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Integrated Building Energy Design of a Danish Office Building Based on Monte Carlo Simulation Method

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Abstract

The focus on reducing buildings energy consumption is gradually increasing, and the optimization of a building's performance and maximizing its potential leads to great challenges between architects and engineers. In this study, we collaborate with a group of architects on a design project of a new office building located in Aarhus, Denmark. Building geometry, floor plans and employee schedules were obtained from the architects which is the basis for this study. This study aims to simplify the iterative design process that is based on the traditional trial and error method in the late design phases and improve the collaboration efficiency.
Monte Carlo Simulation method is adopted to simulate both the energy performance and indoor climate of the building. Building physics parameters, including characteristics of facades, walls, windows, etc., are taken into consideration, and thousands of combinations of these parameters are screened to find those can achieve the design criteria. The software Be15 and BSim are used as two-step solvers to process the calculation of energy consumption and indoor environment.
A solution pool is then obtained for architects to choose from, see Fig. 2 and 3. All these solutions can fulfil the requirements and leaves additional design freedom for the architects. This study utilizes global design exploration with Monte Carlo Simulations, in order to form feasible solutions for architects and improves the collaboration efficiency between architects and engineers.

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Keywords: Monte Carlo Simulations; building design; building performance; multi-collaborative design process.

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1. Introduction

In the latest years, the building design community has been challenged by the increasingly stringent regulations on building energy demands and indoor environment. The collaboration between architects and engineers becomes more and more demanding during the building design process. A close cooperation at an early stage will help ensuring a high quality outcome and reduce implementation costs of design solutions. However, there is sometimes a lack of awareness of early-stage cooperation in practice, due to e.g. prioritizing aesthetic or conceptual parameters. It is necessary to find an efficient and feasible method to optimize the building performance, without compromising those prior parameters. Kanters and Horvat [1] emphasize that parameters such as uncertainties, resolution of model and frequent design changes may be challenging, especially in the search for the most optimal design. Previous studies [2-5] proposed a simulation framework and emphasizes that such a framework may assist a design team by exploring a broad design space in the early design phases. Østergård et al. [6] states that their methodology gives more guidance regarding how to improve a building's design pro-actively when using building simulations compared to the evaluative use.

In this study, we collaborate with a group of architectural students on a design project of a new office building located in Aarhus, Denmark. The building has eight floors with five staggered stories from the 3rd floor and up. These staggered stories forms an atrium in the middle, which stretches through the entire length of the building. The building utilizes hybrid ventilation during the summer and mechanical ventilation in the winter. Through a building energy simulation it was documented that the design proposal from the architects did not meet the legal energy requirements. Therefore, adjustments and optimization become necessary in the late design phase. We aim to simplify the iterative design process and improve the collaboration efficiency by supplying various acceptable optimization solutions based on the design preferences of the architects. The design solution given prior to the optimization contains building geometry, floor plans, as shown in Fig. 1, and employee schedules and energy calculations.

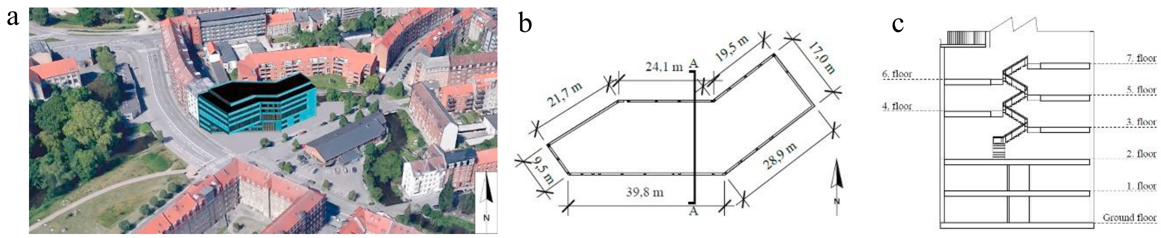

Fig. 1. (a) 3D model; (b) plan view of the outer geometry; (c) cross section view of the architects' design.

2. Methodology

The goal is to conduct a global exploration of the design space, and to obtain the spectrum of the building performances. It is expected that the thorough awareness about the consequences of various design choices would allow a high level of design freedom for the architects. The consequences will be presented by an illustrative method that links the energy efficiency and indoor environment performance to the combination of building physics parameters. Monte Carlo simulations based on a sophisticated building performance model can ensure the exploration of both the realizations of stochastic parameters and the choices of deterministic parameters. The latter are selected to fit the architects' design proposal to have minimum aesthetic impact. The latter are selected since they have minimal aesthetic impact on the architects' design proposal.

The input parameters are inserted into a deterministic model and related outputs can then be examined. Applying Monte Carlo filtering yields the input parameters that potentially have a high influence on the outputs based on the inputs' distributions. If the distribution of an input parameter is uniform after the Monte Carlo filtering, it is likely to have less influence on the output. The results of the Monte Carlo simulation are presented through a visualization technique called parallel coordinate plot, where each line represents a unique solution with its in- and outputs.

To explore the design space of the energy use, the simulation tool "Be15" [7] is used. This tool calculates the energy demand based on monthly-averaged values according to EN ISO 13790 [8], EN 15316 [9] and EN 15193-1