Building Skin Intelligence

A PARAMETRIC AND ALGORITHMIC TOOL FOR DAYLIGHTING PERFORMANCE DESIGN INTEGRATION

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ABSTRACT

The research presents a methodology and tool development which delineates a performance-based design integration to address the design, simulation, and proving of an intelligent building skin design and its impact on daylighting performance. Through the design of an algorithm and parametric process for integrating daylighting performance into the design phase an automated configuration evaluation is achieved. Specifically the tool enables design exploration of semi autonomous and fully autonomous configurations of an exterior building envelope louver system. The research situates itself in the field of intelligent building skins and adds to the existing solutions a validation of systems with interdependent louvers of varying tilt angles. The system is designed to respond to dynamic daylighting conditions and occupants' preferences. Within the framework of this study, Grasshopper, Rhino, Galapagos and DIVA, are linked and coded into one integrated process, facilitating design optioneering with near real time feedback. The paper concludes with a description of the tool set's extensibility, future incorporation of domain integration, and conflation of natural and physical system interaction and complexity.

Keywords: kinetic facades, parametric design, design integration, daylighting, performative design, design optioneering, realtime feedback

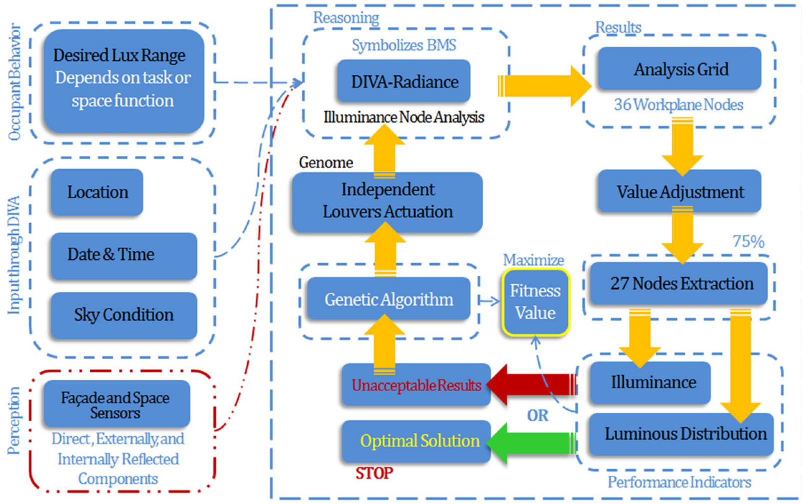

Fig. 1

1 Introduction

Heightened awareness of the importance of integrating performance criteria into design process has generated research and development of computational tools for numerous environmental and structural performance specialties (Kolarevic and Malkawi 2005, Shea 2005). Current Computer-Aided Design and Engineering (CAD/CAE) tools allow architects and engineers to simulate many different aspects of building performance (e.g. financial, structure, energy, lighting) (Gerber 2009, Fischer 2006). However, designers are often unable to leverage simulation tools early in the design process due to time required to complete a design cycle involving the generation and analysis of a design option using model-based CAD/CAE tools (Gerber 2007, Flager and Haymaker 2007). High design cycle latency in current practice has been attributed to software interoperability (Gallaher, O'Connor et al. 2004), lack of collaboration between design disciplines (Akin 2002; Zhao and Jin 2003; Holzer, Tengono et al. 2007), among other issues. While interactive architecture and building intelligence is a topic of current discourse, the research presents a solution for enabling performance evaluated intelligence of a simulated building skin. Here intelligence is understood as a responsive tool, which autonomously makes configuration decisions in search of an adaptive equilibrium to accommodate and optimize a complex set of environmental, and human performance criteria (Clements-Croome 2004).

This paper provides research that bridges the gap between architects and engineers, by addressing the limitations associated with incorporating performance criteria, here in particular the harvesting and optimizing of daylighting through the design, simulation, and semi-autonomous evaluation of a simple responsive and intelligent kinetic façade system. The intelligent actuation optimizes daylight-deflection for maintaining an optimal luminous indoor environment. Uniquely the tool explores and validates the concept of independent tilt-angle for exterior building envelope louver system.

The research enables domain integration and quantitative design optioneering further reducing design cycle latency through rapid design alternative generation and simultaneous evaluation. The research extends the development of performance-based design integration using real time feedback of data processed by technologies from three domains: (1) architectural design, (2) physics based daylighting performance and (3) parametric and algorithmic design computation. The paper demonstrates an intelligent building skin daylight optimization and concludes with implications of the method and tool to increase domain integration and improve upon design complexity management of future natural and physical system incorporations.

Figure 1. *Diagram of the operational logic of the 'Building Skin Intelligence' algorithm and data flow*

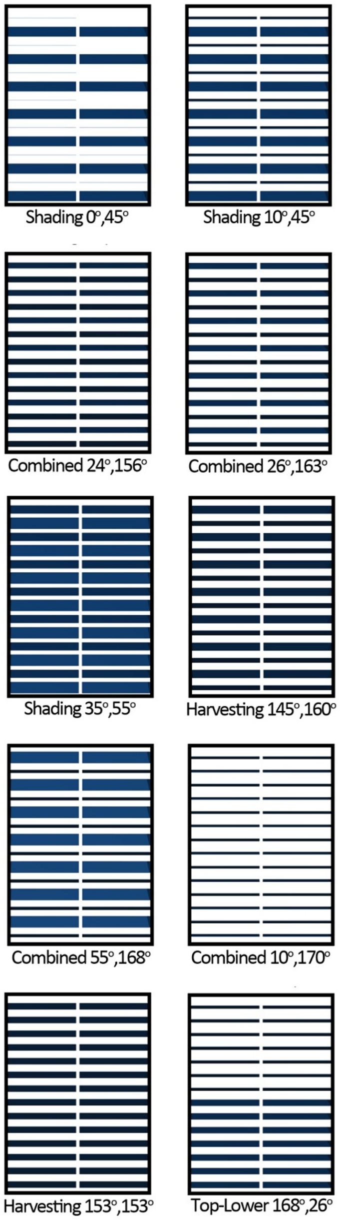

Fig. 2a

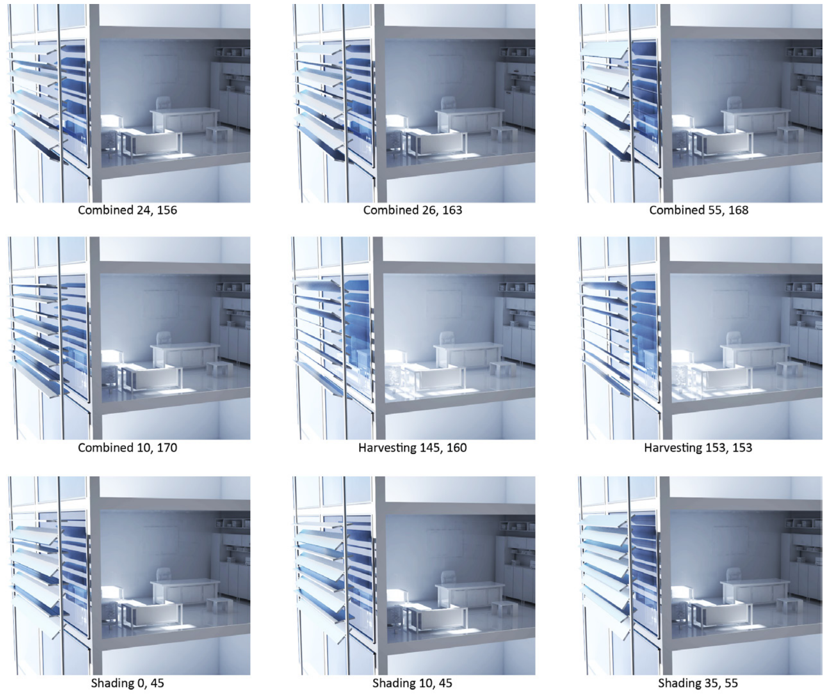

Fig. 2b

Figures 2a/b. *Elevation and 3D views of sub set of louver configuration simulations showing the transparency to the outdoor environment, highlighting parameter values in conjunction with user viewing and daylight penetration and quality*

2 Problem Definition

Our research targets a series of interlinked design and engineering problems: one, design integration through tool development; two, design process improvement through the incorporation of physics based modeling and real world dynamics and complexity; and three, solutions for early stage decision making and a priori methods for minimizing energy and carbon footprint of buildings. Lighting accounts for 20-25% (Ander 2003) of the total electrical energy use in buildings, and in the commercial buildings 30-50% (Phillips 2004). Significant energy savings can be gained if the design process encompasses thoughtful daylighting strategies incorporated into the design process. As a rule of thumb, each unit of electric light requires an additional one-half unit of electricity for space conditioning (Ander 2003) further exacerbating running costs. Improved daylighting design increases the efficiency of lighting by utilizing less electrical lighting and exploiting available natural light that has been proven to result in better worker's productivity and morale (Ander 2003). The daylighting profession uses many solutions for performance-based design; kinetic façade systems are amongst these solutions. However, a real world problem exists; kinetic louver systems have yet to be designed to work for daylight throw optimality and quality of luminous environments. Therefore the research asks the question, how one designs a responsive kinetic louver system autonomously so as to most efficiently harvest daylight. The purpose of which is to reduce a building's overall energy footprint while maximizing human comfort and here in particular lighting for working conditions.

This research addresses a narrow digital design problem and specific performance integration and optimization, that of designing for hyper efficient daylight harvesting through kinetic and semi-autonomous external louver systems. The research experiment incorporates the use of parametric design methodologies, algorithmic design, dynamic simulation, and further validates the importance of design computation and automation for harnessing and '*designing in*' issues of project performance complexity.

3 '*Designing-in*' the Daylight Performance Workflow

Through the incorporation of kinetic and autonomous systems, designers are being exposed to the challenges and limitations of incorporating motion into geometry modeling and formal design (Wierzbicki-Neagu 2005) and more poignantly the

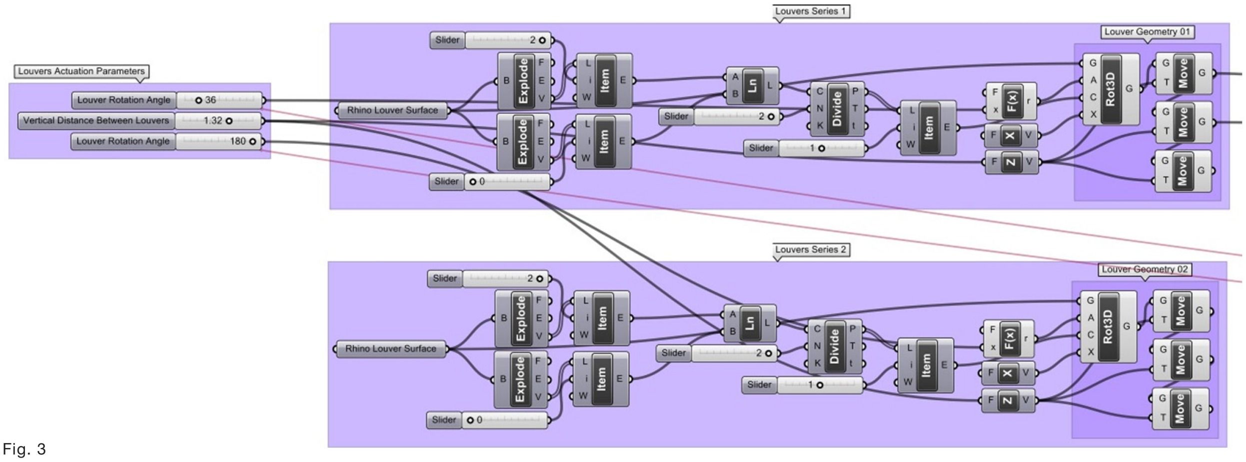

Fig. 3

Figure 3. *Illustration of parametric logic of louvers within Grasshopper Algorithm*

validation of performance criteria in these design centric phases. A key feature within the workflow, the tackling of complexity and performance of kinetic façade design, is the integrated daylighting simulation and evaluation process enabled through the linking of parametric and algorithmic tool sets. The efficiency and design cycle latency reduction of our methodology is achieved through the newfound ability of a designer to rapidly design optioneer - generate and evaluate design alternatives - and through domain specific tool integration. The workflow presented leverages the interoperability between the parametric and algorithmic tools described subsequently, which allow for the execution of kinetic façade designs that require realtime feedback and seamless data streaming.

The workflow operates in a closed-loop control system where daylighting data is being continuously fed to a layer of simulated work-plane sensors which detect changes in the environmental conditions or occupants' behavior, which then triggers the system to actuate, evaluate and self optimize to maintain the desired luminous conditions. The logic incorporated requires defining the following performance criteria: (1) illuminance and (2) luminous distribution (contrast ratio), and a set of inputs upon which the search process operates. These inputs include user preferences/task requirements, weather data, and external or internal surface reflections **(Figure 1)**. All except the user input/task requirements are collected through DIVA for simulation purposes, which calls Radiance for performing daylighting calculations. The user input symbolizes changes in tasks-activities in space.

The research and experiment is based on the use of off the shelf parametric tools and the custom coding and linking of these tools to simulate and evaluate a real world condition: that of daylight throw, quantity and quality. Through background literature review and survey we have not found an existing tool and methodology to optimize efficiently the complex interaction proposed and in particular the designing of a system which validates independent tilt angle of an intelligent external kinetic louver system.

The experiment design uses a simplified office space which is modeled within a parametric design engine, Rhinoceros/Grasshopper. Through the defining of a set of variables: geometries of the kinetic louver system, the performance and space driven constraints, and a set of design drivers, the tool (1) automates iteration upon parameter value changes, and (2) externalizes them to interface with an algorithmic evaluation and optimization technique. Most significantly, the use of such tools does not only allow for rapid generation of designer driven design alternatives, enabling design exploration of a larger solution space without extending design cycle latency, but incorporates instant evaluation of daylight performance when façade elements actuate or environmental conditions change.

The workflow uses the following tools to develop the logic of the algorithm: (1) Rhinoceros as the 3D NURBS-based modeling program; (2) Grasshopper as the graphical parametric definition and automation platform; (3) DIVA as a daylighting simulation tool which supports a series of performance evaluations including links

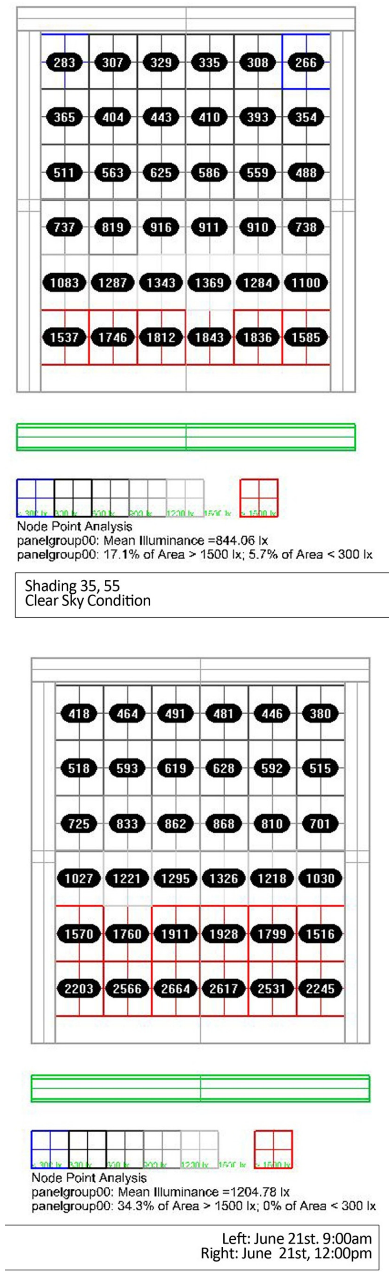

Fig. 4

Figure 4. *2 illuminance node point value maps from the DIVA plug-in simulations for 2 different time samples, 9AM and noon for one of the 156 simulation runs*

to Radiance, Daysim, and Evalglare; and (4) Galapagos as the genetic algorithm component for Grasshopper. Animated building performance can be achieved through using a DIVA component in the Grasshopper script, which provides dynamic visualization of daylighting performance. The integration provides designers with instant feedback of building performance by reflecting the results on the architectural model in the Rhinoceros scene using false-color mappings; hence, facilitating the decision making at the schematic design stage (Lagios, et al. 2010). The algorithm is used as a design tool for exploring kinetic façades geometries and actuation scenarios for optimizing daylighting performance at different times of the year.

3.1 PARAMETRIC PROCESS AND ALGORITHM DESCRIPTION

The tool is developed first as a parametric model in which variable geometries are defined and fixed or constraints are associated. The 3D model and components are then actuated through the algorithm simulating intelligently evaluated independent tilt angle louver system configurations **(Figures 2a/b)**. Given two independently-actuating façade layers, the algorithm's geometry definition is split into two angle controls each of which operates one layer of the louvers **(Figure 3)**. The design of the secondary skin originates in Rhino, from a simple pair of rectangular louvers. The research defined variables for skin alterations are the rotation angle of the louvers and the distance between them. The rotation angle is set to a range of 0^0 to 180^0 for every other louver, where 0^0 to 90^0 allows for a "shading" configuration, and 90^0 to 180^0 allows for daylight "redirection." A range of 0.50m to 2.00m is set as the distance between louvers. This enables different configurations that allow louvers to overlap for more surface reflections, less obstruction, more light penetration and better views of the outdoor environment.

Then within the algorithm, the louver geometry is connected to the daylighting analysis component, DIVA version 1.1 which uses Radiance as the daylighting calculation engine. Results are passed simultaneously to two main evaluation functions of the algorithm – (1) illuminance and (2) luminous distribution - calculations. These values are filtered based on the Illuminating Engineering Society of North America (IESNA) recommendations for illuminance levels in office spaces which range from 300 lux to 1500 lux, depending on the type of tasks (IES North America 2000). The algorithm then evaluates the space for three particular criteria, whether: (1) 75% of the nodes are within desired illuminance range (300-1500 lux); (2) the luminous distribution in terms of contrast ratio between highest and lowest node values exceeds 1:10 (IES North America 2000); and (3) whether the nodes – beyond a distance twice window height – are within acceptable illuminance range. All values are then sent to the genetic algorithm. These values are then sorted in a descending order. The target of the study is to bring at least 75% of the 36 work-plane calculation points into the range for acceptable luminous environment. After which a series of "list item" components are used to extract the values of 75% of the total nodes inside the space; hence the "mass addition" of 75% of the nodes should give a total of "27", in case of an acceptable scheme. If the total value is less than "27", the scheme is considered unacceptable.

Concurrently, while results are evaluated for illumination levels, another function of the algorithm is testing the results for luminous distribution (contrast ratio) evaluation. Since the illuminance values have been sorted in a descending order, the highest point will have an index of "0" and the lowest value will have an index of "26"; both values are extracted using the "list item" component and divided by each other. If the resultant numeric value is within 1:10 ratio for luminous distribution or contrast ratio, the scheme is considered acceptable and the opposite is correct.

In order to add to the efficacy of the experiment, a genetic algorithm has been incorporated into the definition to enable a search of the best skin configuration at specific dates and times, and under different sky conditions. The genetic algorithm works on finding a suboptimal solution that fits certain parameters and conditions, predefined by the designer. Galapagos – a genetic algorithm component – is used and run based on our "one" numeric fitness value which is a result of dividing the

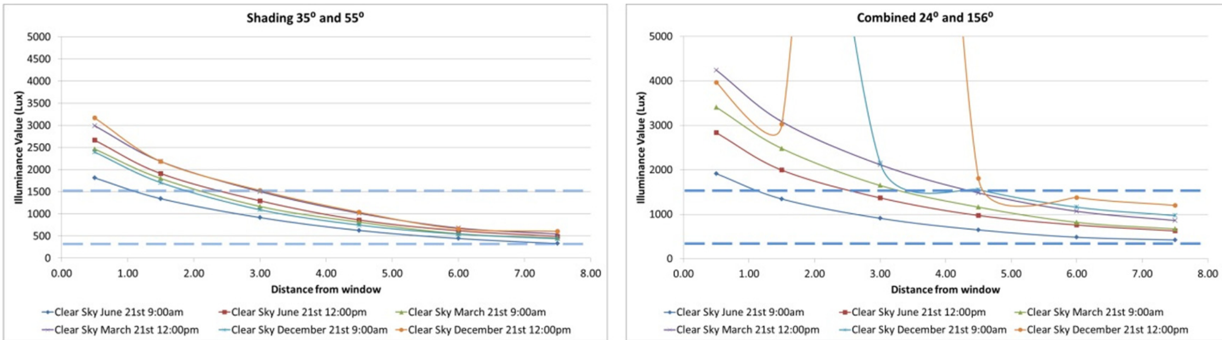

Fig. 5

value of illuminance (numerator) by the luminous distribution value (denominator); Galapagos works on maximizing the fitness value. The algorithm operates by randomly generating numerous skin configuration louver combinations, evaluating a different configuration each time, recording the results, and so on until it hones in on a group of skin configurations that maximize the quality and throw of daylighting, falls within the indicators' boundaries, and have the highest numerical fitness value as desired.

4 Tool Validation and Data Analysis

The experimental set up is designed to validate an optimized daylighting penetration while maintaining lighting quality,optimal illumination and even luminous distribution. The tool has been tested, through simulating a series of tilt-angles at different times of the year: March 21st, June 21st, and December 21st, each at 9:00am and 12:00pm for clear and over-cast sky conditions. Our study's simulation cases are based on a precedent validation method and sampling of various tilt angles derived by McGuire; however, this research extends beyond internal blinds and ceiling illuminance to the more important environmental factors of the luminous environment quality (McGuire 2005). Beyond the precedent research, our sampling includes different tilt-angles in shading, re-directing and combined configurations.

A generic office space with dimensions of 6.00m width, 7.50m depth, and fully-glazed height of 3.00m is modeled in Rhinoceros. The interior surfaces are assigned reflectance of 80% for ceiling, 50% for walls, and 20% for floor. The external louver system is assigned a reflectance value of 90%. The opening is assigned generic doubled glazed material with 72% visual transmittance. A calculation grid is placed at a work-plane height of 0.75m and divided into 36 calculation illuminance nodes. Los Angeles is chosen to be the location of the test due to its climate data (NCDC 2011).

Figure 4 presents two of the 156 simulation runs performed in this study. The shading 35º-55º scheme showed 61% of the work-plane nodes within a desirable illumination range. This configuration presented successful results at 9:00am on December 21st and at 9:00am on June 21st; 71.4% and 77.2%, of the entire surface fell within the recommended illumination range, respectively. This louver configuration resulted in a contrast ratio of approximately 10% which, according to IES, is an acceptable luminous performance. The combined 24º-156º scheme showed only 42% of the nodes falling within the recommended illumination range; it does not meet the objective of the algorithm. Though the configuration can be understood as in part unsuccessful, i.e. out of range, it in fact emphasizes a validation of an 'intelligent'skin, namely that it can self- optimize per user input and may not always default to overall optimized daylight harvest and uniformity. For example, if the occupant is working on high-contrast tasks at the back of the space, desired illumination levels can be closer to the lower boundaries (300 lux) of the recommended range, providing adequate illumination at 3.00m from the window and beyond. If the occupant switches to a low contrast task, he/she will require more illumination closer to the upper boundary (1500 lux) of the recommended range (Figure 5); though it will result in undesired levels at distances closer than 4.50m from the window. What is critical is that the system design

Figure 5. *Graphs illustrating the data and analysis from the testing of the system, demonstrating illuminance values over distance from window wall*

can be asked to optimize for both task specific and overall generic daylight harvesting and light quality.

The data most significantly illustrates an increased throw and improved upon distribution of daylighting while including input from user driven workplane task light requirements. The research methodology and algorithm has been specifically limited to integrating illumination levels, luminous distribution (contrast ratio), and the penetration depth of daylighting into the space. The research was further limited by data exchange capabilities of DIVA 1.1 in its current version. However, manual simulations were performed to validate the quantitative results. The manual simulations were run for 13 configurations, each of which had 12 conditions, a sampling of 156 simulation runs, drawn from the precedent study by (McGuire 2005). Given the limitations, the selected configurations are not necessarily what the algorithm would have picked autonomously as optimal solutions. However, as a means to validate the results which indicate clearly an improved upon daylight throw and quality, the sampled configurations do illustrate a quantifiably increased harvest in conjunction with the user defined preferences and scenarios. This increase in daylight throw from 2X to 2.5X the window wall height is considered significant within the daylight harvesting community and within the interactive architecture community.The successful incorporation of user defined task environment preferences is as well (Wyckmans 2005).

5 Conclusions

The paper presents the current state of a new methodology and the development of a parametric and algorithmic tool implementation to simulate daylight efficiency for design centric phases of architecture. While the experiment design is at present simplified the research clearly indicates that through the incorporation of daylighting sciences, design computation and an empirical research methodology, design teams can begin to implement the system to manage the simulation and evaluation of daylighting during the design process. The study showed the enhancing of daylighting performance in indoor spaces in complex response to occupants' preferences and task requirements. Most poignantly the research proves that through the automation of independent tilt angles the '*Building Intelligent Skin*' system can improve significantly, from 2X to 2.5X upon daylight harvesting throw and luminance optimality. The tool, methodology, analysis and findings demonstrate that the research contributes to the three problems enumerated; design domain integration, *designing-in* real world complexity, and finally minimizing building energy footprints.

6 Future Work

The future domain integrations include the application of the tool and methodology to more complex geometry, intrinsic and extrinsic to the '*Building Intelligent Skin*' System; the incorporation of more complex and precise energy performance factors; and finally the integration of social sciences and human behavior to better 'design-in' the real world complexity of natural and physical system interactions. The Phare tower in Paris by Morphosis is the initial case study for the research to be completed. While the tower incorporates an "optimized" static skin system that enhances the energy performance of the architecture and maximizes the glare-free daylit indoor spaces (Morphopedia 2011), it does not provide the occupants with optimal illumination over a course of changing solar conditions. And because it lacks intelligent-responsive kinetic capabilities, the external louvers skin is not capable of optimizing illumination at all times of the year. This problem presents an ideal real-life case study for validating the effectiveness of the proposed technique in the real world. Fundamentally the work will seek to contribute further to design domain integration and design optioneering through completing and analyzing its applications to real world projects.

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