Ain Shams University
Faculty of Engineering
Department of Architecture Engineering

Utilizing Genetic Algorithms and Parametric Design for Efficient Daylighting Performance in Educational Spaces

A thesis Presented in Partial Fulfillment of the Requirements for Master of Science Degree in Architecture Engineering

By

Fatma Mohamed Fathy Ahmed AbdelAziz

BSc in Architecture 2012- Ain Shams University

Under Supervision

Professor Dr. Yasser Mohamed Mansour
Professor of Architecture and the Head of the Department of Architecture
Ain Shams University

Professor Dr. Hanan Mostafa Kamal Sabry
Professor of Architecture and Environmental Control
Ain Shams University

Dr. Sherif Morad AbdelKader AbdelMohsen
Assistant Professor of Architecture
Ain Shams University

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Disclaimer

This thesis is submitted as partial fulfillment of M.Sc degree in Architecture, Faculty of Engineering, Ain Shams University.

The work included in this thesis was carried out by the author during the period from May 2014 to September 2015, and no part of it has been submitted for a degree or qualification at any other scientific entity.

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Name: Fatma Mohamed Fathy

Signature:

Date:

Examiners Committee

Board	Signature
Professor Dr. Yasser Hosny Sakr Professor of Architecture and President of Helwan University	
Professor Dr. Samir Sadek Hosny Professor of Architecture Department of Architecture Faculty of Engineering Ain Shams University & The Head of the Department of Architecture Engineering in FUE	
Professor Dr. Yasser Mohamed Mansour Professor of Architecture and the Head of the Department of Architecture Faculty of Engineering Ain Shams University	
Professor Dr. Hanan Mostafa Kamal Sabry Professor of Architecture and Environmental Control Department of Architecture Faculty of Engineering Ain Shams University	

Acknowledgement

First, I would like to express my gratitude to my supervisors: *Prof. Dr. Yasser Mansour* for his continuous support and encouragement; *Prof. Dr. Hanan Sabry* for her valuable feedback and guidance -She was the first to put me on this track and I would like to thank her for believing in me- *Dr. Sherif Morad* for his insightful comments and tolerance. I pride myself on being one of their students so thank you for giving me this opportunity.

I am also grateful to all of the department faculty members, professors, colleagues, and friends who directly or indirectly have supported me. I am honored to be one of them.

A special thanks to *Arch. Ayman Wagdy* for his priceless parametric workshops and generous feedback. His expertise has greatly assisted this research. It would not have been the way it looks except for the innovative tool he developed for parallel simulation.

At last, I wanted to take this opportunity to thank my parents and my brother for everything they made. I believe that I wouldn't have reached this point without them.

Abstract

Building simulation tools are used in many domains for the evaluation of various performance criteria. Due to the uprising awareness of more efficient and greener buildings besides, the recent progress in computational techniques, this trend became easier to evolve than ever before. However, design problems cannot be completely explored merely through these tools. They are useful in the analysis and the evaluation of a specific design, or a limited number of alternatives, according to certain criteria. On the other hand, they are not efficient for evaluating a large number of solutions. Hence, the integration of parametric design with genetic algorithms as an optimization tool was investigated as an approach to overcome this problem. A focus of this integration was in conceptual design phase, which returns to the key impacts of decisions taken in this phase.

In chapter one, an emphasis was on performance models and how *"performance"* issues were incorporated in different design models to serve as the driving engine for design exploration. By paying attention to the capabilities of generative models in capturing formal qualities, the integrated approach "generative Performative approach" was highlighted. Moreover, contributions of optimization algorithms in reaching high performance designs were investigated.

In chapter two, the investigated performance criteria was set to be daylighting design. Daylighting is an important building aspect that needs concern from the early beginning of the design process. Still successful daylighting design is a challenging task due to the conflicting requirements to reach the balance between daylighting adequacy and visual comfort. Besides, the fluctuating nature of daylight along the day and year complicates the process. Hence, the significance of integrating optimization algorithms for efficient daylighting design was discussed.

In chapter three, different generative systems were explored for pattern generation, focusing on cellular automata (CA). As a matter of fact, they lack the capability of meeting performance requirements without being guided by performance feedback. Thus, CA was integrated with Genetic Algorithms (GAs) to explore their effectiveness in solar screen formation. The designed solar screen was intended to meet daylighting performance requirements of a south oriented classroom in Cairo. An exhaustive search method was first applied and then was replaced by GAs.

In chapter four, findings of the classroom case study were discussed. All investigated CA rules proved their applicability in reaching satisfactory solutions in terms of the assigned daylighting criteria. In addition, GAs revealed their robustness in finding satisfactory solutions with less computational demands than the exhaustive search method which could be impractical in other cases.

The last chapter introduced the conclusions and recommendations. It elaborated the potentials of parametric design coupled with Genetic Algorithms (GAs) as an optimization tool in reaching highly efficient solutions. A workflow for utilizing generative performative design approach was suggested to meet designers’ subjective visual demands and the required performance criteria. At last, future research concerned with optimization studies for building design was suggested.

Acronyms

ASE: Annual Sunlight Exposure

BOP: Building Optimization Problems

BPS: Building Performance Simulation

CA: Cellular Automata

DA: Daylight Availability

DA_{con}: Continous Daylight Availability

DDPM: Dynamic Daylight Performance Metrics

DF: Daylight Factor

GAs: Genetic Algorithms

GUI: Graphical User Interface

IES: Illuminating Engineering Society

LEED: Leadership in Energy and Environmental Design

LS: L-Systems

NSGAII: Non-dominated and crowding sorting genetic algorithm II

NURBS: Non-Uniformal Rational Basis Spline

PSO: Particle Swarm Optimization

SA: Simulated Annealing

sDA: Spatial Daylight Autonomy

SG: Shape Grammars

SQP: Sequential Quadratic Programming

UDI: Useful Daylight Illuminance

WWR: Window to Wall Ratio

Keywords

Daylighting Simulation- Genetic Algorithms- Cellular Automata- Parametric Design- Generative Systems- Solar Screen- Performative Design

Software Used

DIVA: It is a simulation program which interfaces *Radiance and Daysim* engines for the daylighting calculations and *EnergyPlus* engine for thermal analysis. It stands for Design, Iterate, Validate, and Adapt.

Galapagos: It is an evolutionary solver for optimization in Grasshopper which was used to represent Genetic Algorithms.

Grasshopper: It is a graphical algorithm editor as a plug-in Rhino 3-D modelling software for parametric modelling without the need for a prior experience in programming.

Rabbit: it is a plug-in for Grasshopper which can explore pattern formations using Cellular Automata as a generative system.

Rhino: It is 3-D NURBs modelling software used for computer graphics and as computer aided design tool.

Speed-Sim: It is a parallel simulation tool used for DIVA in Grasshopper. It exploits the number of cores in the computer to speed the simulation time.

Other Software

BEopt (Building Energy Optimization): It is an optimization software that can evaluate residential building designs which uses EnergyPlus for simulation analysis.

DOE-2: It is a building program for energy analysis which can perform hourly simulation to predict energy use and cost.

GenOpt®: it is an optimization tool for multi-dimensional problems which can be coupled with simulation programs like EnergyPlus *(a whole energy simulation program).*

ParaGen: It is a tool that explore design alternatives combining parametric modeling, performance simulation software and genetic algorithms.

TRNSYS: It is an energy simulation software package.

GENE-ARCH: It is design tool that combines DOE-2 for the simulation analysis with Genetic Algorithms as the search engine.

Important Definitions

Algorithm: It is a number of steps to find a solution for a definite problem.

Cellular Automata: It is a well-known generative system that imparts a sense of visual quality and guides form generation**.**

Black count: It is the number of solid cells in the first row of the screen array. It controls the openness factor of the solar screen.

Circadian System: It is acting as a biological clock in the human beings affecting sleep patterns and alertness level and it is regulated by daylight.

Deterministic algorithms: They take predictable exact values as an input for the design variables thus, they do not accept the possibility of chance or probability

Exhaustive enumeration method: An optimization method where all possible solutions are evaluated. They are most probably not practical due to computational time.

Generative Design: It is a rule-based design process through which design forms are generated.

Generative Performative Design: An integrated design approach that combines Performative design and generative systems.

Genetic Algorithms (GAs): They are an evolutionary algorithm that are used widely in building optimization. They work on replacing a population of solution with another fitter population by simulating the genetic operators of reproduction, mutation and crossover.

Heuristic methods: They are problem solving techniques that enable searching and discovering the design space.

Optimization: To make something perfect, functional or effective as possible which could be by finding the maximum or minimum of a function.

Parametric Design: It is a design process in which numerous design alternatives of building models can be generated through the identification of a set of relationships between the geometric entities. Interdependencies are governed by mathematical function(s).

Pareto optimal/optimization: It is referred to multi-optimization problems where no objective can be better unless the other is negatively affected.