AUTODESK® ROBOT™ STRUCTURAL ANALYSIS PROFESSIONAL

Exploiting Autodesk Robot Structural Analysis Professional API for Structural Optimization

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Access to an open API (application programming interface) can assist in the automation of common and repetitive tasks, helping to save time and costs. The open API provided with Autodesk® Robot™ Structural Analysis Professional software enables programmatic control of Robot, through which sophisticated bespoke tools for structural design optimization can be developed.

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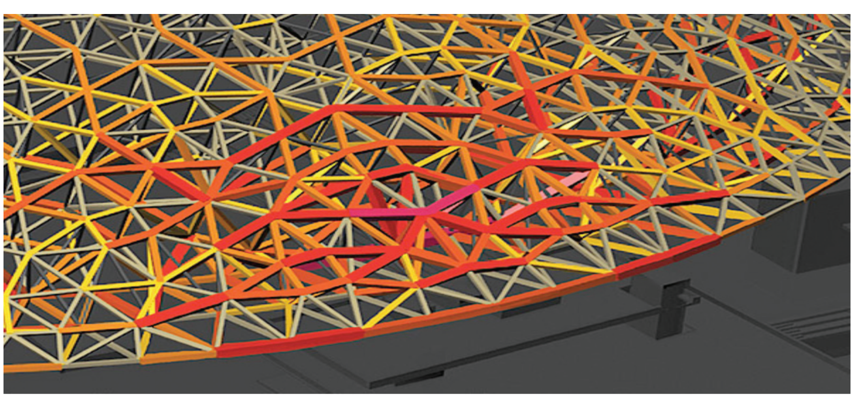
Within the construction industry, there is constant pressure to deliver projects more effectively on multiple fronts. This is most notable in the desire to reduce project time scales, while also consistently increasing capability and design quality.

This double-edged challenge leads designers to continually seek more effective ways of working. In this white paper, we demonstrate the use of Robot Structural Analysis Professional API to increase efficiency through automation of design processes, which can help reduce time scales and simplify workflow.

Furthermore, with this automation capability, innovative design processes such as rationalization, standardization, and design optimization become possible.



Structural optimization applied to a freeform space frame. (© Buro Happold Ltd.)

Overview of Autodesk Robot Structural Analysis Professional API

Autodesk Robot Structural Analysis Professional software inherently offers full access to an open API. Robot Structural Analysis Professional API exposes the standard functionality of Robot, facilitating programmatic control through external software.

Access to Robot through this mechanism can enable any routine tasks or processes accessible through the standard user interface to be fully automated and, thus, more rapidly repeatable, extendible, and scalable.

With help from Robot Structural Analysis Professional API, users can drive their analysis model for a number of tasks, including creating complex models; generating and modifying geometry/mesh; applying and editing material properties, sectional information, and boundary conditions; and running analyses and extracting results.

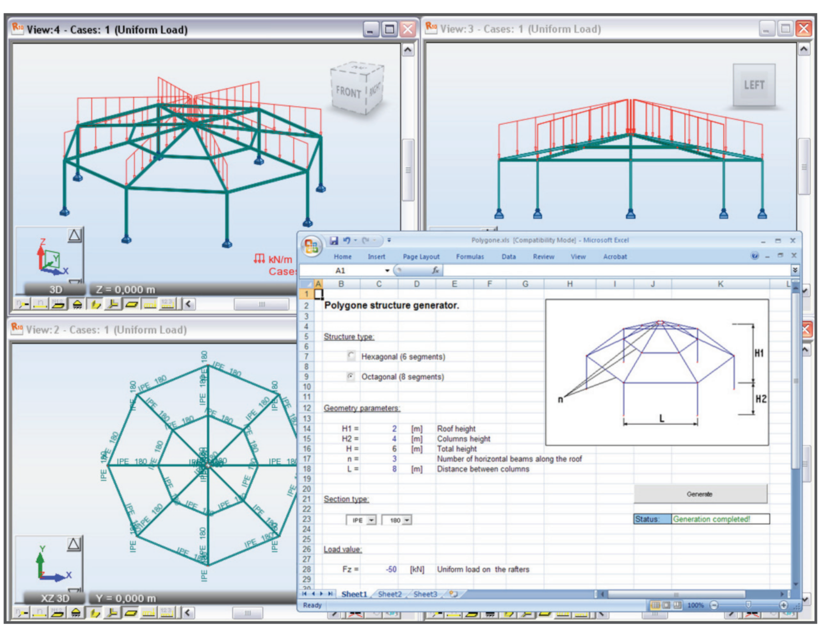
Programmatic access can enable the execution and control of the analysis tasks so multiple design options can be more quickly evaluated while also testing for design compliance. Therefore, Robot API is a powerful tool for concept design optioneering as well as detailed design.

Automation of Design Processes
A typical design analysis process involves the following steps:
1. Geometry generation
2. Mesh generation
3. Assignment of structural material and sectional properties
4. Analysis run and results evaluation

This is invariably followed by step five:
5. Iteration through the above four steps until design criteria is met

The Robot Structural Analysis Professional API enables programmatic control of each of the above processes, helping provide rapid reduction in each design iteration time. The example below illustrates automation through links to Microsoft® Excel® software; however, the open API enables real customization of the design processes by integrating Robot with proprietary CAD packages, post-processing software, or bespoke tools developed as a plug-in to the Robot interface.

The API uses Microsoft's component object model (COM) technology. This means the user can develop simple Visual Basic® for Applications (VBA) code from within applications such as Excel, Microsoft® Word, AutoCAD® software, or develop sophisticated .Net applications to link Robot analysis software with external software.



Example of automation using Robot API enabling parametric model generation from within Microsoft Excel

The benefits of automation are numerous. Automation can help:
• Reduce of design time
• Increase accuracy
• Increase efficiency
• Eliminate arduous, repetitive tasks
• Support rapid design exploration

The culmination of all these benefits can result in a greatly improved workflow. In addition, as we go on to show in the paper, a major advantage of automation is the potential for increased capability through optimization.

Introduction to Structural Optimization

Optimization as a process seeks to minimize or maximize a design "target" (for example, weight, cost, deflection, and so forth) through modifying a number of design variables (for example, geometric form, member sizes, prestress, and so on).

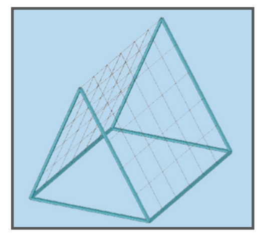
As an example, the images on the right illustrate an iterative form-finding procedure in which a minimum energy state is sought by modifying the design geometry. In this case, the form relaxes to the optimum equilibrium state converging on a minimal saddle surface. Form optimization is just one such example. Optimization procedures can be applied to virtually any feature of a design or design process.

Why Optimize?
Iterative optimization is inherent to every design process. This is especially important at the concept design stage, where the engineers explore a number of design options in terms of geometric forms, structural schemes, and individual member sizes before arriving at a working solution. The process continues through the detailed design stage, where more precise member sizes and connection specifications are detailed.

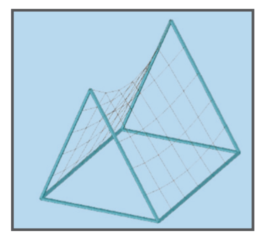
In the majority of projects, the iterative design process is manual and trial-and-error based. The engineers typically decide on a design target, for example maximum deflection, or a target weight for the structure, and manually adjust the geometry and sizing parameters until the target is achieved. Manual design iterations are often ad-hoc and inefficient; it can take a long time, and engineers can never be certain of how far the design is from the true optimum solution.

Automated design optimization can help to drastically reduce design time, reduce costs, and enhance confidence in the design.

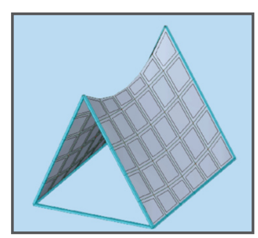
Example of form optimization through an iterative dynamic relaxation procedure



Starting geometry



Form found geometry



Clad final geometry

Optimization Targets, Constraints, and Variables

Typical objectives or targets for optimization may include:

Minimizing
- Stress
- Deflection
- Weight
- Cost
- Embodied energy

Maximizing
- Repetition of components

In many cases, these objectives will need to be met within a framework of other conflicting architectural, engineering, fabrication, and client constraints. Typical constraints may be the minimum or maximum section sizes available, maximum deflection due to physical constraints, maximum curvature, total cost not to be exceeded, and so forth.

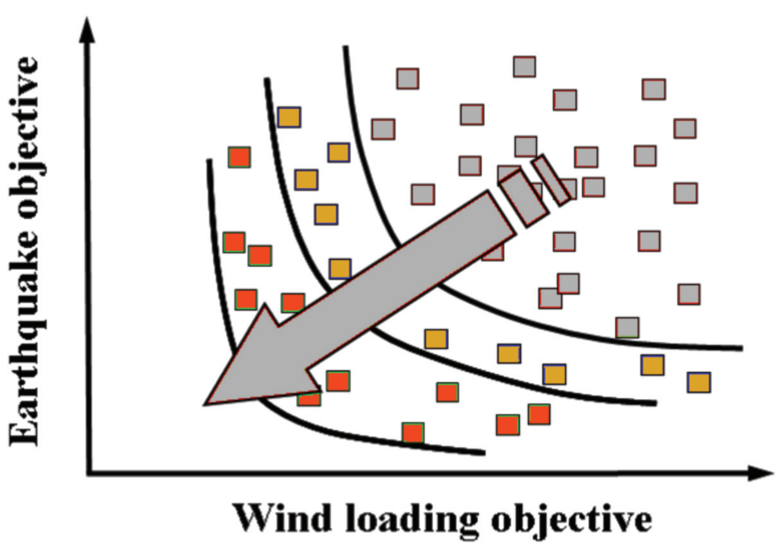
Variables of optimization process are typically the section sizes, but may also be the whole geometric form, numbers of section types used, and so on.

The optimization question then is: Given the constraints, what are the most appropriate values of the design variables to achieve the optimization target? The answer to this question requires use of mathematical techniques that iteratively seek the optimum solutions.

Optimization Techniques
Optimization as a topic is vast and spans a wide range of mathematical and numerical techniques. A sample of which include:
- Simple Newton Raphson techniques
- Dynamic relaxation
- Genetic algorithm
- Simulated annealing
- Hill climbing methods

Each algorithm is a common factor in that it seeks to (progressively) improve a design based on the targets and constraints defined above.

When applying these optimization techniques to real design projects, the emphasis must be on practical, constructible solutions. Thus, we go on to look at how novel, but practical, tools can be developed and integrated into established design processes and existing software practices.



Example of a multiobjective optimization

Analysis Automation and Design Optimization

As introduced earlier, Robot Structural Analysis Professional API helps to provide control over the following aspects of analysis:

1. Geometry generation and manipulations (for example, node coordinates)
2. Mesh generation (for example, mesh size)
3. Structural size and property assignment (for example, section database, material stiffness)
4. Analysis runs (for example, nonlinear) and results evaluation (for example, deflections, member forces)

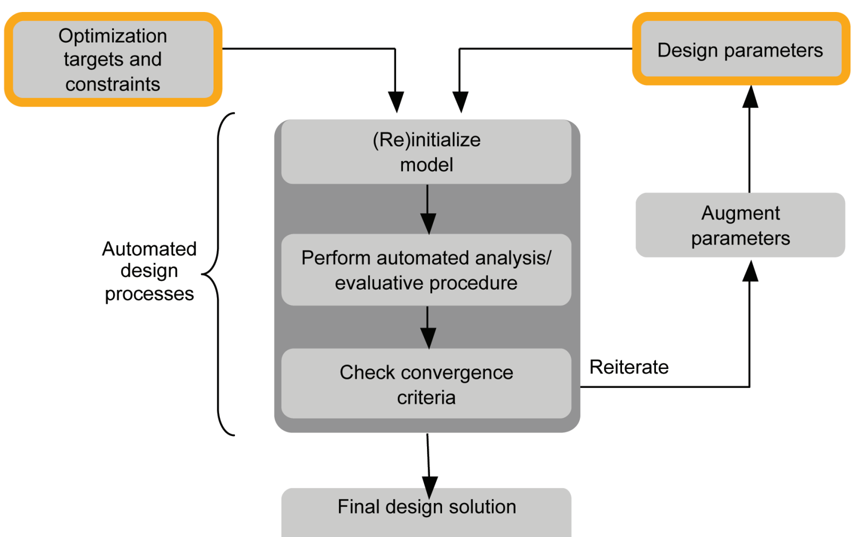
With a programmable COM interface, the API helps enable automation of the analysis. Using this capability, one can more easily write a program that automatically:

- Re-creates the geometry and mesh parametrically
- Applies the sizing and material properties to the mesh elements
- Runs the analysis
- Interrogates the results
- Reports the results, for example, forces schedules in a table or a drawing

The integration of Robot Structural Analysis Professional with a powerful BIM application, such as an Autodesk® Revit® product, helps to further benefits including direct linking of the analysis with the parametric design model, as well as automated generation of fabrication scheduling.

Automation of design analysis by itself helps increase efficiency. When integrated as part of an optimization procedure, the capability and benefits can be greatly enhanced.

Optimization is then just a step forward from automated analysis. As illustrated in the diagram below, the procedure setup for automated analysis is run in a closed loop, varying the design parameters and checking for results until the target is met.



From this generic template for optimization, elaborate algorithms can be defined through a combination of automation and reiteration; thus, the key is in defining effective performance criteria together with a feedback loop that updates the design variables.

Implementation and Application Case Studies

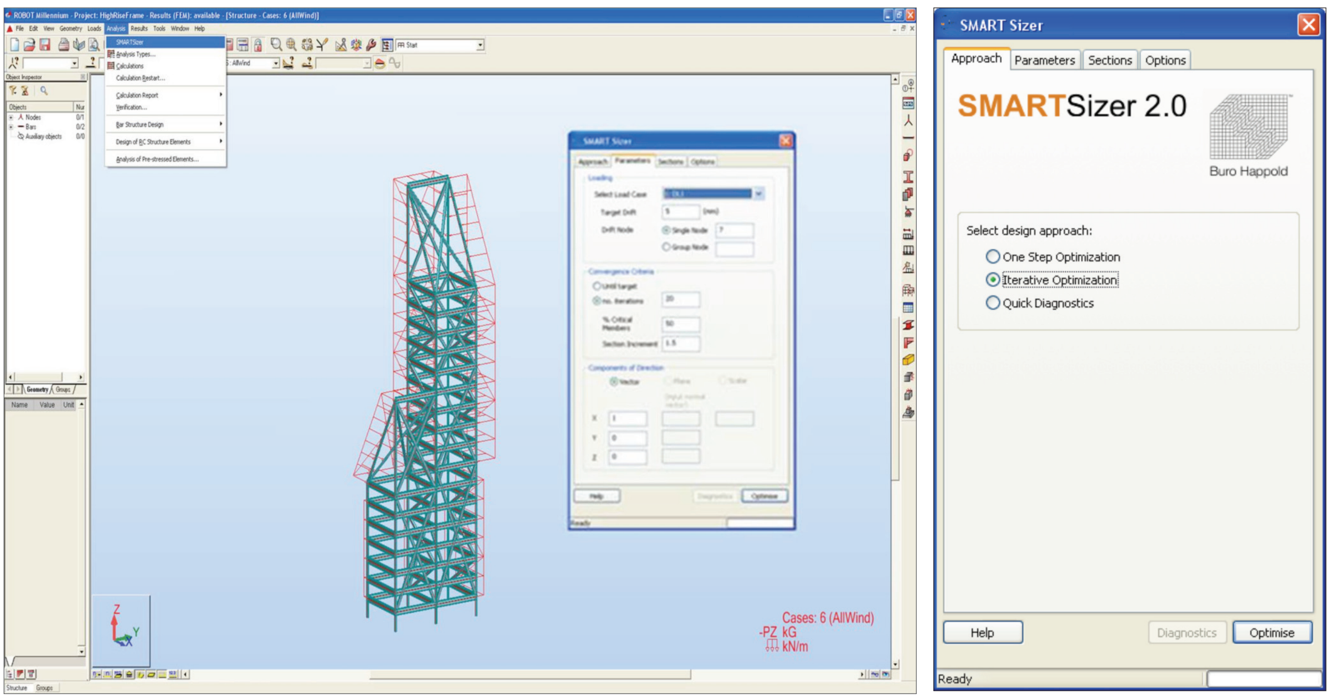
The screenshot below is a good example of practical implementation of a bespoke structural optimization tool SMART Sizer, developed by the SMART Solutions team of Buro Happold Ltd., a global engineering consultancy firm.

Responding to the challenges highlighted above , SMART Sizer was developed as a plug-in to Robot Structural Analysis Professional.

The tool enables fast interrogative and diagnostic facilities to evaluate the effectiveness of an individual design solution, as well as full design optimization capability. The later functionality actively resizes individual structural members to meet specific serviceability and ultimate limit state requirements specified by the designer.

When meeting the serviceability constraints for advanced projects such as tall buildings and lightweight and wide span structures, sizing members for effective distribution of structural stiffness and optimum performance is a challenging and time-consuming process. A tool such as a SMART Sizer helps these complex constraints to be accurately met and frees the designer from routine number crunching to spend more time designing and exploring more effective design options.

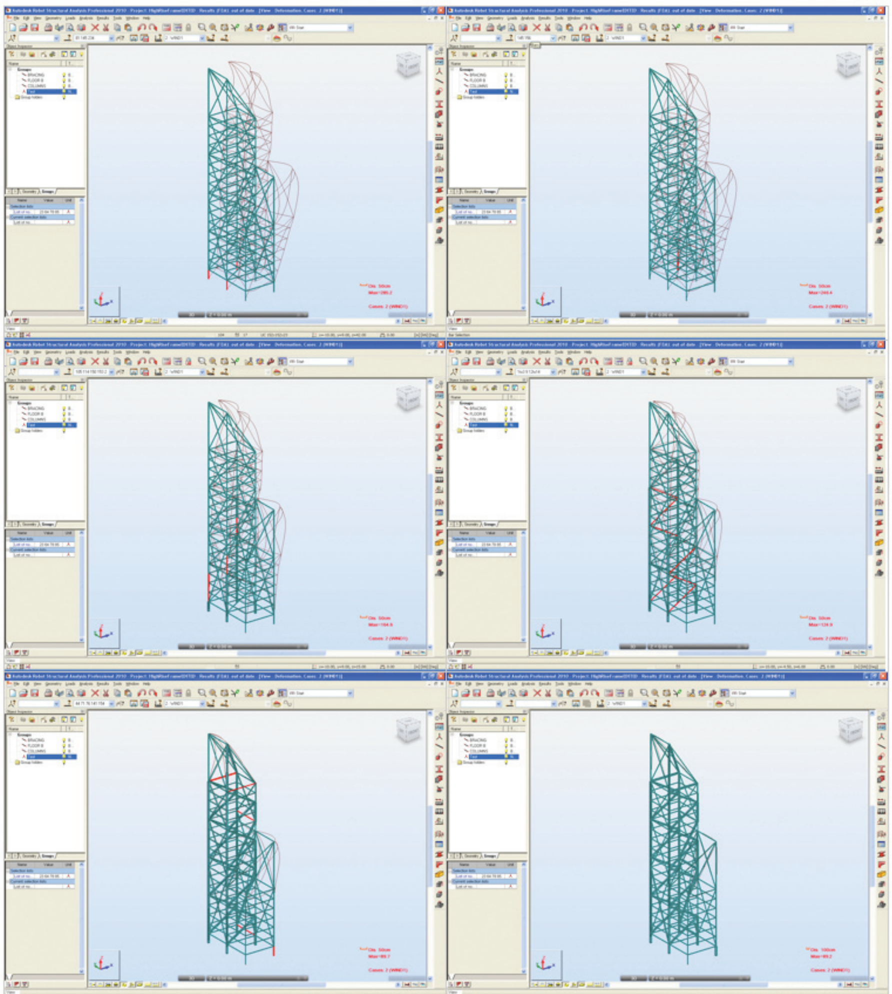
SMART Sizer
(© Buro Happold)
Example of a bespoke structural optimization tool built using Robot Structural Analysis Professional API



Optimization of a Tall Building Structure

The screenshots below taken from Robot show an application of SMART Sizer on a high-rise building structure.

The optimization algorithm implemented here identifies the most influential members within a structure to limit the deflection at a determined point and subsequently increases the sizes of those members. This process is reiterated until the maximum deflection criteria are met. This powerful design tool thus enables the overall stiffness distribution throughout the structure to be carefully controlled, helping to meet the design requirements while minimizing the structural mass and, thus, material used and potentially cost.



Even in this simple example, the individual steps of analyzing the structure, selecting crucial members, and subsequently sizing the pertinent members appropriately is repeated numerous times—an impractical and virtually impossible process to perform manually without full automation.

Selected Steps Illustrating an Automated Iterative Deflection–Based Optimization
Within each step, crucial members are identified and increased in section size.

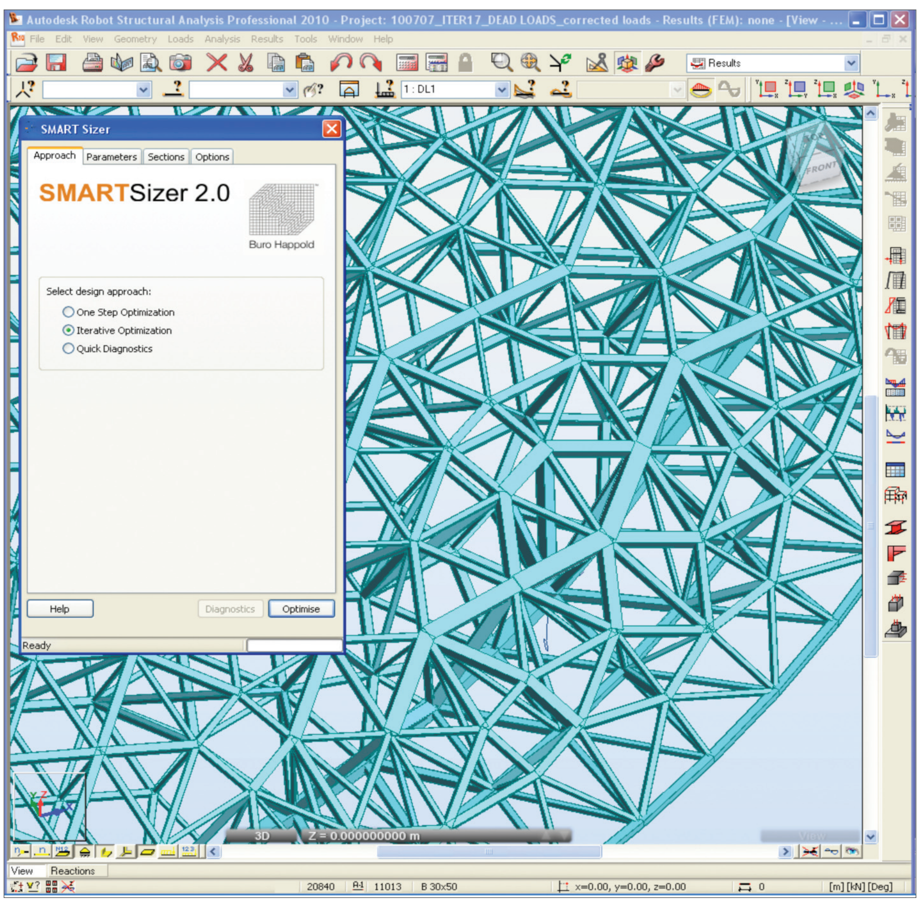
After multiple iterations, the structure has converged, naturally satisfying the imposed deflection criteria.

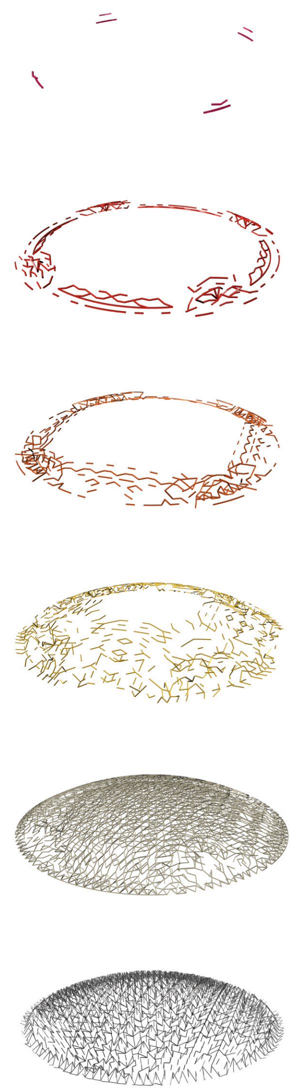
The true power of automated design processes and optimization becomes more readily realized when scaled up and applied to large, complex structures.

The example model below is made up from more than 10,000 elements. Thus, together with additional symmetry and rationalization constraints, performing advanced analysis procedures and sizing each member by hand becomes not only laborious, but logistically infeasible.

The images show the results of how through use of the automated design tool, the global behavior of the structure could be controlled and crafted, forcing efficient stiff regions within the structure to emerge.

Although the final result appears naturally complex with an elaborate and freeform distribution of members of different sectional capacities throughout the structure, the automated procedures harnessed enable full rationalization to be performed simultaneously with the optimization, helping to produce a final solution that is practical and constructible.





The images illustrate the intricate distribution of sections evolving naturally from the stiffness based optimization capability of SMART Sizer tool

Summary

This paper introduced the capabilities of Autodesk Robot Structural Analysis Professional and the Robot Structural Analysis Professional API, and their exploitation to help automate analysis and to develop tools for design optimization. It highlights the concepts of analysis automation, design optimization, rationalization, and standardization, demonstrated using Robot API–based examples, while illustrating how these can help streamline workflow and design efficiency.

Robot Structural Analysis Professional API exposes most of the standard the standard functionality of Robot, facilitating programmatic control through an external piece of software. Access to Robot through this mechanism can enable any routine tasks or processes accessible through the standard user interface to be fully automated and, thus, more rapidly repeatable, extendible, and scalable.

Programmatic access enables the execution and control of the analysis tasks, so multiple design options can be more quickly evaluated, while also testing for design compliance. Robot API is therefore a powerful tool for concept design optioneering as well as detailed design optimization.

The paper shows an example of practical implementation of a bespoke structural optimization tool, SMART Sizer, developed by the SMART Solutions team of Buro Happold Ltd. SMART Sizer has been developed as a plug-in to Robot Structural Analysis Professional. The specific examples presented in this white paper cover a broad range of engineering tasks from concept form-finding to detailed optimization, and project examples from tall buildings to long-span structures.

About the Authors

Al Fisher joined SMART Solutions, Buro Happold's advanced analysis and simulation group, in 2007 following his PhD at the University of Bath. His expertise lies in the field of numerical modeling and generation of complex geometries, with applications in the definition of arbitrary architectural geometries. As a structural engineer with this background in computational design and analysis, his interests include form-finding, geometric rationalization, optimization, parametric design, and nonlinear structural analysis.

Al is particularly interested in the design and analysis of freeform engineering geometries where the structural and architectural forms are inextricably linked. Since joining Buro Happold, he has worked on developing a number of novel tools to generate rational structural geometries from arbitrary forms.

Al is also developing software to model wind flow around surfaces of freeform geometry. This shall have an immediate application in the wind loading analysis of tensile structures where complex doubly curved geometries are intrinsic to their design.

Shrikant Sharma leads SMART Solutions—Buro Happold's specialist service that offers engineering innovations driven by computational modelling, analysis, and simulations. SMART Solutions specializes in the development of efficient solutions for the built environment and beyond. The team, founded by Shrikant in 2002, has won a reputation for providing simple, practical, and innovative solutions to complex engineering problems.

Shrikant has a PhD in engineering and is an expert in the analysis and optimization of complex forms and structures. Shrikant has more than 15 years of experience in the development and application of numerical software and new technologies. Prior to working with Buro Happold, he worked at the universities of Cambridge and Manchester with consortia of automotive and aerospace firms on modelling and manufacturing of complex composite structures.

Shrikant's expertise lies in developing and applying digital technology to provide solutions that integrate architecture, structural engineering, and fabrication. He has led the integrated modeling, optimization, and digital fabrication process on a number of high-profile projects at Buro Happold.

About Buro Happold

Buro Happold is a world-class multidisciplinary engineering consultancy operating out of an international network of offices in the United Kingdom, Europe, North America, the Middle East, and India. Founded in Bath in 1976 by the late professor Sir Ted Happold, Buro Happold is now a limited liability partnership, providing a comprehensive exemplary engineering consultancy for complete developments, buildings, and infrastructure.

Buro Happold's aim, on behalf of its clients, is to achieve maximum value in our engineering design. The company provides design solutions that are elegant, easily constructed, environmentally responsible, and efficient in their use of materials and energy.

As architectural design becomes increasingly more challenging and complex in nature, Buro Happold is continually developing new technology to enable us to deliver original, innovative, and efficient design solutions. SMART Solutions is at the center of Buro Happold's innovation process and offers cost-effective engineering solutions on technically demanding projects.

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