The Karamba plug-in developed by Clemens Preisinger in collaboration with Bollinger + Grohmann Engineers has been developed to predict the behaviour of structures under external loads. Intended to be used by architects rather than being solely confined to an engineering setting, it enables a seamless flow of data between structural and geometric models. Preisinger here describes the program’s evolution and application.
Karamba is a finite element (FE) program for predicting the behaviour of structures under external loads. Though developed in a structural engineering firm, its main focus does not lie in this field. It is geared towards use within an interactive, parametric architectural design environment. One of the goals was to create a fast, lightweight tool that facilitates a seamless flow of data between structural and geometric models. The origins of the Karamba plug-in for Robert McNeel & Associates’ Grasshopper® date back to a research project entitled Algorithmic Generation of Complex Space Frames,1 carried out at the University of Applied Arts Vienna in collaboration with Bollinger + Grohmann Engineers. The project focused on the viability of applying genetic algorithms (GAs) to the structural optimisation of real-world structures.2 GAs rely on a large number of evaluations of the function to be optimised – in the case of structural assessment these are FE calculations. It was found that the main impediment for scaling up the optimisation tasks was the time spent on the recurrent computation of the statical models, which amounted to days in some instances. This motivated the implementation of a custom FE code which now forms a large part of the calculation core of Karamba. The parallelisation of time-consuming calculation steps, a fast and extensive interface to scripting languages, and results calculation on demand, have led to a reduction of computation time of two to three orders of magnitude compared with using off-the-shelf FE programs.

The Skylink bridge links Frankfurt Airport with a 300-metre (984-feet) distant car park. The work of Lengfeld & Wilisch with Bollinger + Grohmann Engineers, it is a trussed bridge with the diagonal elements placed by the Karamba design tool.3 The four longitudinal girders at the corners of the bridge are fixed. Two sets of connecting elements join the main girders: one set encloses the top, and the other encloses the bottom, resulting in the box-like truss. Along the sides of the bridge, the diagonal elements run in different planes so that complex, costly connections are avoided. The parameterisation used consisted of joining predefined poly-lines with sets of diagonals whose position was subject to optimisation.

Maximum displacement and mass of steel served as measures for ranking the solutions in the GA optimisation procedure. The number of variables to be optimised amounted to about 400, which made it a very large-scale problem for a GA approach. Roughly 200,000 variants of truss layouts were tested before arriving at the final result. The solution performs similar to a regular truss with respect to total mass and maximum deflection. Although the truss layout arrived at is probably not the global optimum, it certainly provides a useful alternative to conventional, regular geometries.
Karamba has been used at Bollinger + Grohmann Engineers for a number of projects, either for checking statical feasibility in the early stages of design, or for performing structural optimisation. A recent example of the latter is the design of White Noise by the Austrian firm soma Architecture. A mobile pavilion for cultural events, it consists of a large number of aluminium rods that interact in a seemingly chaotic manner.

The static system of the pavilion is made up of a number of arches that span a distance of 12 metres (39 feet). Each of the arches is made of multiple layers of rods. The members of one layer connect to elements on the neighbouring layers via short, circular studs. The number of connections between neighbouring elements thus depends on their inclination with respect to each other. The optimisation task here involved selecting the elements orientation for minimum displacement under given loads at minimum total structural weight. The parameterisation of the geometry was done entirely in Grasshopper, and the solution process handled by its built-in probabilistic optimisation engine.
INTEGRATION OF KARAMBA WITHIN AN INTERACTIVE MODELLING ENVIRONMENT

During the research project at the University of Applied Arts Vienna, the design of a user interface for the program package played a very minor role. However, in the day-to-day work of the design office at Bollinger + Grohmann Engineers, the necessary coding of geometric parameterisations as scripts proved cumbersome and reduced the range of possible users to a small circle of scripting experts. To solve this problem, the program was ported into existing software that offered an interactive, generative modelling environment. Grasshopper allows the integration of custom plug-ins that can then make use of the program’s graphical user interface elements and thus interact with other plug-ins in a well-defined way. This led to the first public version of the Karamba plug-in.

Most aspects of a Karamba model can be made dependent on parametric input. Such a model consists of an assemblage of visual components which look and feel like the native software’s building blocks. The fact that Karamba reacts immediately to any change of input parameters helps to understand structural mechanisms in the design. Using Karamba is like watching a film compared to a fixed image; one can easily create a series of images in real time by manipulating the corresponding user interface widget instead of the more traditional approach of having a systems response only at one particular state.

Although its development has been rooted in the context of Bollinger + Grohmann Engineers, Karamba has always been a stand-alone project. As development proceeds, the range of its applications constantly widens; for example, shell elements can now be included in calculations. But what is perhaps most interesting is how the structural properties that are normally hidden from view—deflections, natural vibrations, force flow lines—can be used creatively in an architectural context. With the advent of new digital tools that combine architecture and engineering, demand has grown for professionals who have knowledge in both areas. Karamba is the instrument for this new generation of architectural engineers and engineering architects to play their new tunes on.

Notes