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Optimization of Building form to Minimize Energy Consumption through Parametric Modelling

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Abstract

The assessment of a building's energy performance as a design factor in the early design stages is a very demanding and complex procedure. Over the last decades, a number of tools and methods have been developed to address performance-related design questions, mostly using Multi-Objective Optimization Algorithms. Parametric modelling offers dynamic control over geometry and components, allowing the designer to assess multiple variants at the same time. In this paper, a new design workflow methodology is proposed, integrating evolutionary algorithms and energy simulation through Grasshopper for Rhinoceros 3d, for a comprehensive exploration of performance-based design alternatives in the building scale.

Peer-review under responsibility of the organizing committee of SBE16.

Keywords: evolutionary algorithms; multi-objective optimization; environmental design; visual programming; generative design; parametric modelling.

1. Introduction

Energy savings in the building sector has evolved to a major research topic over the course to a sustainable and low-carbon society. The environmental design of buildings addresses the issue of energy efficiency whilst maintaining adequate thermal and optical comfort over an aesthetic and functional architectural form. The methods currently used, rely on simulation models to predict the thermal behavior of the future construction. However, due to their time-consuming and specialized nature, these models are usually intended for the analysis of an already designed building or for the assessment of a small number of alternative solutions, rather than the synthesis of an

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optimal one. The assessment of a building's energy performance as a design factor in the early design stages is a complex procedure which, nonetheless, can have a great impact on its energy expenditure. Towards that direction, a number of tools and methods have been developed to address performance-related design questions, mostly using Multi-Objective Optimization (MOO) Algorithms.

Computational Generative Design or Parametric/Algorithmic Modelling, an emerging trend in architecture during the last decades, is now considered a valuable tool to explore design potential and enrich the process of architectural synthesis. When designing forms or systems, this method offers dynamic control over geometry and components, allowing the designer to seek appropriate solutions on complex problems with the assessment of multiple variants at the same time. Visual/graphical coding tools for design, such as Dynamo Studio for Autodesk Revit or Grasshopper for Rhinoceros 3D, offer the opportunity to implement parametric design concepts using visual logic, thus automating complex tasks.

This paper aims to explore the capabilities and current limitations of performance-driven generative design in architecture, through an introduction of a new architectural workflow methodology where genetic algorithms and energy simulation are integrated in the synthetic procedure, for a comprehensive exploration of performance-based design alternatives in the building scale.

Nomenclature

MOO	Multi-Objective Optimization
VP	Visual Programming
EAs	Evolutionary Algorithms
MOEAs	Multi-Objective Evolutionary Algorithms
BPS	Building Performance Simulation

2. Performance-based generative design: an overview

2.1. Performance simulation in building design

Computer simulations are a powerful tool for studying the environmental performance of buildings since they provide useful feedback for the on-going process of design. In 2000, W. N. Hien et al.[1] concluded that the main reasons architectural firms would not use simulation tools in the design process were lack of pressure/appreciation from the client, high cost of software acquisition and insufficient staff training/skills due to steep learning curves and not user friendly interfaces that would extend the, already limited, design time. Since that time, a lot has changed in the field, and simulation software has become widely available and specialized, influencing the way buildings are designed, analyzed and constructed. In the Building Energy Software Tools (BEST) directory website[2], formerly hosted by the US Department of Energy, one can search and find information on all the available simulation software for energy, lighting, acoustics, indoor air quality simulation, solar and photovoltaic analysis, etc.

A considerable amount of comparative studies and reviews concerning Building Performance Simulation (BPS) is available. T. Ostergard et al.[3] have categorized these studies into several topics, such as solar design[4], simulation software and tools[5], sensitivity analysis methods[6], computational optimization methods[7] etc. Whilst BPS is mostly valuable in the early design stages (when design decisions have a major impact on a building's resulting environmental performance, construction and operational costs) its application is still reduced in the final design stages due to several challenges, such as time-consuming modeling, large design variability, conflicting requirements, input uncertainties and other factors[3].

2.2. Computational building optimization and evolutionary algorithms

From as early as 1990, N. M. Bouchlaghem and K. M. Letherman[8] have introduced a numerical optimization method applied to the thermal design of non-air-conditioned buildings, combining an optimization technique and a thermal analysis model. Early optimization studies used the generic optimization process[9], but soon it became clear