Architectural Design Optimization (ADO) opens new horizons in practice

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Catalogue of variations of the same design concept of the free form roof defined by parametric model with associated price evaluation; author: J.Cichocka.

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"Nothing in life is to be feared, it is only to be understood. Now is time to understand more, so that we may fear less."– Maria Sklodowska- Curie

Due to the rapid technological development, architects have been more and more often afraid that the technology can replace them. Overwhelming news about evolutionary strategies, computational morphogenesis or Artificial Intelligence applied to design process bring the thrill of fear to their professional lives.

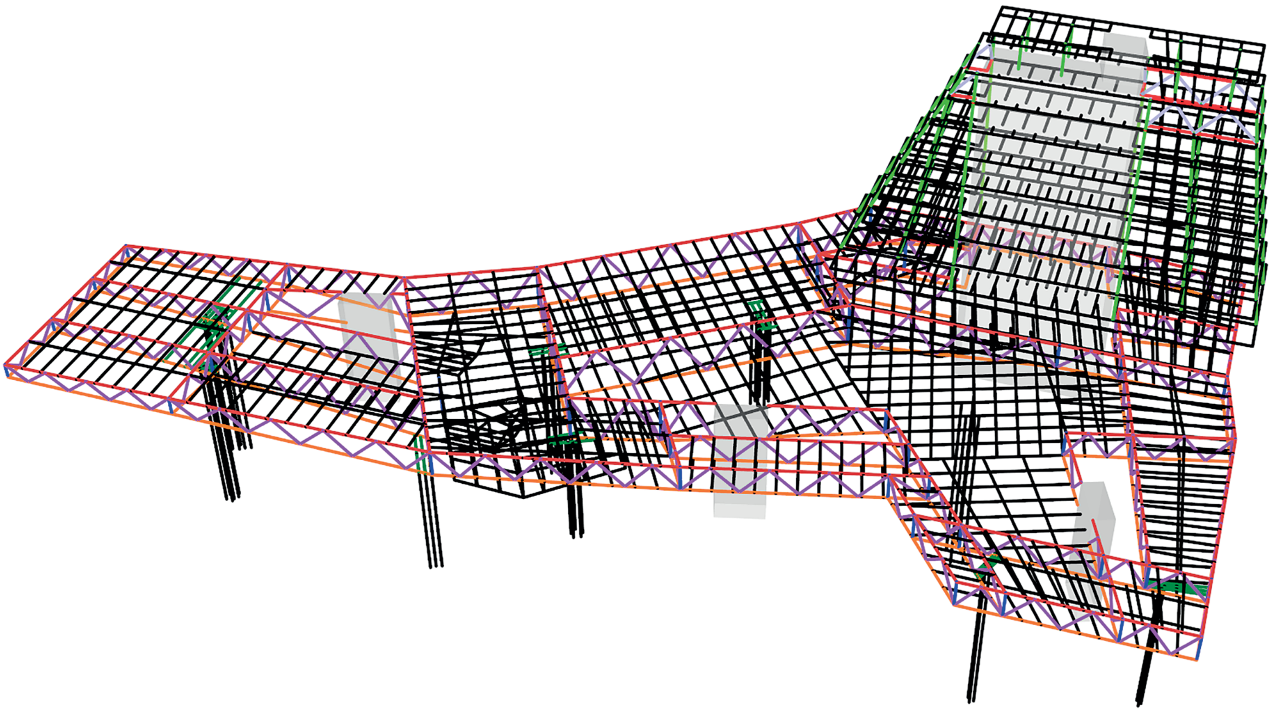
The future of architectural profession

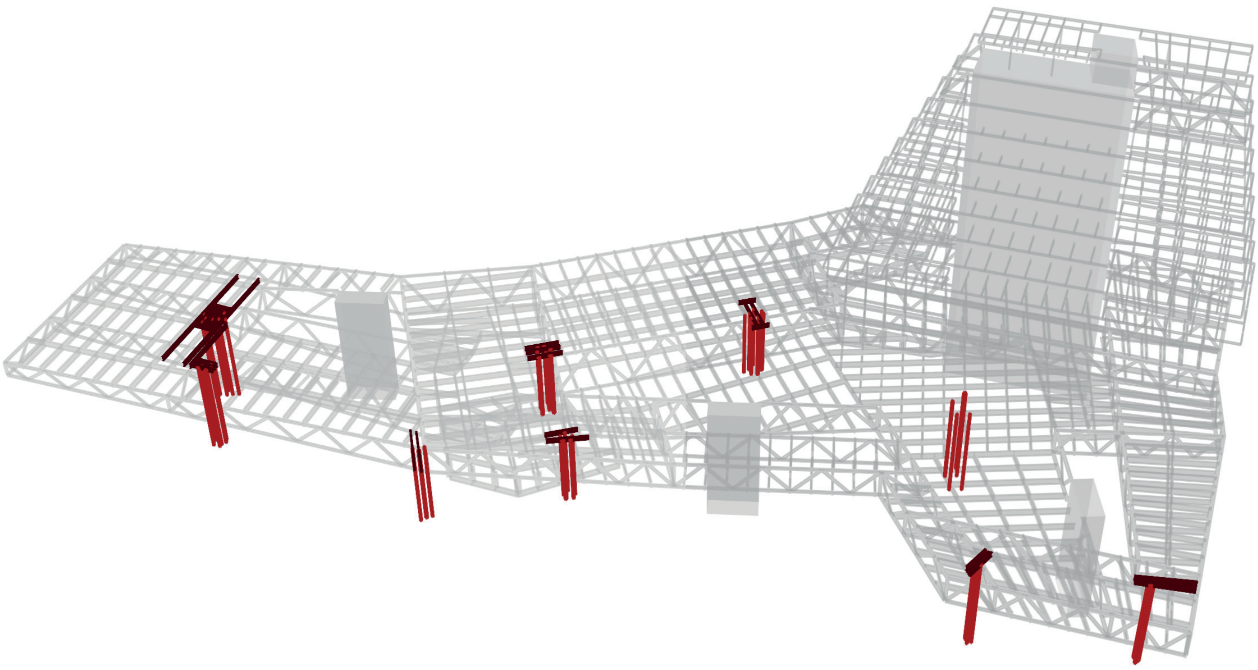
As the CAD systems made the hand-drafting skills irrelevant, the professional expertise may be discredited by machine intelligence? Let's be honest here, it is a fact: computation and automation is being replacing traditional means of design. Up to 40% of current tasks such as cost estimation, preparation of documentation and scheduling, performance evaluation could be automated. Does it mean less architects will be needed? We should not think too narrow about the future of profession. The future of architectural profession shouldn't be considered as 0 or 1, fully- machine driven or fully traditional. As Daniel Sasskind, author of multiple Oxford studies on future of professions, writes in his article "The way we'll work tomorrow" for RIBA: "Technology does not displace entire jobs; it changes the 'tasks' that people do in their jobs.". Architects as human-decision makers cannot be replaced in the such sensitive process which the architectural design is. Referring to Daniel Susskind, computation and generative design augments rather than replace the skills of designers.

There are two ways architects, engineers and designers can perceive the technological shift now: either as a threat or as a great opportunity for their professions. In this article I would like to present some of the benefits of using parametric modelling and optimization in the design process. The most relevant Architectural Design Optimization (ADO) techniques will be presented and supported by the examples from architectural practice. Decide on your own what ADO means to you. Is it a threat or amazing opportunity for the future of the profession?

Optimization

Computer Aided Design has been recently enriched with parametric design techniques. More and more architects, engineers and designers use visual programming and scripting tools to represent their designs. Parametric modelling enables generation of thousands of variations of the same design concept. The number of alternatives usually exceed the human capabilities to evaluate or compare all the options. Optimization itself is an art and a science of selecting the best element or a set of elements from the pool of the available alternatives in terms of





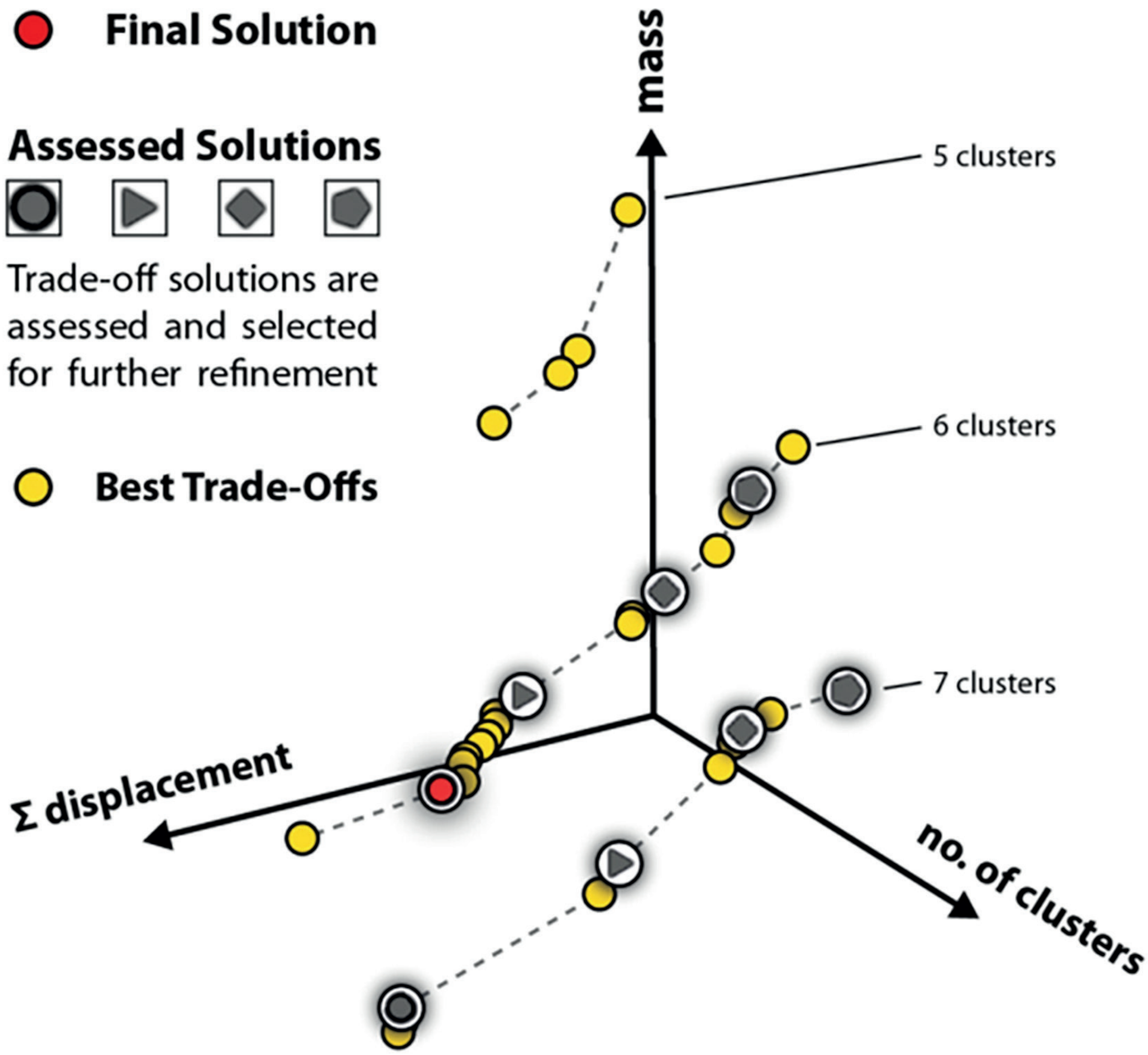
Multi-objective optimization applied in the optimization of the structural system of the Hyundai Motorstudio Goayang in Seoul (Bollinger+Grohmann) above: visualization of the solution space. Below: selected solution. Pictures courtesy of Bollinger+Grohmann.

specified selection criteria. This process has been natural for architects since ever, only now it could be performed in more formal way and enhanced by computation.

Optimization tools support architects, designers and engineers in the choice of the best performing design solution. In order to select the best option, decision-maker has to specify the criteria which allow to order the design alternatives from the best to the worst performing. To be more specific, we could evaluate design using criteria like its cost, energetic performance, structural performance, access to direct sunlight and by almost any criterion which could described as a computable formula. Most of the architectural design optimization problems incorporate the environmental, energetic or structural simulations and the result of such simulation determines how "fit" is the considered solution. Usually such simulations are conducted by means of third-party software (we do not write ourselves the evaluation procedure), therefore the internal function remains unknow and it is consider as black-box. The black-box problems require black-box methods to solve them. Increasing relevant know-how in the area of ADO should eventually result in the increase of employment of mathematical approaches and dedicated methods (Wortmann & Nanncini, 2017). Nevertheless, nowadays ADO is currently dominated by generic solvers aimed to handle black-box problems.

Optimization tools

For the most popular platform for parametric design, which is Grasshopper– now an in-built visual programming tool in Rhino 6, there are several tools for black-box optimization. We could find tools based on the metaheuristics such as: Galapagos – Genetic Algorithm and Simulated Annealing, Silvereye – Particle Swarm Optimization (PSO), Octopus - SPEA-2 and HypE or recent Design Space Exploration- NSGA-II. Apart from metaheuristic procedures in the black box solvers we could find Direct-Search algorithms (Goat – DIRECT) and model-based methods (Opossum – surrogate models). This list is still growing, while other optimization tools appear in other design systems e.g. Optimo, which utilizes MOEAD, a multi-objective metaheuristics is currently part of Dynamo, a visual programming tool for Autodesk Revit. All



The overview of structural system of Hyundai Motorstudio Goayang in Seoul. Picture courtesy of Bollinger+Grohmann.

these generic type tools could handle most of the problems that are encountered in the practice.

Why is it worth to employ optimization tools? First of all, using parametric modelling and optimization methods, we are able to consider and evaluate far more alternatives, therefore chances that our design is actually the best are higher. The use of optimization tools gives a numeric evaluation, stamp and confirmation for an informed-decision in the design process. Without them choosing the best option is more similar to playing darts not even knowing where the "10th point" is. On the one hand, simulations and optimization could aid architects in the decision-making process providing verified data and helping them making more reasonable decisions. On the other hand computational approach can save a lot of time in early design stage, where the design is changed, adopted, modified accordingly to the input of the all parties engaged in the design process. If the design model is properly defined by the parametric rules, the change of dimensions or shape, is not a time-intensive activity anymore. We change the input parameters and the model adopts accordingly.

Arup

Let's discuss now, the optimization benefits coming for projects followed by several examples from architectural practice. Arup is one of the practices well known for employing optimization for solving engineering problems. Arup established in 2002 Foresight, Innovation and Incubation (FII) in London, which main aim was to incubate expertise in computational design + optimization (CDO). In the project of the DIFA Bishopsgate Tower realized in conjunction with architects Kohn Pedersen Fox Associates, FII managed successfully employ the topology op-

NOTE ABOUT AUTHOR

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timization and optimization of section size of members (Luebkeman & Shea, 2005). The variants of Pattern Search method (Hooke and Jeeves 1961) was used for topology optimization and Optimality Criteria methods for section sizing (Baldock, 2007).

The topology optimization problem had 3x10^48 possible designs. Let's imagine we would like to evaluate all of them in order to choose the best one. Let's assume that computer needs only 5ms for one evaluation. It results in around of 5x10^38 years of calculations (3x10^48 x 5 x10^-3 s= 15x 10^45s =15x10^45/ 86400 days = 17.36x10^40 days = 0.048 x10^40 years = 5x 10^38years)! That is why we need optimization techniques - to complete these operations and find the best performing option in finite time. The goal of the whole topology optimization procedure was to minimize the number of bracing elements. Reduction in the total number of bracing elements results in decrease of material cost and construction time, therefore let increase of the potential revenue. At this time most of optimization tools were tailored to problems. In this case the implementation of the computational solution was developed as a C# plug-in for Generative Components. This project is an example of the early developed dedicated methods – which are understood as specific technique developed to solve a specific problem. The area of computational design and optimization (CDO) the earliest was adopted to structural systems in building technology, as the structural member sizing strongly resemble mechanical components in automotive or aerospace industry. This industries adopted optimization much earlier than the AEC industry (Luebkeman & Shea, 2005). The Bishopsgate Tower skyscraper is currently still under construction.

Curved surfaces

Another family of dedicated optimization methods is inspired by discrete surface optimization techniques which been initiated by practical needs of manufacturing, animation and gaming industries. These methods aim at rationalization of the curved surfaces in architecture. What does it mean a rational surface in architecture? Cheap? Buildable? With different panelling methods, penalization of the freeform shapes in architecture in such manner that the panels could be fabricated with selected technology at reasonable cost. Kunsthaus in Graz, designed by Peter Cook and Colin Fournier and Hunger-burgbahn in Innsbruck from Zaha Hadid Architects are the projects involving double-curved panels, where a separate mould was built for each panel. Extremely expensive. In most of the cases rationalization aims at covering all the curved surface with perfectly flat and repetitive panels (reduction in the number of families). Size, number of panels, complexity of panel geometry, reusability of the molds for custom-built panels are the main cost-drivers (Eigensatz et al., 2010). Below example of the planerization of the panelling for the National Holding Headquarters which managed to reduce the cost of the building skin by more than 7 times.

Rationalization of the surfaces is a very common problem in architectural practice. Such optimization problems appear in any architectural projects involving curved surfaces, just to mention a few: Lilium Tower in Warsaw, Heydar Aliyev Merkezi Cultural Center in Baku (both projects Zaha Hadid Architects) or Islamic Art Museum in the Louvre in Paris (Bellini Architects) Emporia Shopping Centre in Malmo (Wingårdhs). Currently there is also software dedicated for surface rationalization problems among others Evolute tools and VaryLab. Dedicated methods were a kind of natural extension of the methods of applied in the engineering optimization problems in other than building scales.

Octopus

Let's come back to our black-box methods, which I name as generic or universal, which are able to solve almost any problem encountered in practice. One of such tools is Octopus which was developed by Robert Vierlinger at the University of Applied Arts Vienna, and Bollinger+Grohmann Engineers. Currently B+G employ Octopus on regular basis in their practice (Heimrath, 2017). For instance, Octopus was used for multi-objective optimization in the Hyundai Motorstudio Goayang in Seoul, South Korea. The structural system composed from four concrete cores and clusters of steel columns was optimized to minimize 3 objectives: displacement of the structure, its mass and the number of clusters of the steel columns. The option balancing these 3 objectives in the best way was implemented in realized project.

Buro Happold with UNStudio integrated conceptual energy and daylight optimization in the Deutsche Bank Areal in Frankfurt. Simplified thermal, radiation and daylight models were built to specify the energy preconditions. The overshadowing effects of the four towers made it obvious to adopt the façade glazing ratios and depth in accordance to specific requirements of functional zones. By smart manipulation and gradient glazing, the reduction in unwanted solar gains and over lit was achieved. In this case the applied optimization strategy helped to balance the building energy management.

Multi-criteria optimization

In our practice, working on pilot projects with Mexican architectural practices, we encountered a repetitive problem of enhancing the sea view and decreasing the amount of earth works especially for hotels built on the sea coast. You could find an elaborated case study on our blog: http://parametric.support/coastal-masterplan-development-optimization. In the mentioned pilot project, using multi-objective optimization the average view angle was improved by 65% and earthwork decreased by 17%. It means that using multi-criteria optimization we can easily increase the Return On Investment both through the directs savings during the construction process on the earth work and in the building life time on the higher rental price of the rooms with the sea view. A few hours of smart optimization process during early stage design could increase potential gains by thousands of euro.

In conclusion Architectural Design Optimization could aid the creation of more efficient structures through decreasing the construction cost and time by minimizing the amount of structural elements and reducing their complexity. It could enhance the sustainability of the design through rational panelization or enhancement of energetic efficiency of the building. Possibilities do not stop there. Any design feature which can be expressed as the computable formula can be optimized. We should get to know Architectural Design Optimization better to fear less and to eventually achieve more. **MAG**

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