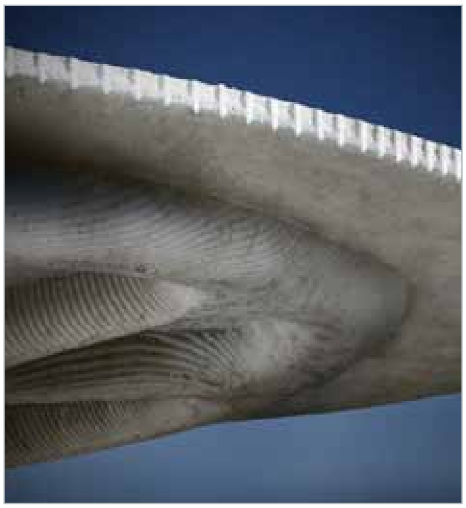
Success Story

Danish Team Uses HyperWorks to Prove the Value of Topology Optimization for Concrete Architectural Structures



Aarhus School of Architecture

Unikabeton

Key Highlights

Industry
Architecture Engineering Construction

Challenge
Combine structural optimization with fabrication and aesthetic

Altair Solution
An integrated package for form finding modeling and structural optimization

Benefits
Significant reduction in design time and environmental costs

Customer Profile

Denmark's Aarhus School of Architecture was interested in exploring the potential of applying the kind of simulation-based topology optimization used in the automotive, aeronautical and naval industries to architectural concrete structures and coupling it with robotic fabrication of polystyrene formwork for concrete casting. Led by Per Dombernowsky, who served as project manager and engineer, and Asbjørn Søndergaard, who headed the project's design and optimization aspects, the combined academic and industrial team created the Unikabeton Prototype project.

Unikabeton (unique concrete structures) involved collaboration among the eight largest institutions and corporations in the Danish building industry, all working to develop a series of optimization experiments meant to conclude with the design and optimization of a full-scale prototype of a concrete structure.

Challenge: A change in mindset

The use of computerized optimization tools is largely foreign to the field of architecture. Søndergaard observed that the principal reason for this was "conservatism in the architectural industry toward embracing CAE as constitutive design tools," a reluctance to lose design control to the optimization software.

The Unikabeton project would be one of the first academic research projects to address the use of topology optimization in architectural design. The payoff of the team's experiments could be significant, since CO2 emissions from the production of concrete produce 5 percent of total global emissions.

Keywords: Architecture,Optimization, HyperWorks, OptiStruct

Aarhus School of Architecture Success Story

"We see a great potential in application of HyperWorks tools within commercial architectural projects as methods of digital fabrication become more and more economically accessible."

Asbjørn Søndergaard,
Coordinator of Digital Experimentation
Aarhus School of Architecture, Denmark

Solution: An integrated package for modeling and optimization

The team chose Altair's HyperWorks for their optimization experiments. In online research and questioning their contacts, the team discovered the value of OptiStruct in the HyperWorks suite.

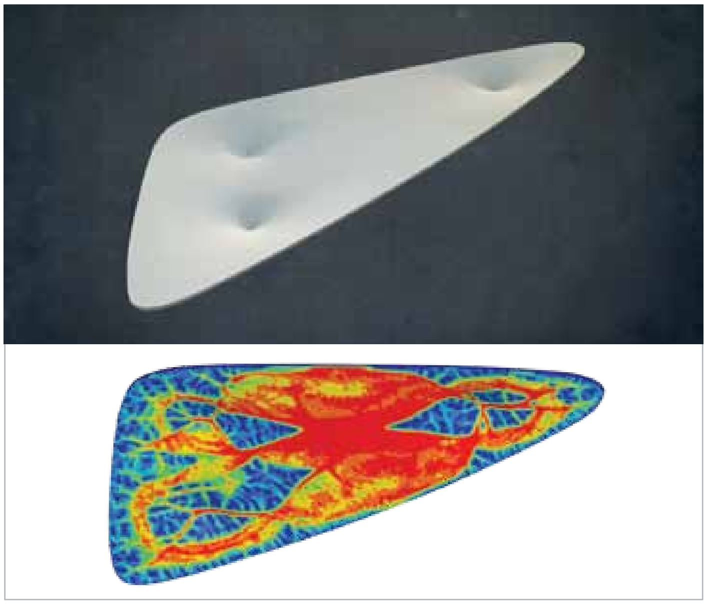
"The HyperWorks suite with OptiStruct held the benefit of offering an integrated package of finite-element modeling and optimization," Søndergaard said, "such that the acquisition and training could be held within one software platform. Further, the impressive range of Altair's previous optimization case studies and the extent of the organization were critical to inspiring confidence in the project managers, who were initially skeptical about the feasibility of large-scale topology optimization."

The team first carried out structural analysis and small-scale simulation of the digital fabrication process, comparing the effect of topology optimization with a series of familiar pre-fab and in-situ concrete members. Analysis showed that the optimized structures produced a 60 to 70 percent reduction of material usage compared to standard equivalents while meeting normative structural requirements. At the same time, new aesthetics were discovered, such as designs that would render the structural forces visible to observers in the final design.

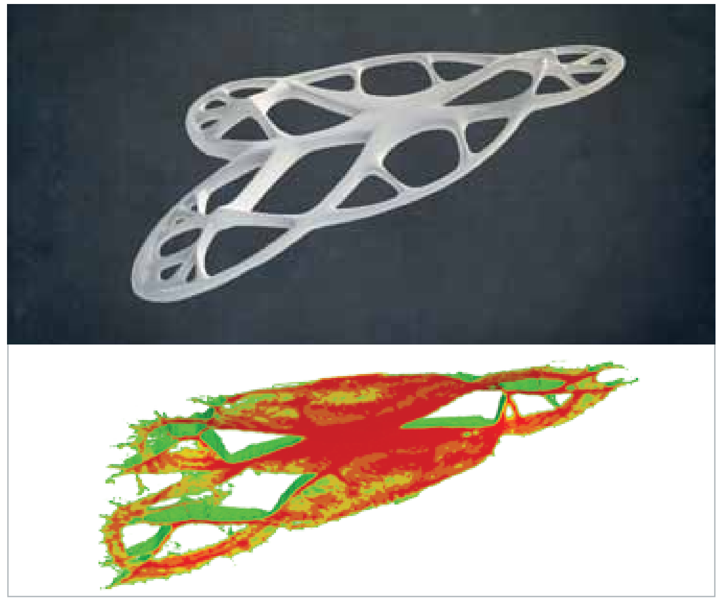
After these initial efforts involving discrete structural members, the team set out to optimize a non-uniform doubly curved concrete slab supported by three asymmetrically placed concrete columns that were fixed at the foundations. The prototype structure would be 12 x 6 x 3.3 meters in size.

Detail of the Unikabeton Prototype

Detail of the structural ribs



Above: Top surface of the slab
Below: Optimized distribution of density



Above: Remodeled optimization result
Below: Topological optimization result

Topology optimization was carried out to meet the fabrication requirements of the CNC milling process for the structure's EPS formwork. The team milled the forms in polystyrene blocks, which were assembled at the site using traditional assembly techniques and scaffolding. Self-compacting concrete was cast into the formwork.

With topology optimization, the architect relinquishes a significant amount of direct control over the form of the structure, because the software grows the shape of the structure from immense amounts of data. The circumstances require the architect to devise new strategies of design intervention, which can take the form of "non-design spaces"—areas that are excluded during the optimization process. In the Unikabeton project, non-design spaces were designated for the top concrete member and the three columns to meet design requirements so that, for instance, the design would result in a non-perforated top surface for weather protection.

Results: Significant reduction in environmental costs

The successful optimization of the Unikabeton project demonstrated the significant value of simulation-generated topology optimization for architectural structures. The optimization offered the opportunity to mimic the morphology of biological structural systems, sharing with them the principle of maximum structural performance generated by the smallest possible mass.

"Topology optimization can be viewed not only as a facilitator of novel tectonic languages," said Søndergaard, "but also as a pragmatic tool for generating intimate form-structure relationships within processes of architectural design, relating to already established formal traditions of industrially built architecture."

The team noted that the subtraction of superfluous material from the design significantly reduces the environmental costs related to producing the structure, in terms of energy saved in concrete production and transportation. Moreover, the polystyrene used to create the formwork can be recycled and used for new formwork.

On a larger scale, the project marks a potential larger shift in architectural practices. "While non-computational structural design implies an empirical process of form development, drawing on historically accumulated experience with architectural typologies," Søndergaard noted, "topology optimization enables a shift from typological to topological design thinking, in which the need for empirical experience is exchanged for the need for a generic knowledge of the prerequisites of optimization." Citing Japanese engineer Mutsuro Sasaki, Søndergaard pointed out that optimization enables new types of structures in which members are created in a continuous whole, eliminating such conventional sub-classifications of systems as beams, slabs and columns.

In his experiments, Søndergaard said, he found HyperMesh to be a very strong FE-modeling component, meeting a critical aspect of creating advanced design space models. The team also employed HyperView post-processing for analytical checking of displacement and stresses.

"The robust and versatile HyperWorks analysis tools were a great aid in understanding the structural intricacies of the optimization results and assessing their feasibility for realization," Søndergaard said.

Søndergaard reported his team anticipates a bright future for using HyperWorks in commercial architectural projects. "We see great potential use of the HyperWorks suite as a conceptual structural design tool in the initial phases and in project design and engineering phases for topology optimized architectural designs."

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