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Energy performance optimization as a generative design tool for nearly zero energy buildings

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Abstract

In order to effectively design nearly Zero Energy Buildings, the assessment of energy performance in the early design stages through simulation is an important, although very demanding and complex, procedure. Over the last decades, various tools and methods have been developed to address performance-related design questions, mostly using Multi-Objective Optimization Algorithms. Technological advances have revolutionized the way Architects design and think, automating complex tasks and allowing the assessment of multiple variants at the same time. In this paper, a new nZEB design workflow methodology is proposed, integrating evolutionary algorithms and energy simulation, and its capabilities and current limitations are explored.

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

1. Introduction

On our path to achieve a sustainable and low-carbon society and in order to address the incredibly high percentage of end-use energy buildings consume, energy conservation measures have been introduced in the building design and construction industry, during the last decades, worldwide. Consequently, the environmental design of buildings has evolved to a major research topic. In this context, the Directive on Energy Performance of

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Buildings - recast (EPBD) [1] establishes the "nearly Zero Energy Buildings" (nZEBs) as the target for all new buildings in the EU from 2021.

The methods currently used for the design of nZEBs, rely on the application by the Architects of standardized bioclimatic design measures according to their professional expertise and intuition. The assessment of these measures' impact on the building's energy performance and the thermal/optical comfort of its occupants through simulation is a complex procedure, which normally requires a great amount of effort, time and special skills. For these reasons, it is normally conducted after the decision on major building elements, or in 2-3 alternative solutions. The idea of the energy simulation as a design factor in the early design stages is not new. A number of tools and methods have been developed towards that direction, to address performance-related design questions, mostly using Multi-Objective Optimization algorithms.

Technological advances, on the other side, have revolutionized the way Architects design and think, making it possible to partially automate the design procedure and integrate in it huge amounts of data. 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 a review of present and potential applications. A new workflow methodology is then proposed, integrating genetic algorithms and energy simulation through Grasshopper for Rhinoceros 3d and the plugins Ladybug and Honeybee, for a comprehensive exploration of performance-based design alternatives in the building scale.

Nomenclature

nZEBs	Nearly Zero Energy Buildings
MOO	Multi-Objective Optimization
VP	Visual Programming
EAs	Evolutionary Algorithms
MOEAs	Multi-Objective Evolutionary Algorithms
BPS	Building Performance Simulation
RES	Renewable Energy Sources

2. Performance simulation in building design and nZEBs

Computer simulation tools are increasingly used for the assessment of a building's energy performance and the thermal/optical comfort of their occupants. They represent 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. [2] 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 [3], 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) in building design is available. T. Ostergard et al. [4] have categorized these studies into several topics, such as solar