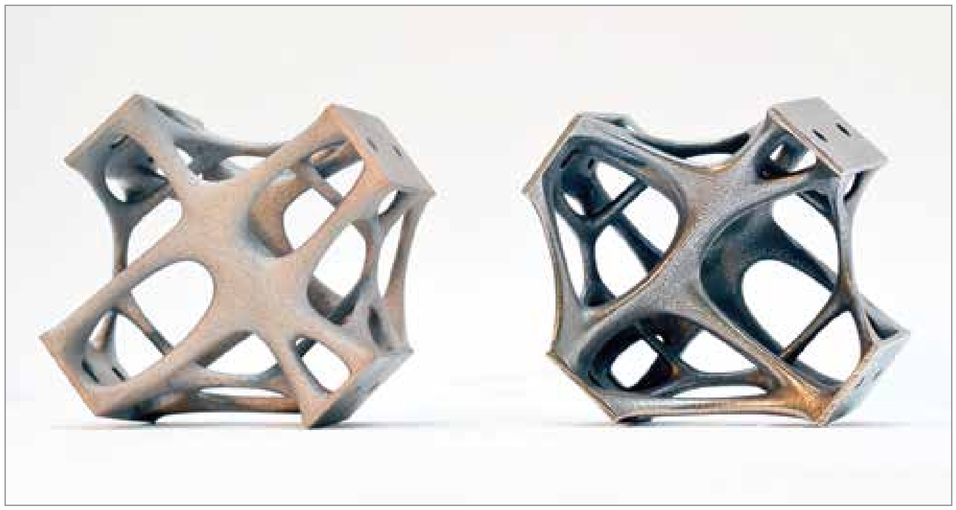
Benefits of the Symbiosis of Topology Optimization and Additive Manufacturing in Architecture



TU Delft ARUP

Key Highlights

Industry
Architecture, construction engineering, civil engineering, education

Challenge
Investigate the potential offered by the symbiosis of topology optimization and additive manufacturing for architectural projects

Altair Solution
Use of Altair's HyperWorks suite, especially OptiStruct for optimization tasks

Benefits
Reduced construction time and costs due to decreased material usage while receiving better and more esthetic results

The combined use of topology optimization and additive manufacturing is quite common in industries such as automotive or aerospace, but up to now this technology combination is rarely used in architectural projects. To investigate the potential offered by the symbiosis of topology optimization and additive manufacturing for architectural projects, Bayu Prayudhi, an architectural student of the University of Delft, re-designed an existing architectural project and included topology optimization upfront in the design process. The object to be re-designed was the outdoor canopy located at Baku international airport in Azerbaijan.

The original design was created by ARUP, a firm of designers, planners, engineers, consultants, and technical specialists offering a broad range of professional services. Arup's office in Amsterdam was involved in Bayu's project as one of the supervising consultants.

By leveraging OptiStruct, an optimization tool and structural solver included in Altair's HyperWorks suite, and some additional tools, it was possible to re-design the structure and adapt the design for 3D printing.

The new 3D printed design led to a potential weight reduction of approximately 32 percent (with a reduced mass of about 9 tons). Since it was not possible to actually build the re-designed canopy in the scope of the university project, Bayu created a small mock-up prototype to showcase the novel structural approach.

During the project Bayu was supported and supervised by his mentor, Dr. Michela Turrin and Prof. Dr. Ing. U. Knaack, from the department of Architectural Engineering and Technology at TU Delft and Shibo Ren, a Senior Structural Engineer, Buildings Amsterdam at ARUP.

Keywords: Architecture, Additive Manufacturing, Optimization, HyperWorks, OptiStruct

TU Delft Success Story

"Looking at the entire structure and the applied process, a joint use of topology optimization and additive manufacturing could change the entire architectural creation process, from design to the actual construction, helping to save material, development and construction time and costs, while at the same time offering better and more esthetic results."

Bayu Prayudhi
Architectural student of the University of Delft

The Faculty of Architecture and the Built Environment of TU Delft was established in 1904. Since then the faculty has always had a leading role in architecture education and research in the broadest sense. Some three thousand students, hundreds of researchers, lecturers and professors follow or provide education, do research and support work in a dynamic, distinctive, and internationally oriented environment. There are various specialist associations linked to the Faculty of Architecture and the Built Environment. These include a study association for students and an alumni association, as well as several active practical associations.

How to create best architectural solutions that combine form, function, and efficiency?

Architects have always been striving to combine function, shape, and innovation with given boundary conditions such as costs, lead times, and technological limits. The use of innovative approaches and technologies such as the combination of topology optimization and additive manufacturing opens up new possibilities, yet need to be evaluated before such a process can be leveraged in the architect's every day work. Since it is of equal importance to know about the limits of new technologies it is a common approach to conduct pre-studies to gain valuable experiences.

To investigate the potential of the symbiosis of topology optimization and additive manufacturing in architecture Bayu chose an existing project, an outdoor canopy, designed by ARUP, located at Baku international airport in Azerbaijan.
The canopy had been built to cover the way from the front end of an airplane to the building, providing shelter to passengers entering and exiting a plane. The roof canopy has a surface area of 417 square meters with the highest soffit point being at 9.18 meters and a length of 29.5 meters. While the original structure, of course, fulfilled all requirements, it still showed some potential in terms of weight and material reduction.

Though one of the primary goals in architecture is to design esthetically appealing buildings, also statics, material use, and weight play important roles – like in the re-design of the canopy.
To reach all these goals at the same time, architects have to use design and simulation software helping them to find functional, structurally efficient and surprising shapes.

The objective of this research project was to design a structural system for a free-form envelope of a building by leveraging the potential offered by additive manufacturing and topology optimization to develop lighter and more structurally efficient products.

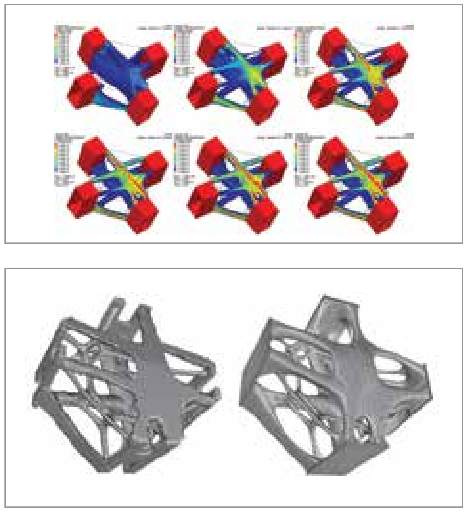
Topology optimization and additive manufacturing lead to lighter and more efficient structures

Altair's optimization tool and FE-Solver OptiStruct, available via the HyperWorks suite, was used to drive the new design, prepare it for additive manufacturing, and to optimize the structural performance of the canopy, while also reducing weight and the amount of material needed.
The use of OptiStruct helped to create a functional and visually captivating design ready for additive manufacturing. Other tools of the HyperWorks suite used in this project were HyperMesh for pre-processing and HyperView for post-processing tasks.

In a first step the geometry was imported into HyperWorks and the occurring load cases were applied. The HyperWorks model was created as a single independent node, and each force was modeled manually.

Manufacturing constraints arising in additive manufacturing, such as supporting structures and printing direction, were then applied. The maximum size of the nodes was determined by and limited to the size of the building chamber of the used 3D FDM printer. Following that the design space was defined, which in this case only included the node, because the connecting beams were not subject of the optimization.

Physical mock-up prototype to demonstrate the development approach



OptiStruct topology optimization (density distribution at different iteration steps) and HyperWorks mesh output (standard (left), and smoothed final design (right) of the connecting node structure.

Metal 3D printed prototype node

As the amount of computational power available to conduct this project was limited, Bayu could not perform an analysis of the entire structure. The number of elements, load cases, and details would have led to a very large FEA model, requiring professional-grade computing power and a cluster distributed or cloud computing environment. Therefore, Bayu decided to perform the optimization only on one node, using the numerical data of different occurring forces, and to extra-polate the results to estimate the impact an overall structural optimization might have.

Since no 3D model of the original project was available, the design of the original structure had to be remodeled relying on approximation and assumptions. The total weight of all nodes was averaged. Further research of the detailed weight and cost comparison between the original and re-designed structure is still to be done.

Summarizing his results Bayu estimated that the new canopy design would approximately lead to a weight reduction of around 32 percent, bringing the total mass of the roof down from 34.9 tons to 23.7 tons. At the same time the overall area the canopy would cover increased from 417 to 423 square meters. Moreover, the quad paneling design reduced the required amount of connection detail elements compared to the triangular design in terms of bulk volume and it helped to increase the efficiency of glazing manufacturing. To round up his project Bayu built a small mock-up prototype of the structure which helped to get a hands-on experience and to better understand the characteristics of the structures. The objective of this sub-prototype was to carry the weight of the student, which was successfully reached. The nodes were manufactured in a scale of 1:4, with an approximate dimension of 100 mm. The nodes of this model were printed by Shapeways, a 3D printing service provider. The metal printing was done in binder jetting of stainless steel powder with 40 percent infused of bronze powder instead of direct laser sintering.

Proofing new methods

OptiStruct enabled the student to generate an optimized node structure, designed for additive manufacturing. Bayu came up with a new, improved design with a significantly lower total mass and an increased overall stiffness. In addition to the weight saving the combination of topology optimization and additive manufacturing also led to a lower lead time, improved the overall design, and made it easier and faster to design simple connection parts (i.e. bolted connections).

The simplified design of the connecting parts also led to a quicker and easier assembly process, which usually can be handled on site. This led to a reduced need to transport large pre-assembled structural parts. By using topology optimization and additive manufacturing, the overall construction time could be dramatically reduced, helping to also cut down general construction costs.

The research also showed that designs created with topology optimization and additive manufacturing should not only be compared to traditionally designed and manufactured parts in terms of weight reduction or volume differences.

Looking at the entire structure and the applied process, a joint use of topology optimization and additive manufacturing could change the entire architectural creation process, from design to the actual construction, helping to save material, development and construction time and costs, while at the same time offering better and more esthetic results.

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About HyperWorks

HyperWorks is the most comprehensive open-architecture simulation platform, offering technologies to design and optimize high performance, efficient and innovative products. HyperWorks includes modeling, analysis and optimization for structures, fluids, multi-body dynamics, electromagnetics and antenna placement, model-based development, and multiphysics. Users have full access to a wide suite of design, engineering, visualization, and data management solutions from Altair and its technology partners.

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