Supplied and sponsored by **SCIA** A NEMETSCHEK COMPANY

Industry CPD

Parametric design and visual scripting

This CPD module, sponsored by SCIA, explores the productivity benefits that structural engineers could gain by adopting a parametric approach to design

Continuing professional development (CPD) ensures you remain competent in your profession. Chartered, Associate and Technician members of the Institution must complete a specified amount each year. All CPD undertaken must be reported to the Institution annually. Reading and reflecting on this article by correctly answering the questions at the end is advocated to be:

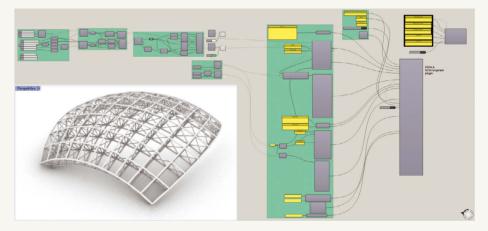🕐 **1 hour of verifiable CPD**

Introduction

Parametric design is increasingly becoming embedded in engineering and design workflows, as the construction industry embraces wider use of technology. In recent years, we have observed an increase in non-traditional tools targeting the whole construction industry. Ever-more complex structures are being designed, for which traditional design methods cannot easily be applied. It is during times like these that innovation occurs. Parametric design tools – which until a few years ago were almost exclusively used by architects – are now available for structural and civil engineers. Let's take a closer look at parametric modelling and design.

Why go parametric?

In general, companies could benefit from increased productivity by using parametric design. A parametric design workflow helps to create, maintain and optimise structural analysis models while keeping the model definition clear and readable. The most common way to design structures parametrically is through visual scripting.

Grasshopper, a plugin for Rhinoceros (a 3D modelling package), is one of the most widely used visual scripting environments. Likewise, Dynamo offers a similar function for Autodesk products.

Visual scripts use an algorithm to create various entities (i.e. points, lines and surfaces) in a 3D model space. This algorithm follows linear logic

⬆**FIGURE 1:** Visual script that generates 3D space truss topology (resulting structure topology shown at bottom left)

and is relatively simple to define in the graphic user environment. Compared with traditional programming languages, a visual script is far more intuitive. Provided the visual script has been robustly created, then changes to the structural topology (i.e. the geometry of the structure) can be carried out extremely quickly.
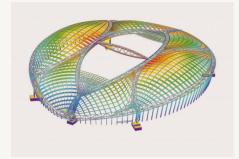
The most basic workflow is simple – define two points (i.e. nodes) and connect those points with a line. If the location of either point changes, the line will still connect them. The same idea can be applied to creating lists of nodes and lines, ultimately generating a structural system.

It is certainly fun to begin visual scripting, and anyone can become quite productive in a short space of time. For example, **Figure 1** shows a visual script that generates a 3D space truss for a roof canopy with customised geometry. With practice (and a little training), this visual script could be created in as little as 15 minutes.

Visual scripting offers a readable 'script' that may be transferred to most commercial structural analysis software. The scripted model topology (structural geometry and cross-section sizes) can be imported into popular analysis and design software packages by using other software

↓**FIGURE 2:** Al-Janoub Stadium, Qatar[1]

a) Structural analysis model in SCIA Engineer as featured in SCIA user contest 2020

b) Architectural visualisation

Rapid prototyping using parametric design with SCIA Engineer and interoperability with virtual-reality environments allowed the engineers to test different solutions and evaluate options to produce a stadium befitting the architect's vision.

The approach taken to create the parametric model of the Al-Janoub stadium is not that different from the space truss example in **Fig. 1**. The script, however, was much more complex, and the designer needed to be in complete control of the data. Usually, such projects are divided into several parts that are connected but modelled by separate partial scripts. In the final steps, all members are merged into a single long list which can be then linked to the structural analysis model.

components. These components are widely available and regularly provided free of charge. Examples include connections from Grasshopper to SCIA Engineer, Tekla Structures, Dlubal and IDEA StatiCa.

One significant advantage of Grasshopper is openness; anyone with basic programming skills can create a new component to serve a specific need and share it with the community. Of course, advanced programming skill is required to create finite element analysis (FEA) solvers or analysis tools for complex topics such as real-time analysis of tensile membrane structures (e.g. the Kangaroo plugin), computational fluid dynamics (CFD) solvers for wind tunnel simulations), or advanced weather calculations (e.g. the Ladybug plugin).

The open nature of visual scripting allows users to choose the most appropriate tools to complete any number of design tasks while using the same scripted model topology. As well as the model topology, the engineer must also add boundary conditions (supports, hinges, loads, etc.) which can all be defined within the visual script. For example, users can automatically loop a SCIA Engineer analysis to optimise the structure while printing the resulting values and running member checks in each iteration.

It is worth noting that when working with SCIA Engineer, some settings cannot be defined in the scripted model, e.g. mesh settings or selecting the appropriate results to export. In these cases, users could use template project files to predefine these parameters before transforming the scripted model into the analysis model.

Challenging structures: airports and stadia
One of the main applications of the parametric design approach is structures that would be too complex to model manually. Stadia, airports and high-rise buildings (or any landmark structure) designed by ambitious architects have one thing in common: highly complex shapes that are often too complicated to model by conventional means within feasible time restraints, and even more difficult to modify once created. Large architectural practices (e.g. Zaha Hadid Architects) use the parametric approach on a daily basis.

Structural engineers can become extremely

efficient if they learn to use the parametric model produced by the architects to generate the structural geometry. Parametric design methods allow the engineer to create analysis models of the most demanding projects in minutes instead of months. These models might contain thousands of members, but changes can be implemented, analysed and designed with relative ease.

A recent application of this approach is the monumental Al-Janoub Stadium in Qatar **(Figure 2)**, where engineers from AECOM used parametric methods to conceptualise and design the structure. The stadium was built for the 2022 FIFA World Cup. It seats 40 000 spectators and will be used up to the tournament's quarter-finals. Afterwards, it will be converted to a capacity of 20 000 seats and used by the Al-Wakrah Sports Club.

The roof comprises two symmetrical parts, each side composed of three shells. The upper tiers of the stadium were designed to be removable after the tournament. The roof structure, which comprises 185m propped arches, underwent construction staging design, fire engineering and plate design for the sculpted V-columns supporting the primary arches.

The challenge was to create a landmark stadium that offers a world-class experience.

From parametric to generative design
Emerging fields in parametric design include topology optimisation, form-finding and generative design. In all of these cases, the engineer defines the boundaries of the possible solution and then advanced algorithms iteratively find the optimal solution.

In generative design, artificial intelligence (AI) is combined with parametric design to select the best structural form. For pragmatism, the AI is not totally free to find the optimal form; the engineer will need to define some boundary conditions to guide it. Typically, these conditions are defined support areas and the volumetric domain in which the structural form can exist.

Generative design algorithms can often lead to one-of-a-kind results because structures are optimised for their unique conditions. Interestingly, structures optimised this way often resemble shapes found in nature **(Figure 3)**.

Structural forms produced by generative design very often resemble trees. If you examine the 'superstructure' of a tree, the trunk is strongest at its base as this is the spot where all the forces and moments due to leaves, branches and wind loads are the most substantial. The trunk first divides into large branches, which continue to divide into smaller and thinner branches. Eventually, optimally

↙**FIGURE 3:** Typical example of generative design[2]

shaped leaves at the branch ends cover as large an area as possible to catch sunlight.
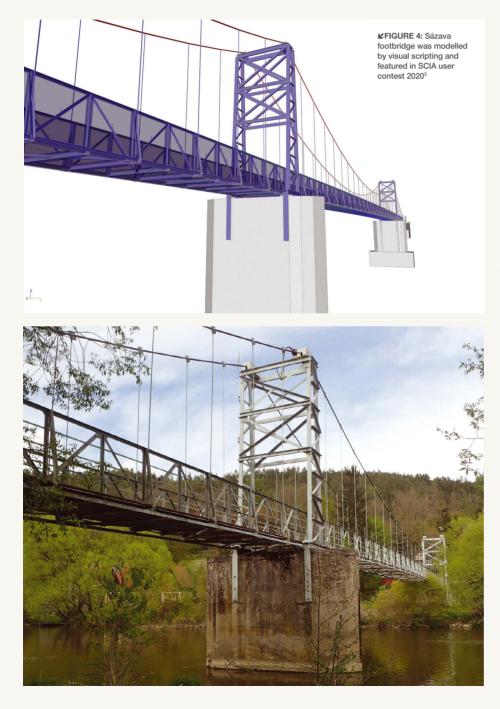
Evolution drives trees to be as efficient as possible, and the forms that develop are directly linked to the conditions where the tree species exist. The same principles can be applied to design, architecture and engineering. Similar efficiency may be observed in long-span bridges, where material utilisation largely drives structural design. Efficiency has always been a fundamental question in structural engineering.

Of course, generative design may be used in other areas besides the design of natural shapes and organic structures. It could be used to find an optimal arrangement of flats in a multistorey building or to optimise whole urban areas to be more convenient for their inhabitants. Adding a layer of AI or machine learning on top of parametric design algorithms allows the engineer to compare vast amounts of potential design solutions and select the most efficient scheme. This process would not be possible using traditional engineering methods.

Parametric bridge designs

One sector of structural engineering where projects might benefit from parametric methods is bridge design. When designing longer and longer spans, the structural system must be highly efficient to remove unnecessary structural mass. This is very much aligned with the parametric design approach.

The profile and plan curvature of a bridge are often determined by the alignment, profile and cross-section of the carriageway or railway it supports. When the bridge curvature is significant in plan or profile, creating an analysis model often becomes tedious and error-prone. This is especially true for bridge forms (e.g. trusses, suspension or cable-stayed) that are generally composed of many elements.

Parametric design offers a more efficient method to create that same analysis model in less time. Moreover, there is potential to generate the analysis model directly from the highway model if it is also created parametrically.

Additionally, a significant benefit of parametric bridge design is the option to reuse existing scripts, which greatly increases productivity. Since bridges are generally quite similar, reusing scripts from previous projects of the same bridge type could save a lot of design time. However, it is important to note that good scripts rely on satisfying design conditions and not exclusively exact numbers.

The suspension bridge shown in **Figure 4** is in the Czech Republic. After the parametric model was created, it was transformed into an analysis model in SCIA Engineer by a Grasshopper plugin – Koala. The FEA and design check of the steel members was then completed in SCIA Engineer.
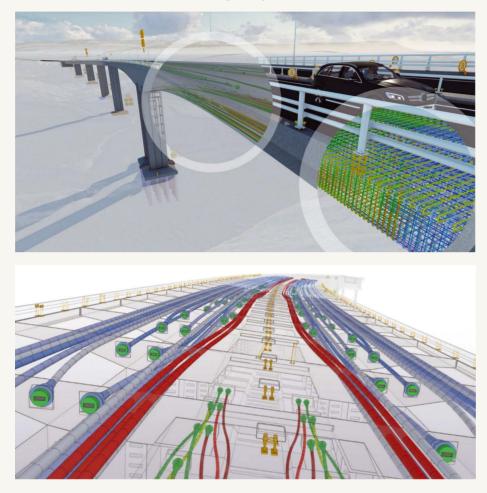
Various bridge types can be modelled and designed parametrically, but the way in which documentation is provided to authorities, stakeholders, and the construction team could be transformed by connecting BIM software tools to the parametric model. Combining these tools enables designers to produce models rich in data that can be used during the construction and maintenance phase of the bridge lifecycle.

The country that appears to have made the most progress in this direction is Norway. The Randselva Bridge **(Figure 5)** was designed in 2016 by the Norwegian road administration. The construction was based on an extensive BIM model. The model contained information including the reinforcement of every construction phase, railing and road surface finishes.

Having a central model helped resolve clashes between reinforcement bars, prestressing tendons and other service routes on the bridge. This process mitigated and minimised potential clashes on site that would otherwise have caused delays in the construction process.

The as-built BIM model was also archived by the Norwegian road administration as comprehensive information for maintenance and operational purposes. In fact, nowadays, most bridges in Norway are submitted to authorities and contractors in the form of a BIM model. Undoubtedly, other countries will follow suit.

◤**FIGURE 4:** Sázava footbridge was modelled by visual scripting and featured in SCIA user contest 2020[3]

↓FIGURE 5: Visualisation of BIM model of Randselva Bridge, Norway[4]

Conclusions

Parametric design will undoubtedly change how engineers approach and tackle complex structural projects. Currently, its power is utilised most often in the design of wild architectural structures. Yet, it offers a fast method for engineers to create analysis models for complicated structural geometries, with the added advantage of being able to keep up with project changes. For the majority of bridge engineers, it is also a viable solution to automate the design process while potentially saving even more time by better reusing previous work from completed projects.

REFERENCES

1) **SCIA (2020)** *Al Janoub Stadium* [Online] Available at: www.scia.net/en/company/references/projects/al-janoub-stadium (Accessed: February 2022)

2) **Building Designers Association of Australia (2022)** *Generative Design Generates Results* [Online] Available at: https://bdaa.com.au/generative-design-generates-results/ (Accessed: February 2022)

3) **SCIA (2020)** *SCIA user contest 2020* [Online] Available at: www.scia.net/en/company/references/uc-books (Accessed: February 2022)

4) **Ulvestad Ø. and Vieira T. (2021)** 'Randselva Bridge: Planning and Building a 634m Long Bridge Solely Based on BIM Models', *e-Mosty*, 3, pp. 7–18 [Online] Available at: https://e-mosty.cz/wp-content/uploads/e-mosty-Sept21.pdf (Accessed: February 2022)

Questions

To claim your CPD certificate, complete the module online by 30 April 2022 at: **www.istructe.org/industry-cpd**

1) Which of the following is one of the most used environments for graphical scripting?
☐ Kangaroo
☐ Rhinoceros
☐ Grasshopper
☐ Koala

2) Which of the following is the most important benefit of working parametrically over simply creating the analysis model in a traditional fashion?
☐ Better representation of the real-world structure
☐ Ease of incorporation of design changes
☐ More visually appealing structures
☐ Development of programming skills

3) Koala is a plugin for parametric interoperability linking parametric design to which software?
☐ Tekla Structures
☐ Dlubal RFEM 6
☐ Autodesk Revit
☐ SCIA Engineer

4) When a parametric model is updated (e.g. a variable is altered), the changes in the geometry model are reflected:
☐ once the engineer has commenced analysis and results are generated
☐ in real time
☐ after export to another software package
☐ once a new visual script has been created

5) Generative design is:
☐ a type of parametric design where the selection of the structural form may be partially determined by AI or a similar advanced algorithm
☐ a type of parametric design where engineers determine the flow of loads in the structure to determine the optimal form
☐ not used by architects because of the complexity of shapes
☐ a parametric design approach where machine learning has complete freedom to design a structurally efficient structure

Supplied and sponsored by

SCIA
A NEMETSCHEK COMPANY