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Multi-Objective Design Balancing

Architectural, Structural & Environmental Aspects

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INTRODUCTION

Buildings are responsible for a third of the worldwide energy demand as well as anthropogenic greenhouse gas emissions. Therefore, a holistic approach for energy efficient design over the life cycle of buildings is necessary. In this thesis, the relationships between structural efficiency, energetic performance and aesthetic design are explored in the context of tall buildings.

Considering the aesthetic, spatial and architectural qualities of a structural system simultaneously with the structural aspects, in the design phase, can yield a more cohesive and efficient building

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as a whole, than when the structure is only considered as a final step.

OBJECTIVES

The objective or goal is to reduce the structural mass in order to reduce the embodied energy while considering the operational energy as well as the aesthetic expression of the structure.

This thesis is focusing on the relationships between structural efficiency, energetic performance and aesthetic design of tall buildings. Structural efficiency deals with minimizing the structural mass to reduce the embodied or grey energy while maintaining structural integrity, i.e., withstanding dead loading and wind loading.

METHODS & TOOLS

To achieve this various methodologies & approaches adopted in this research are -

. Particle Swarm Optimization

The Particle Swarm Optimization (PSO) method was introduced by Kennedy and Eberhart in 1995, and essentially works on the basis of mimicking the behavior of flocks or swarms, searching for food or escaping a predator. The interested reader is referred to for an extensive review on successful applications of the PSO method. The advantages of PSO compared to GA comprise a simpler setup,

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December 2017

an often faster convergence rate, and computational efficiency, while still providing the same quality solutions.

. Genetic Algorithm

While the particle swarm method mimicks the motion of a flock, genetic algorithms (GA) are based on the principle of natural evolution, i.e., adaptation to a particular task or objective, through survival of the fittest

. Multi-objective Optimization

A multi-objective (or multi-criteria) optimization problem is described as complex method. This reduces the multi-objective problem to a scalar problem, which can be solved using classical optimization methods.

.Non-Uniform Rational Basis Spline (NURBS)

The development of NURBS curves and surfaces was pioneered in the 1950s by the French engineers Bézier and Casteljau in their research for a sound mathematical description of free form structures, in their case for car bodies.

PROCEDURES

In this thesis, we introduce two frameworks. In the first, we develop an interactive structural optimization tool that allows the user to give aesthetic feedback during the optimization process. We apply this tool in the design of curved truss tower structures in 2D and 3D with real users, and demonstrate the successful integration of user feedback in the optimization algorithm. In the second frame-work, we integrate code-based structural design of

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tall buildings with energy demand simulations, and perform a multi-objective optimization for a tall building in various climate zones. We show that structure can act as shading, i.e., cooling savings are achieved with respect to a fully glazed building. Further, we illustrate the trade-offs between buildings with reduced mass, with comparatively little cooling savings, and heavier buildings, with increased, e. g., up to 50%, cooling savings potential. Finally, we discuss the impact of the column design in the different climate zones. The resulting trade-offs allow the architect to make an informed decision between structural design and energy efficiency of the building without sacrificing the architectural intent.

CONCLUSION

The proposed interactive PSO-based optimization process is a valuable tool for the architectural design of various forms of structures, further enabled via the use of NURBS for reducing computational complexity and favoring architectural freedom of design by allowing for free form shapes that meet structural requirements, with certain limitations as detailed in project.

Further simplifications of the whole optimization process are conceivable. In the beginning, given a base structure, possible design variables (geometry sizes and topology) could be detected automatically and proposed to the user. The designer could then choose which variables to use and what their range would be. Based on this, the integration of meta-modeling or surrogate

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modeling techniques, such as those employed in reliability and risk engineering could reduce the computational time considerably, especially for a large number of design variables.

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