OSZCAR

OPTIMIZATION SYSTEM FOR ZERO CARBON ARCHITECTURE

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Abstract

This paper presents early stage of development of novel CAD system for design and optimization of near zero energy buildings (nZEB). Its framework is based on parametric program that supports performance based modelling by integrating detailed physical simulation, construction, cost and fabrication modules. The system provides multi-criteria optimization methods to address contradictory design objectives. During the optimisation process the solver tests different combinations of values for the design variables in order to find the best feasible geometrical configuration of the building within its search space. In addition, the user interface offers graphical analysis and navigation through all design possibilities. The system is intended to be a design tool capable of advising designers how to adapt their designs in order to meet the criteria of nZEB at a cost-optimal solution.

Keywords
nZEB buildings, multi-criteria optimization, parametric design, building performance, BIM.

1 Introduction

With the heightened awareness of the need for more resource efficiency in building and with the advent of the EU’s Energy Performance of Buildings Directive, the building industry in Europe is forced to do a significant amount of retooling. While most engineering industries have seen dramatic gains in efficiency and cost savings in their design and production cycles throughout the last fifty years, the building sector has not been able to do the same. [1] There are a number of explanations for this. One is the fact that buildings are usually unique, one-of-a-kind constructions. Therefore the experience and efficiency gains due to repetition that are present in other industries do not apply in the design and construction sector. Another often cited factor is that the building sector was relatively slow in the adoption of IT. With the development and first applications of Building Information Modeling (BIM) programs, this is
currently changing, but there is still much room for improvement and more wide spread acceptance and use. [2][3]

There is also another factor: Architecture is more than just a commodity – great works of architecture transcend their functional designation. There is general consensus that cities and architecture are the most prominent physical representations of a culture. That architecture is defined as the art of building, that many things about it cannot be measured, is a key part of the profession’s identity. As a consequence, the notion of “optimization” is largely absent from traditional architectural discourse. Many architects don’t like the very idea of optimization. They see it more as compromising and losing quality, and therefore as an insult to their profession. It is probably not an accident that no commercial architectural design software currently has any built-in optimization capacities.

On the contrary, the transition from traditional Computer Aided Design (CAD) to virtual building design phrased as Building Information Modelling (BIM) [4] has created a tremendous potential to adopt analysis driven optimizations in all stages of the design process, from inception and concept design to design development and construction, that can be beneficial for the architecture, engineering, construction, and owners (AECO) industry. However, such optimisations involve the application of multiple specialized software tools, requiring the user to switch back and forth between different programs in a process that is tedious to set up and requires expert knowledge. In our publicly funded research project we are developing a novel building performance analysis and optimisation framework to be used by architects in a coherent parametric design workflow.

2 Research background

2.1 Design framework

A standardized frameworks for architectural and construction process has been long publicly available. One of the example is the “RIBA Plan of Work” [5], which had been established in 1963. The goal is to provide clearly defined stages and responsibilities that reflect the actual process as well as the organizational structure that exercises these processes.

With the increase of computational support for design the amount and nature of data potentially available to improve design decisions has challenged the industry in respect of the actual ability to exercise, evaluate and use these data. In recent years new technologies and processes, such as BIM have disrupted the AECO industry due to its integrated design approach [6] that suggests a Lean BIM process [7] towards better performing buildings. The integrated approach implies that more information has to be processed early on in the design stage, which is also when the cost and performance of the building can be optimized the most (Figure 1). This puts pressure not only on the design team, but also challenges the “Plan of Work” in respect of fee structure, contracts and responsibilities. As a result the time needed for analysis, evaluation and transformation becomes critical.
2.2 Design Decision Support Systems

In recent years several novel approaches toward Design Decision Support Systems (DDDS) have been introduced [8]. Especially relevant to the current research are Activity-based models, Micro-Simulation Models, and Virtual Environments. It has been concluded that design teams frequently struggle to acquire and visualize data about their projects, most noticeable during the early phase of design. There is an increased demand on rapid data collection and creation, as well as accessibility and exercisability. As the common denominator, visual conversation has been identified to play a significant role during the cognitive processes of collective decision-making. It is argued that the negotiation between digital and physical data navigation and representation currently presents a bottleneck for further improvements. The presented research has investigated the three fundamental components of a DDDS, such as knowledge base, model and user interface. Interactivity has been highlighted as the key towards effective data visualization and exploration for improving DDDS in collaborative settings.

3 OSZCAR’s philosophy

In proposing a system in which architectural designs can be optimized, the OSZCAR project thus could be seen to commit some sort of heresy, to go against firmly held notions of what architecture is about. But the gains in efficiency that our proposed system can help achieve are not only a pragmatic necessity with regard to the EU directive, they are also benign with respect to the traditional cultural responsibility of architecture. The OSZCAR system merely supports the designers, it doesn’t challenge their judgment, their priorities, their
understanding of space, and their conception of beauty. Quite the contrary: by taking over tedious number-crunching, it frees designers up to focus on these key issues. [9] OSZCAR can’t design anything itself, it isn’t supposed to. In the hands of a mediocre designer, it will optimize mediocre designs. But in the hands of skilled architects, OSZCAR can help to make great buildings that are at the same time more cost efficient, resource efficient and environmentally responsible over their lifetime. OSZCAR ties in with and contributes to the increasing deployment of BIM in the construction industry. It strives to reduce cost by using the potentials IT is currently opening up, and it also honors the fact that buildings are unique, made for a specific use and one place with its specific climate and environment.

4 OSZCAR’s concept and approach

OSZCAR aims to support the entire design to production chain, starting in the early design stages. From a sustainable point of view, the early stage contains the most potential to achieve an increase in building quality and cost savings in the long run [10]. This early stage is characterized by a dynamic back and forth process between an array of spatial, environmental or economic analysis, and massing studies and form finding. These analytical processes generate a large number of data during their iterations that have to be collected and stored initially, and later accessed, compared and evaluated.

Decisions made in the first stages of the design process (positioning, orientation and shape of the building, layout and distribution of windows on façades, consideration of solar potential and shading options) have a significant impact on the overall energy performance and costs of a building. Nowadays, these decisions are usually made without the specific requirements of nZEB in mind. And if the basics are non-optimal, more sophisticated technological solutions need to be deployed in order to meet nZEB requirements, making such designs more expensive, complex and thus requiring more costly maintenance during operation. Therefore design decision support for nZEB must start in the first design stages. Since energy performance criteria are not the only criteria on buildings and other criteria are often contradictory, the design decision support system must support a multi-criteria approach. [11] To adequately deal with the complexity of conflicting constraints, such a system should include optimization modules for costs, energy performance, embodied energy, budget, lighting performance, indoor environment, structural stability and manufacturing limitations.

The OSCZAR process of nZEB design utilizes a three steps approach that is fully integrated into a standard CAD environment. Each step is suitable for a different stage of design development and operates with according levels of complexity, speed and precision.

4.1 Massing design

During this step the building’s overall geometry is optimized. The optimization process uses OSCZAR’s simplified “naked” parametric model linked to the BIM database. The architectural and urban intentions are evaluated on a concept design level. The medium problem complexity in most cases enables usage of single criteria solvers for high-speed optimizations. The optimization results are considered to be in low to medium precision levels.
4.2 Scheme design

During this second step the building’s geometry and properties of the building elements are tuned. The optimization process utilizes a parametric BIM model translated from OSCZAR’s naked model (Figure 2). Architectural and urban intentions are evaluated on a scheme design level. The high complexity level requires multi-criteria solvers. The optimization results are considered to have medium precision levels. Easy access to high-level optimization approaches and bidirectional parametric modelling capabilities are supported in the same way as in the massing study model.

Figure 2: a) simple model for optimization b) converted BIM model with building attributes

4.3 Detail design

During this third step the building elements are fine-tuned. The optimization process utilizes a parametric BIM model in the final stage of development. Very detailed physical simulation modules (light, structure, energy, cost, life cycle assessment and fabrication) are integrated into the program. However optimization with such computationally demanding tools would normally be near to impossible. The innovation consists in the reduction of the number of unknown variables during the previous optimization process. This means that many variables that were unknown in previous design stages (e.g. geometry) are known already and the solution space that the optimization algorithm has to explore in this design phase is massively reduced. Mostly only the building elements’ properties are tuned at this design stage.

5 Augmented Parametrics

In order to be able to use the presented system OSZCAR effectively, its system architecture forms a novel CAD framework called “Augmented Parametrics” (AugP) [11]. The framework simplifies parametric modelling while maintaining high level of building data in order to
quickly and precisely calculate building’s analysis. The system expands the contemporary parametric systems by embedding bi-directional solving algorithms and multiple simulation modules. The system is subdivided into four main parts.

![Diagram of AugP framework](image)

**Figure 3: Diagram of AugP framework**

### 5.1 Building component data and parametric model

A data system collects building information such as material, wall-type, etc. and parses a database of building elements. All these data are maintained as text attributes that are assigned to the 3D geometry. Therefore, the 3D model can be created relatively simply with only single wall surfaces that hold the wall build-up only as text information.

The parametric rules define the building geometry. They also respond to the global and local constraints of the environment (Figure 4). The framework is an open system, therefore, any attribute can become design constrain or subject of optimisation.

![Parametric model responding to the constraints of the site](image)

**Figure 4: Parametric model responding to the constraints of the site**
5.2 Analysis

As the optimization process of the building must undergo through high amount of variation in order to find the optimum solution, the time required for each iteration becomes an issues. Therefore, the simulation components are built around highly efficient algorithms developed at the Institute for Architecture and Media TU Graz, which allow real-time computation. The development focuses primarily on the analysis of building energy consumption, daylight, cost and structural efficiency.

![Initial Model and Optimized Models](image)

Figure 5: Optimization results for different types of objectives

5.3 Cognitive System Control

The CSC contains single and multi-criteria algorithms. These solvers operate with design variables which are numerical parameters that influence the parametric design and thus the design criteria that is optimised. During the optimisation process the solver tests different combinations of values for the design variable to eventually find the best feasible configuration in the search space. In order to find the best solution, the solvers step through
two optimization stages; during the first stage they target finding the global optimum, then in the second stage the solvers microstep for finding the local optimum.

The CSC also contains an interactive interface for the user to steer and control the optimisation process. During the optimisation process the optimiser goes through a large number of iterations. The possibility of storing and later accessing these iterations is important; the designer gets not only the best solution found, but also the others that are geometrically better, but perhaps with marginally worse performance. For navigating through the variations we implemented a “radar chart”, we refer to it as Interactive Graph Interface.

![Figure 1.2 a) Iteration register of found options, b) Solution space for pre-set objective value range](image)

6 Conclusion, further development

The presented system OSZCAR and its framework AugP is currently under development. However, it already proves its promises in reducing the design to production processing time and enhancing the quality, carbon neutrality and performance of for energy-efficient buildings. The further development consists of inclusion of structural analysis into the optimization and deeper integration into existing BIM modelling platforms. We believe that by forging novel synergies between research and industry, software design and fabrication, OSZCAR promises to take these research results to the next level where they can start to have a wider impact.

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References


