and solution (Maher & Poon, 1996), and integrate knowledge across fields (Kruger & Cross, 2006). Expert designers manifest these processes intuitively to immediately build an interpretation of the problem without extensive evaluation or further analyses. They seems to know in advance the decisions and constraints that capture fundamental trade-offs of the problem and help them frame feasible solutions (Dabbeeru & Mukerjee, 2008). This intuitive behavior plays an important role in decision-making since often times, implicit and not even verbalized heuristics determine the design parti, assumptions, expected results, and the risks while exploring novel solutions and making design moves.

In recent years, parametric and generative design in combination with computational performance analysis have gave rise to techniques of Parametric Analysis (PA) (Roudsari, Pak, & Smith, 2013). The parametric topological architecture embedded in the schema enables geometric variations of the configuration (Oxman, 2017), while performance analysis tools evaluate every new design alternative. PA produces large data sets to supports a data driven decision-making process that, unlike intuition, is based on quantitative evidence and statistical levels of confidence. This paper explores professional case studies, the design developments of a high school and a research facility, to compare how design solutions produced by the intuition of expert design team with those developed through systematic PA. The aim of this study is questioning the accuracy of the design intuition to deal with conflicting objectives and quantifying the contribution of PA.

METHODOLOGY

The methodology assesses the effectiveness of the intuitive assumptions achieve acceptable balance of two typical conflicting objectives: Maximizing daylight illuminance and minimizing Energy Use Intensity (EUI) synthetized in a value function that assigns equal weights to both of them in the overall score. While EUI is expressed in kWh/m2 per year, daylight in the percentage of the occupied area within 300 and 3000 lux based on one of the LEED v4 options that averages four point in time, 9 am and 3 pm in September and March 21st. The intuitive assumptions assign input values to parameters that control geometric features such as window-to-wall rations and shading devices, specification for constructions related to energy performance and attributes relevant for daylight analysis. The process to evaluate the contribution of the systematic optimization process based on PA has the following steps:

Base line

The base line, or starting point to compare with, is the performance result for Illuminance and EUI of the design team intuitive assumptions. These assumptions are not random. On the contrary, they are based on professional experience and code recommendations.

Design Space

In collaboration with the design team, we generate a design space of alternatives by widening up down the assumptions of the original designs. For each parameter, we assign three to five possible values and calculate the full factorial of all possible combinations.

Sampling the Design Space

Since the combinations of multiple values for inputs parameters generate large design spaces ranging from thousands to billions, we use a Design of Experiment (DoE) technique for sampling and reducing the size of the alternatives to evaluate (Chlela, Husaunndee, Inard, & Riederer, 2009). This technique selects significantly different combinations of input values that represent the diversity of the design space with acceptable levels of confidence.

Parametric Analysis

A parametric model of every case study takes in a sequence of the combinations of inputs parameters produced by the DoE. Every simultaneous regeneration of the geometric model and update of the constructions and other attributes triggers the dynamic simulations of daylight illuminance and EUI. The Intuitive base line and the parametric analysis share the same parametric analytical model that includes the geometry and attributes required by the simulation engines, Radiance for Daylight, and Energy Plus for EUI. The implementation of the PA relies on a parametric modeling software that automates the geometric variations, and plugins that exchange information with the engines every time the parametric model updates the geometry.

Data analysis

Finally, we compare the results of the base line and scores achieved by the PA for design space exploration. This comparison entails qualitative and quantitative aspects. While the qualitative registers changes in the design strategy based on feedback from the PA, the quantitative compares the performance value of the intuitive assumptions with the min, max, and average of the DoE sample. The combination of these two different performance indicators in a single value function requires normalizing the results of the analyses of the DoE sample from zero, the minimum, to one, the maximum for both indicators. In addition, the EUI indicator needs inversion since the lower the number the better the performance. The value function represents the average of both normalized indicators also ranging from zero to one. The closer to one the higher the value and better overall performance according to the weights represented in the value function. Once the value function allow us to identify the best combination of indicators, we quantify the percentage of performance improvement by indicator (Clevenger & Haymaker, 2011).

Sensitivity Analysis

The Sensitivity Analysis (SA) correlates inputs and outputs of the PA, sorts in order of importance the inputs that affect the overall result (Hamby, 1994), and contributes to build interpretations and define priorities since identifies these parameters with major impact on the overall result.

CASE STUDIES

The case studies correspond to the work of expert design teams formed by a Project Designer (PD) and a Project Manager (PM) assisted by one or two Building Scientists (BS), all of them with around 20 years of experience. The remaining team members are Architects I, II and III, ranging from 15 to 3 years of experience. These teams have regular internal meetings, meetings with consultants and with clients. The case studies are a High School, and a Research Facility. Even though they differ in terms of design intent, strategy, location and program, they share the same objectives: Maximizing daylight illuminance and minimizing energy consumption.

Case Study 1: High School

The High School case study is the design of the envelope of a four-story classroom building. The original design intent was providing a sense of randomness by exploring different combinations of overhang and vertical fins by orientation. They are supposed to wrap a fully glazed surface that hypothetically perform equally in terms of daylight and solar radiation reduction on the facade while preserving the appearance of randomness. Sixteen parameters ranging from three to five options creates a design space of 8,1 billion of possible combinations (Table 1).

Parameters	Options	Total
Overhang depth N (ft.)	4, 8, 12, 16, 20	5
Overhang depth W (ft.)	4, 8, 12, 16, 20	5
Overhang depth S (ft.)	4, 8, 12, 16, 20	5
Overhang depth E (ft.)	4, 8, 12, 16, 20	5
Fin position N	next to glass = 0, center = 1, border =2	3
Fin position W	0,1,2	3
Fin position S	0,1,2	3
Fin position E	0,1,2	3
Fin spacing N (ft.)	1, 3, 5, 7	4
Fin spacing W (ft.)	1, 3, 5, 7	4
Fin spacing S (ft.)	1, 3, 5, 7	4
Fin spacing E (ft.)	1, 3, 5, 7	4
Fin rotation N (degrees)	-60, -30, 0, 30, 60	5
Fin rotation W (degrees)	-60, -30, 0, 30, 60	5
Fin rotation S (degrees)	-60, -30, 0, 30, 60	5
Fin rotation E (degrees)	-60, -30, 0, 30, 60	5
	Full Factorial Design Space	8,1 billion

Table 1
High school case study design space

Parameters	Options	Total
WWR N	50, 60	2
WWR W	20, 30	2
WWR S	50, 60	2
WWR E	20, 30	2
Wall U-Value	2.82, 3.53, 4.42, 5.29, 7.05	5
Roof R-Value	4.42, 5.29, 6.17, 7.05	4
Glazing U-Value	1.13, 1.17, 2.27, 2.84	4
SHGC	0.2, 0.25, 0.35, 0.4	4
	Full Factorial Design Space	5,120

Table 2
Research facility case study design space

Case Study 1	High School
Design Stage	Design Development
Climate Zone	3A
Intuitive Assumptions	Overhang depth (ft.): N 16, W8, S 4, E 8; Fin depth: 1.5 (ft.); Fin Rotation: 0°; Fin Position: Center; Fin Spacing (ft.): N 7, W 5, S 1, E 7
Base Line Score	65% % Illuminance, EUI 406 kWh/m2, Value: 0.577
Design Space	8,100,000,000
DoE Sample	64
PA Value	Min 0.49, Max 0.99, Avg 0.75
PA Best	81% illuminance, 401 kWh/m2 EUI
Improvements	21% in Illuminance, 1.2% in EUI
Sensitivity	Higher Impact: overhang depth N,S,E,W

Table 3
Results for case study 1, High School

Case Study 2: Research Facility
The two-story research facility explores different attributes for the envelope to control the impact of the internal loads of the laboratories. It has fenestration all over the perimeter to bring as much light as possible. Because of the North South orientation, the window-to-wall ratios East and West are low to avoid potential glare issues. Nine parameter ranging from two to five options create a design space of 5,120 possible combinations (Table 2).

RESULTS
The results show the score of the value function after the normalization of the illuminance and EUI indicators of the entire DoE sample per case study. This function assigns equal weight to both indicators. The base line based on the intuitive responses is normalized against of the DoE sample to enable comparisons with the results of the PA that are expressed in terms of minimum, maximum and average value. The best result of the PA is also expressed on the original metric. Finally, the difference in terms of value is calculates the percentage of improvement between the base line and the maximum value of the DoE sample after the PA.

Result Case Study 1
The intuition in the High School case study (Table 4) shows an intuitive approach that minimizes the depth of the overhang in the south façade and increases the density of the fins. However, the result of the base line scores 65% of the occupied areas within the desirable illuminance range and the reduction from 412.4 to 406 kWh/m2 that represents only 1.5% of improvement of the EUI because of the shading devices (Figure 1-2). The best results from the PA (Figure 2-3) show an improvement of 21% of daylight and an additional 1.2 % in EUI. The SA does not show a significant contribution of the fins for daylight control compared with the overhangs. In consequence, after the PA, the design strategy eliminated the fins and randomness, and specified only overhang depths by orientation for the final design.

Figure 1
Parallel Coordinate Plot showing the casi study 1 base line in the context of the DoE sample

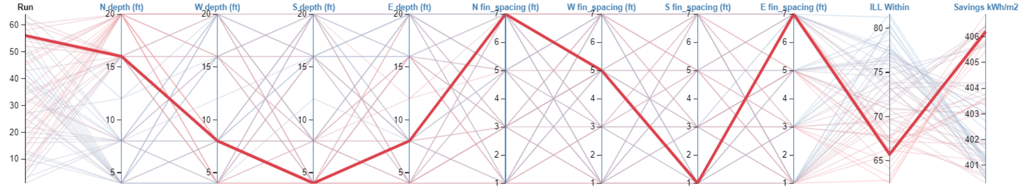


Figure 2
High school base line

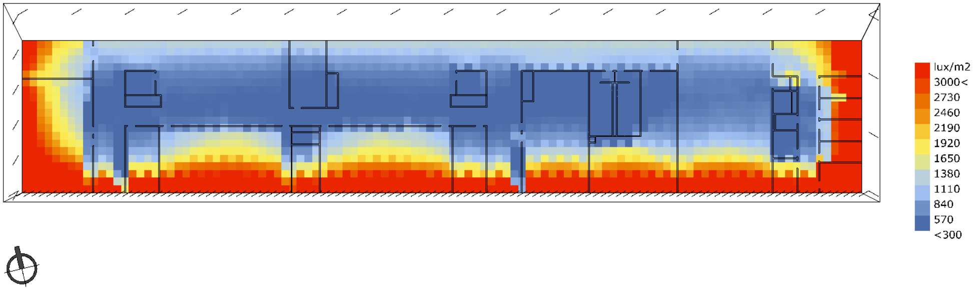


Figure 3
Parallel Coordinate Plot showing the case study 2 PA best result in the context of the DoE sample

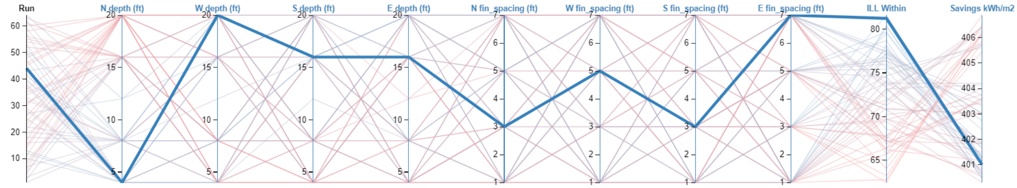
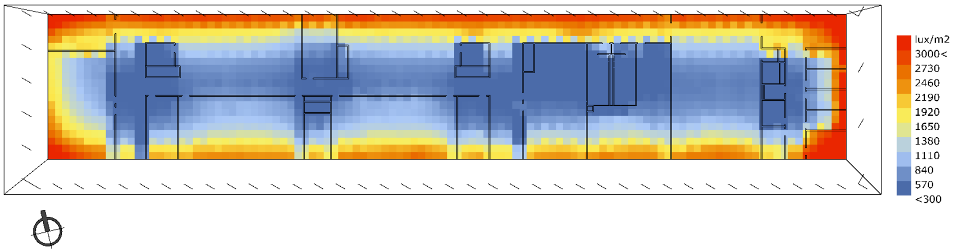


Figure 4
High school PA best result



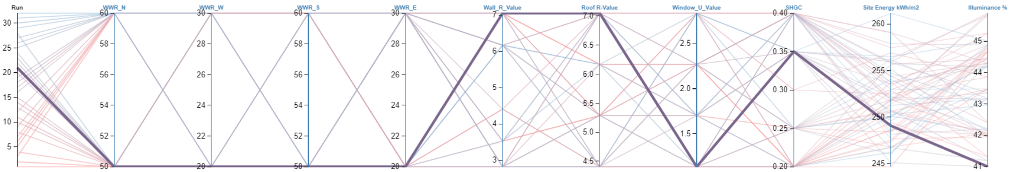


Figure 5
Parallel Coordinate Plot showing the case study 2 base line in the context of the DoE sample

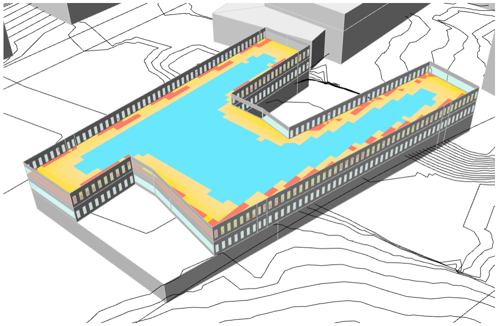


Figure 6
Research facility base line

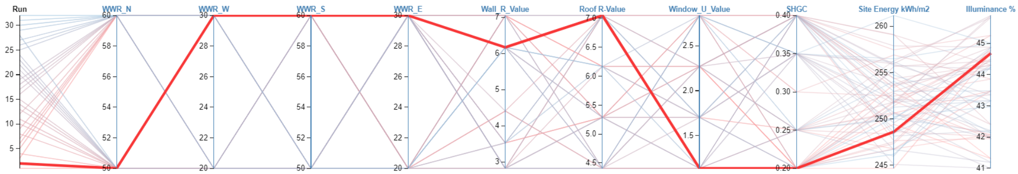


Figure 7
Parallel Coordinate Plot showing case study 2 PA best result according to the value function

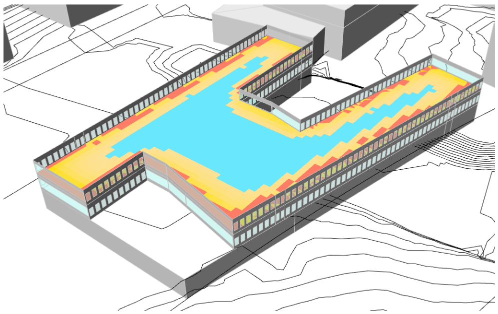


Figure 8
Research facility PA best result

Results Case Study 2

The intuition in the Research facility case study (Table 4) shows an intuitive approach that minimizes the window-to-wall ratios in every orientation. Even though the EUI remains comparative low because of the conservative attributes of the envelope, the result of the base line (Figure 5-6) only scores 41% of the total areas within the desirable illuminance range. The SA shows in order of importance a significant impact on the overall performance of the window-to-wall West, followed by the glazing U-Value, the SHGC, and window-to-wall N. The interpretation suggest a strategy that while increasing the size of the windows to allow more daylight coming in, also increasing the insulation of the building. These fine grain adjustments are difficult to calibrate without a systematic approach. The best result of the PA (Figure 7-8)show performance improvements of 7% in illuminance with an additional 2% in EUI. Based on the PA results, the design team next move was opening a courtyard in the core of the building to increase the amount of daylight coming while monitoring the parameters highlighted by the SA.

Table 4
Results for case study 2, Research facility

Case Study 2	Research Facility
Design Stage	Pursuit
Climate Zone:	4A
Assumptions	WWR%: 50 N, 20 W, 50 S, 20 E; Wall U-Value: 7; Roof U-Value: 7; Glazing U-Value: 1.7; SHGC: 0.35
Base line score	41% Illuminance, EUI 249 KWh/m2 Value: 0.48
Design Space	5,120
DoE Sample	32
PA Value	Min 0.26, Max 0.88 Average 0.55
PA Best	44% Illuminance, EUI 244 KWh/m2
Improvement	7 % in illuminance, 2% EUI
Sensitivity	Higher Impact: SHGC, WWRs E, W,S, Glazing U-Value

DISCUSSION

The migration of the architecture from static to parametric relationships, is not only updating the notion of design thinking, but also questioning the role and precision of the design intuition. The literature on design expertise states that experts can build an interpretation of the design problem without major analyses. The results of the PA of the DoE samples from different design scenarios show that intuitive process regularly underperforms recommendations from the PA process. Even though most of the experts' assumptions of this study are in the right track, the results from the systematic optimization consistently improve the performance of the original intuitive design. Furthermore, they also contribute to evolve the strategies by providing objective feedback that experts can use to make design changes. The results point out that even though their design strategies are viable; their ability to assess potential solutions seems to be less precise making assumptions for several parameters in trade-off spaces. In fact, the case studies, that are just a sample of a larger portfolio of professional projects, show consistent improvements after the systematic optimization. Even though expert designers recognize feasible solutions in advance, the results of this study show something slightly different: Their ability to avoid mistakes, and skip alternatives leading to poor performance. In addition, representing the wright of every indicator in a value function seems to be objective method for searching throughout the design space. Since different of priorities represented as variable weights of the indicators can lead to different solutions. Finally, the preliminary results reinforce the contribution of data driven decision-making processes on maximizing value from intuitive design strategies.

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