BrIM FOR DESIGN

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BIOGRAPHY

Lana Potapova joined the New York Bridge Group of Arup after earning her Master of Engineering degree from Massachusetts Institute of Technology in 2009.

Her supplementary course work at the Harvard Graduate School of Design and MIT School of Architecture exposed her to innovative tools and tactics that facilitate the communication between engineers and architects and drastically expedite the design process of atypical structures.

Prior to graduate school, Lana worked for Alberta Ministry of Transportation as a Bridge Planning Standards Engineer. Her role included ensuring adherence of consultant reports and proposals to provincial and federal standards at the planning level as well as writing new guidelines.

Lana’s expertise in parametric modeling tools allow for highly efficient design of large infrastructure projects and drastically facilitate the delivery of bridges with complex geometries.

SUMMARY

Data collection, analysis, and assembly have been drastically facilitated by the rapidly evolving information technology field. Integration of this discipline into everyday engineering has given rise to powerful tools such as three-dimensional visualization and modeling of structures, bridge information models (BrIM), and digital fabrication.

This new capability to make smarter models and evaluate various solutions in an easy manner has essentially added a fourth dimension to the design.

The ability to control the definition of 3D visual geometry through code and link that code directly to a structural model has transcended current design and delivery methodologies of steel structures.

The paper will discuss how the aforementioned tools, particularly parametric modeling and optimization, helped improve the workflow and create a better product.

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1. Where We Are Today

The advent of the information technology age has drastically facilitated the way engineers visualize, model, and analyze their creations: three dimensional modeling and analysis are common tools used by various leading designers. The next big wave of change has been parametric definition of geometries and data. Whereas parametric definition of calculations has caught on through the use of software like Microsoft Excel and Mathcad, parametric definition of geometries has been much slower to develop. Nonetheless, the principles are the same: flexible approach to design. In basic application, this entails drawing the model through the use of coding language and a set of rules as opposed to drawing lines on a screen in a standard CAD package. The success stories below outline the main advantages of modern techniques embracing parametric technology.

1.1 8 Hour Bridge, Dumfries and Galloway, Scotland

The 8 Hour Bridge Initiative was established to develop a strategy for replacing railway underbridges using 8 hour possessions, as part of Networks Rail's vision of developing a modern seven day railway. The use of digital prototyping (Figure 1) allowed the development of a modular temporary bridge system in Solidworks (1) that could be assembled to address a range of bridge spans and track arrangements and which could be erected in less than 8 hours.

The first trial in the UK of a bridge replacement utilising 8 hour possessions was carried out at Holms Farm Bridge, Dumfries. Photo-realistic renders were used to demonstrate complex phased construction sequence.

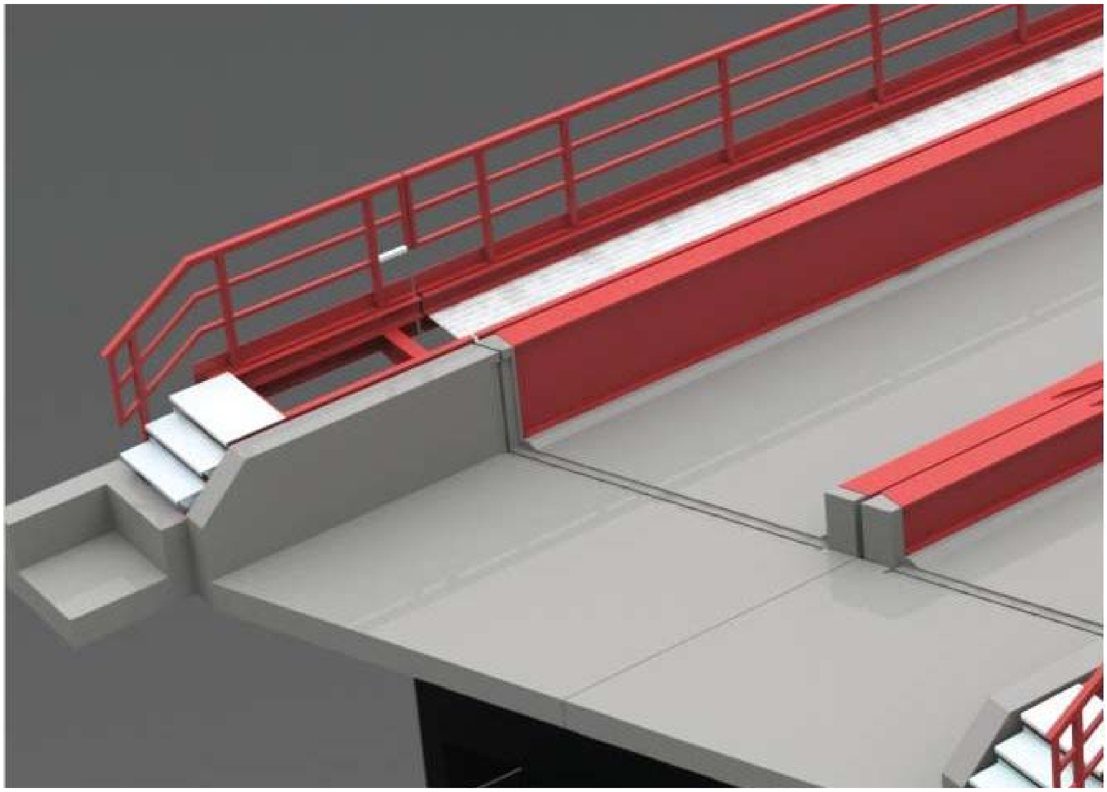

Figure 1. Parametric model allowed to swiftly demonstrate construction sequence of the 8 Hour Bridge with ease.

1.2 Ayer Road Underbridge, Ayrshire, Scotland

Ayr Road Bridge is a typical example of the substandard railway bridges that will need to be replaced in the coming years. Using Solidworks parametric modeling techniques, Arup has developed a digital underbridge prototype (Figure 2), based on Network Rail's standard bridge, to produce the construction, fabrication and pre-casting drawings to procure and execute this project. The prototype has been developed to allow adaption to a wide range of applications, thus ensuring that advantages of standardization of the design, manufacture and assembly of the constituent parts of such bridge replacement works can be delivered to further bridge replacement projects.

The adaptable digital prototype allowed for high quality engineering drawings to ensure the accurate fabrication/manufacture and assembly of the different bridge components for each design. Furthermore, the model allowed for automatic checking and verification the design to ensure correct clearances to the railway, interface with existing structures, road alignment, topography, construction tolerances and setting out was essential to collaboration between various disciplines.

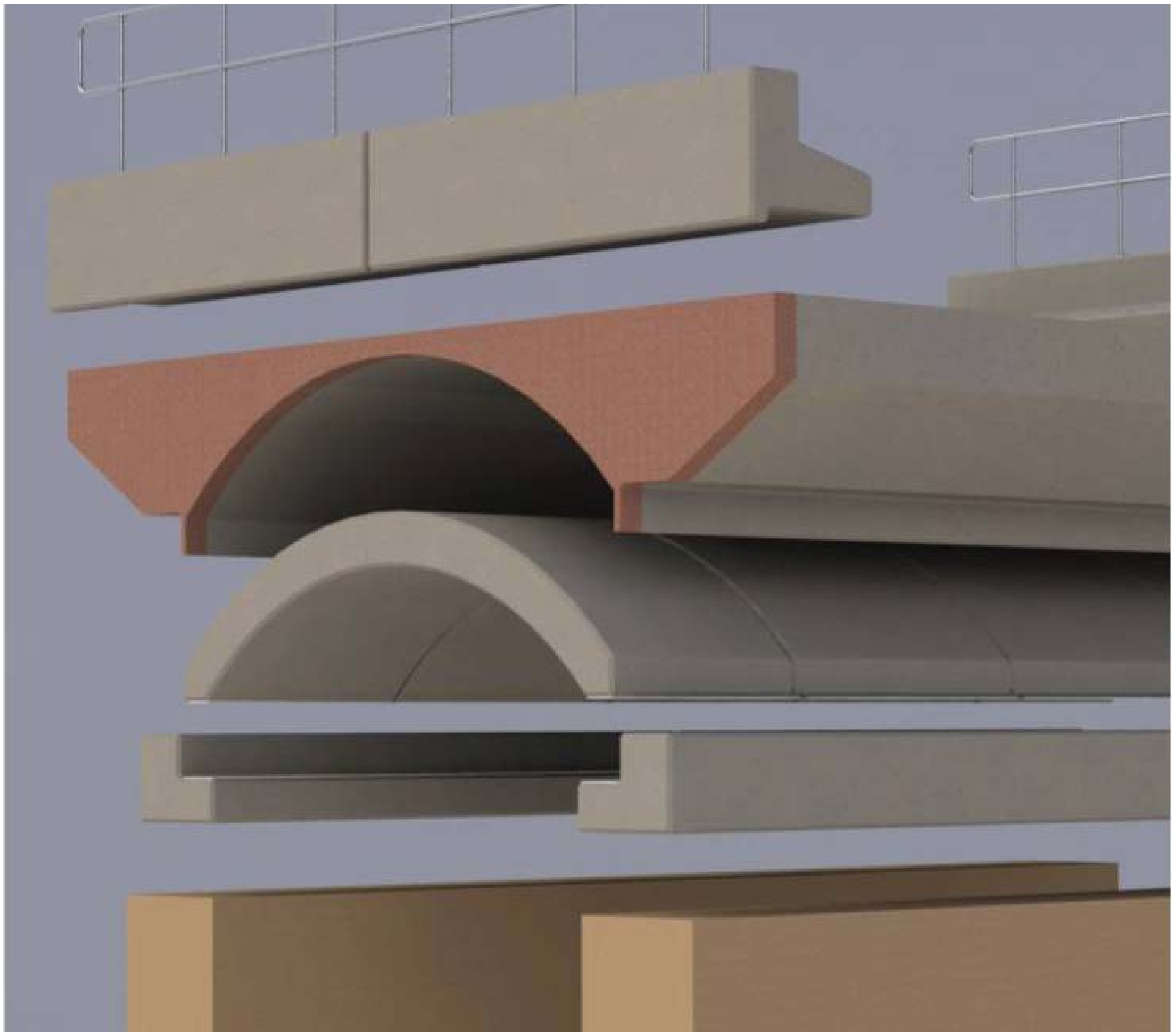

Figure 2. The modularity of the Ayer Road digital prototype allowed its use on various sites.

Figure 3. DNA Helix Bridge

1.3 DNA Helix Bridge, Marina Bay, Singapore

The DNA-inspired pedestrian footbridge in the Marina Bay Sands development of downtown Singapore (Figure 3) is the world's first double-helix bridge.

The ability to flexibly model a complex steel geometry without waiting on final alignment decisions gained valuable time during the project. The Generative Components (2) parametric model (Figure 4) defined the spine of the DNA helix bridge as a flexible parameter thus ensuring that the design could be started, but the complicated geometry did not have to be re-modeled. As the alignment changed, the structure was re-generated and thus automatically updated.

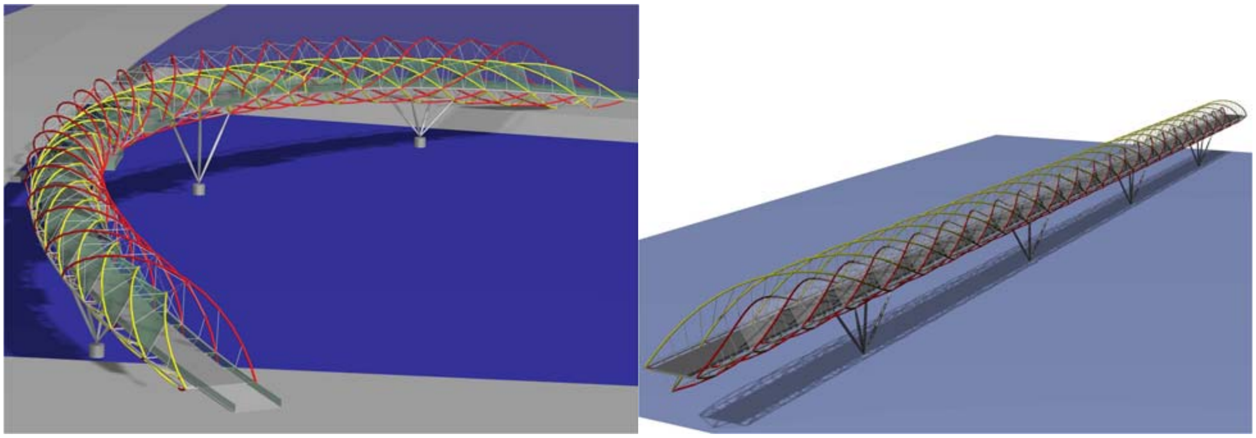

Figure 4. Defining spine of the bridge flexibly allowed the modeling to commence without a final decision on the alignment.

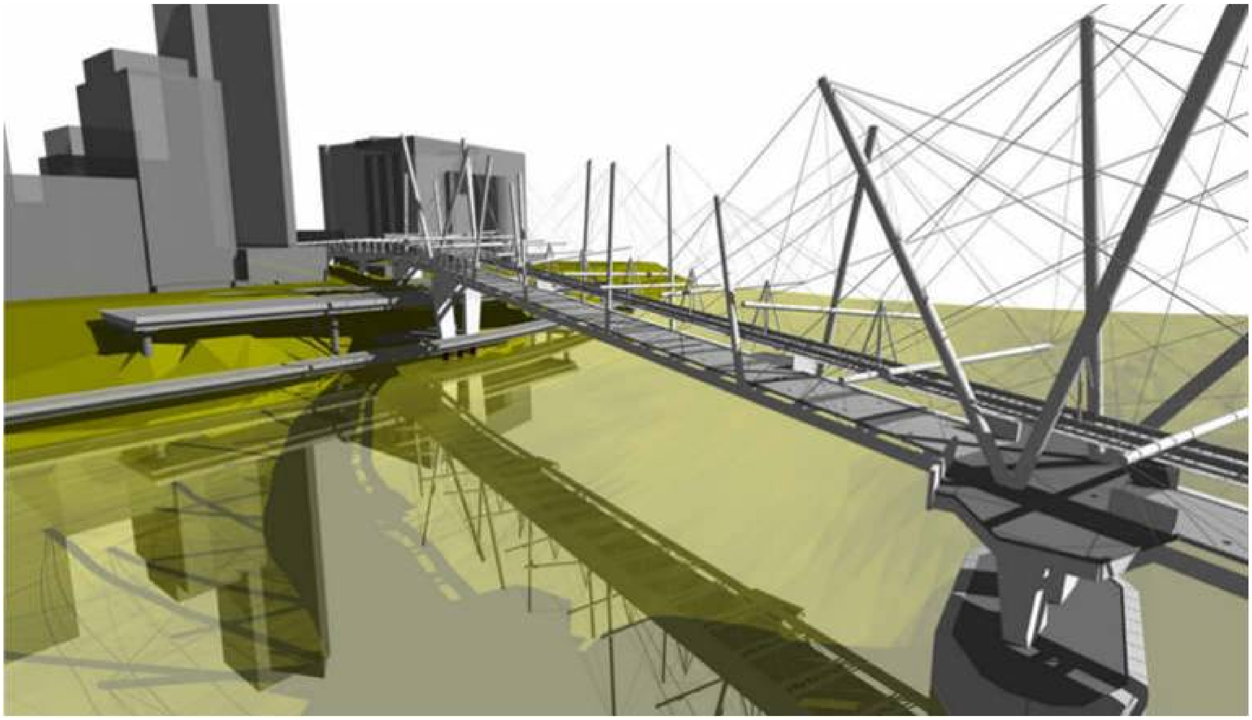

Figure 5. Kurilpa Bridge model optimizes itself for clashes with cables and clearances as new alternatives are explored.

1.4 Kurilpa Bridge, Brisbane, Australia

Kurilpa Bridge is a multi-mast steel cable stay pedestrian and cycle bridge that spans the Brisbane River and riverside expressway. The bridge deck is supported by a complex system of masts, cables and flying struts inspired by the concept of tensegrity.

The 3D definition of the individual bridge components (such as cables) in relationship to other geometric elements (for example mast) was instrumental in addressing changes and allowing continuous information transfer through all phases of design. This was achieved with a combination of Bentley's Generative Components, Structural(3), and MicroStation(4).

The model code included evaluating and mitigating clashes between cables and clearances on the bridge dynamically as various alternatives were examined. Figure 5 demonstrates the complicated mast arrangement.

Various arrangements of masts (Figure 6) were tested and clients were able to make decisions about the additional value of the aesthetic in the randomized pattern of masts versus the small increases in steel costs with minimal effort.

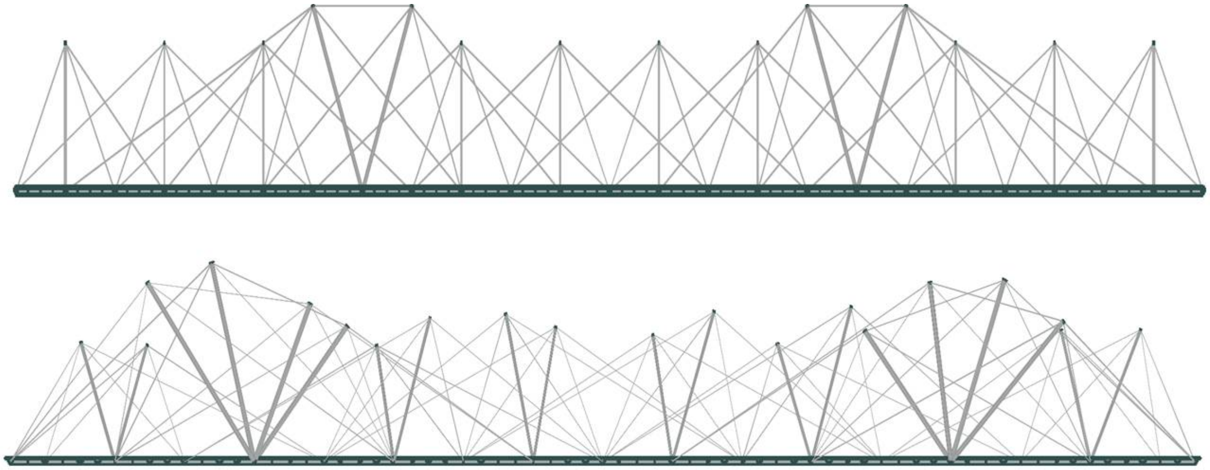

Figure 6. Modularity allowed for various mast arrangements to be tested with minimal effort.

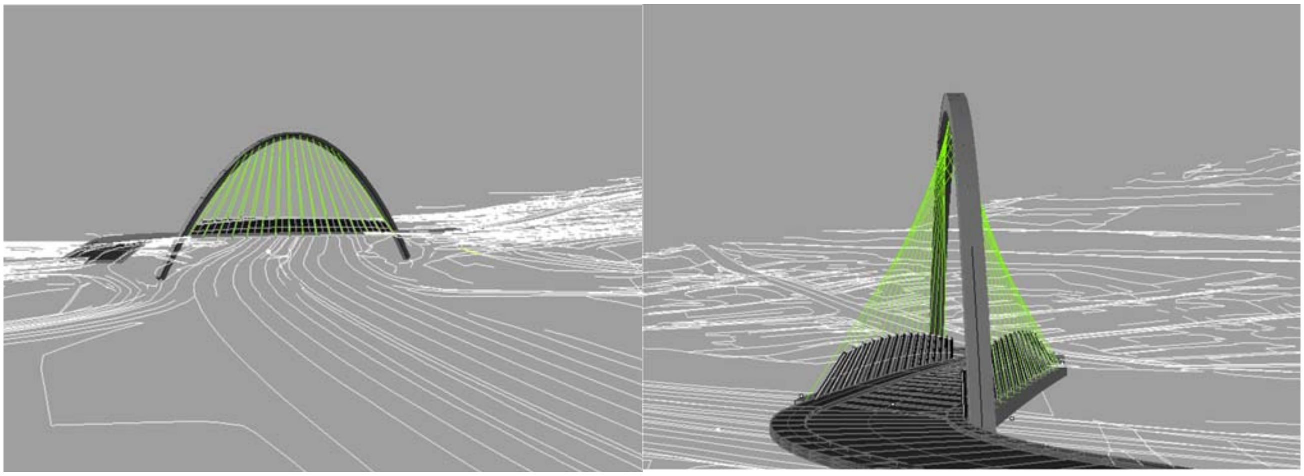

Figure 7. As various arch depths were explored, vertical and horizontal cables clearances were easily checked by adding a clearance box in the code that defined the geometry.

1.5 Gateway Arch, Undisclosed location, USA

The steel arch shown in Figure 7 was one of the alternatives considered for Gateway Arch Project. This single arch that hops over the deck resulted as means to mitigate views from the main highway to the bridge above with a severe skew. It provided an elegant solution; however, ensuring that it works with multiple constraints such as respecting clearances and staying with-in right-of-way (ROW) could not have been achieved fast without parametric definition of geometry.

The logic which drew the geometry of this roadway bridge associates the deck and cable elements with the roadway alignment (Figure 8) as well as locates the arch anchor points flexibly. Due to a clash at the abutment during construction staging with the existing road, the alignment of the new bridge was shifted. New alignment 3D string, generated by InRoads(5), was imported and the bride geometry re-generated within minutes.

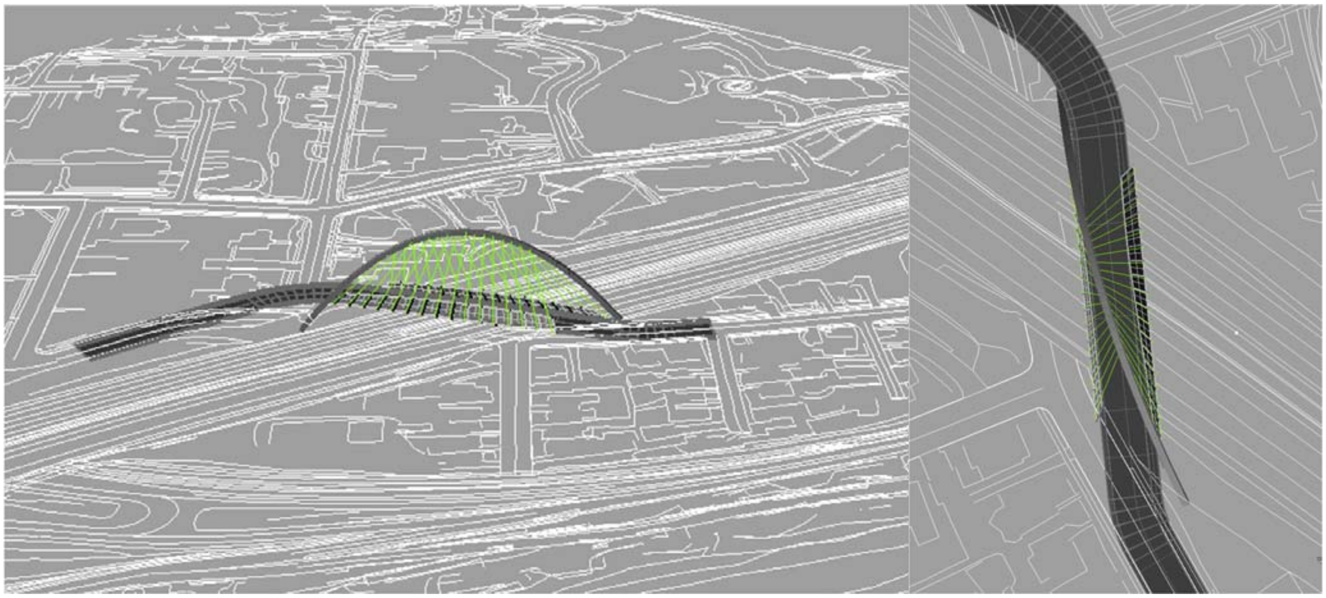

Figure 8. Defining the arch landing points flexibly allowed to 'fit' the arch to the existing ROW as complicated cable geometry updated automatically

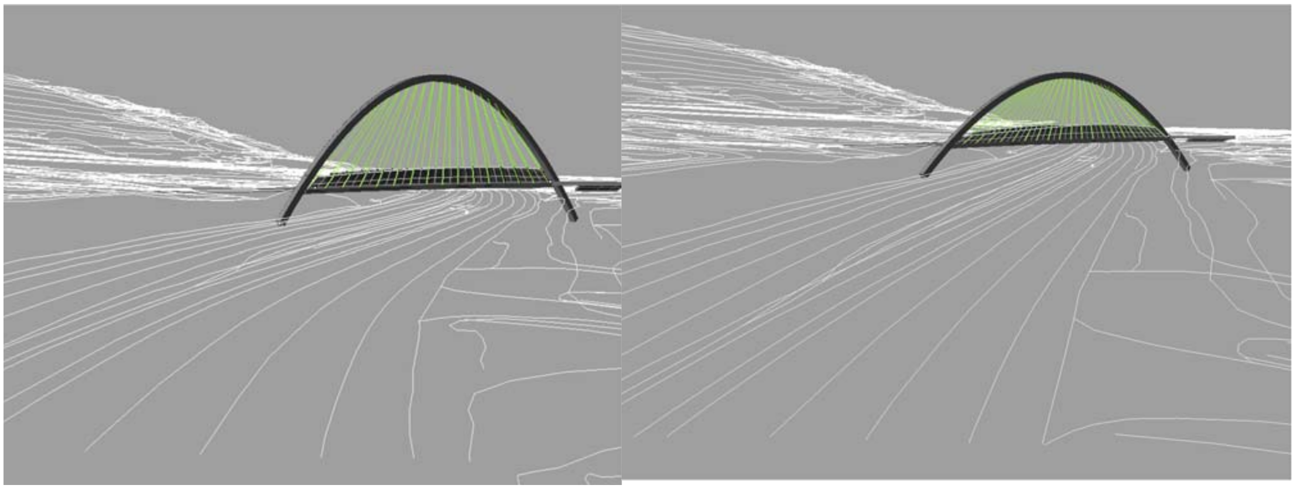

Figure 9. Various arch span-to-depth ratios are explored by regenerating the same model with different inputs

As various arch depths were considered (Figure 9), the cable geometry constantly changed to maintain vertical and horizontal clearances on the bridge. The code for geometry included a tool to define a clearance box and thus it was simple to identify clashes and change the cable positions to resolve them

In the same way that it was fast to generate two different 3D models of this bridge with a different arch span-to-depth ratio (and a different cable arrangement as discussed above), it was just as easy to produce 3D structural models of both (and more!) alternatives.

The geometry of this bridge was defined using a parametric plug-in Grasshopper(6) for Rhino(7). The visual 3D model was then converted to a GSA(8) structural model using Salamander(9). Salamander allows the designer to convert 3D curves and surfaces into structural members, geometric nodes into structural nodes, and assign restraints to those nodes. Furthermore, this tool allows to define loads parametrically. For instance, the weight of deck is defined as a pressure times a tributary area; as the cable spacing changes, the tributary area updates, and the load automatically updates with a simple re-save of the model.

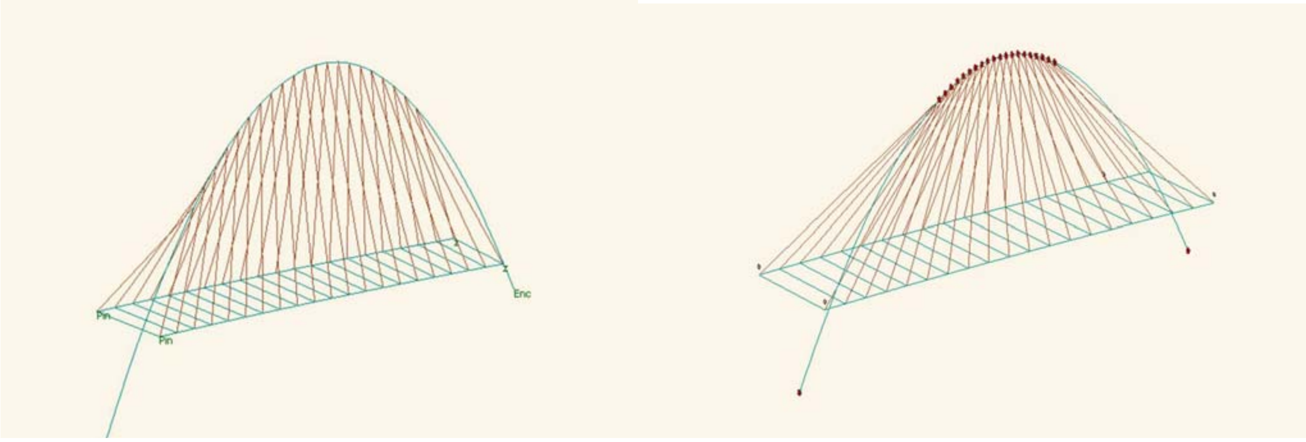

Figure10. Parametric definition extends beyond 3D visualization model; a flexible structural model is created through a plug-in linking analysis software to parametric code thus allowing and update in the structural model as various arch span-to-depth alternatives are explored.

2. Challenges

As with any emerging technology and procedure, using parametric systems is not always a seamless process. The never ending pursuit of faster processing speeds and a better graphics card define the pace of our progress in the field. Frozen computer screens and constantly crashing models can be the sole reason an engineer under a tight deadline will turn away from using parametric software. However, computer hardware components that can accommodate parametric models of even the largest bridges in the world are now fairly cheap and thus these issues are fairly easy to address.

The main challenge with using parametric technology lies in data transfer between various software packages. The overall intent of using parametric technology is that if a component of the structure is changed, then the structure can be swiftly re-analyzed, new drawings reproduced, and a maintenance plan updated; this list expands the further into the project the change is made. This would imply that the logic behind the software has to address all the phases of the project and communicate seamlessly between various tools we use to design and procure bridges. Conversely, a super software package can be created that can handle all the phases within one tool.

The state of current technology exists somewhere in-between the two proposed extremes. Large software developing companies such as Bentley, which already have various tools (MicroStation and RAM Structural System) also have a parametric component (Generative Components) which aims to interact fluidly with their other tools. When a structural engineer requires modeling software such as LS-DYNA(10) whose developers do not produce CAD software the benefit is quickly lost. Plug-ins can be written to facilitate data transfer in a coding language such as Visual Basic – a typical approach at Arup to transfer data between different parametric packages and their own analysis software GSA.

Various other approaches can be taken and the industry is starting to understand the needs and thus is responding as well. What would help it respond faster is if the number of users increases, thus more feedback is provided to the companies. By showing that the software is useful you will incentivize companies to put more effort into development and improvement.

3. Where We Are Heading In The Future

We have now the ability to create a complicated model of a bridge and make it flexible. What next? Optimization of various parameters is now at our fingertips with minimal effort. Some optimization is already being done by the designer, as in Kurilpa Bridge where bridge cables get checked by the model for clashing with pedestrians, thus optimizing clearances on the bridge. Therefore the role of the designer shifted from checking the geometry, to creating a model framework (in rudimentary terms: a computer script) that allows it to maximize a certain parameter itself.

Another field of study involves how we use the models which we created in design for future asset management. A wealth of data is communicated during project planning, design, and construction with digital models; it is natural that the owner inherits these models to facilitate the management of the structure throughout its lifecycle in the same way that the model was used to help the consultants deliver the structure.

Below is a brief description of some of the research being done at Arup promoting this school of thought.

3.1 Structural Components 3.0

The Structural Components research is focused on the development of early-stage structural design tools. The central theme is the quick composition of a schematic structural concept coupled with simultaneous feedback on its performance. This logic is illustrated pictorially in Figure 11.

A very simple example would entail a user that defines parameters which he wants to optimize such as volume of concrete. As the user is changing the geometry in the parametric model, the model shows new geometry and simultaneously evaluates the volume of concrete of each new alternative, stores the data on each alternative, and allows the designer to see most optimal configuration for minimum volume of concrete.

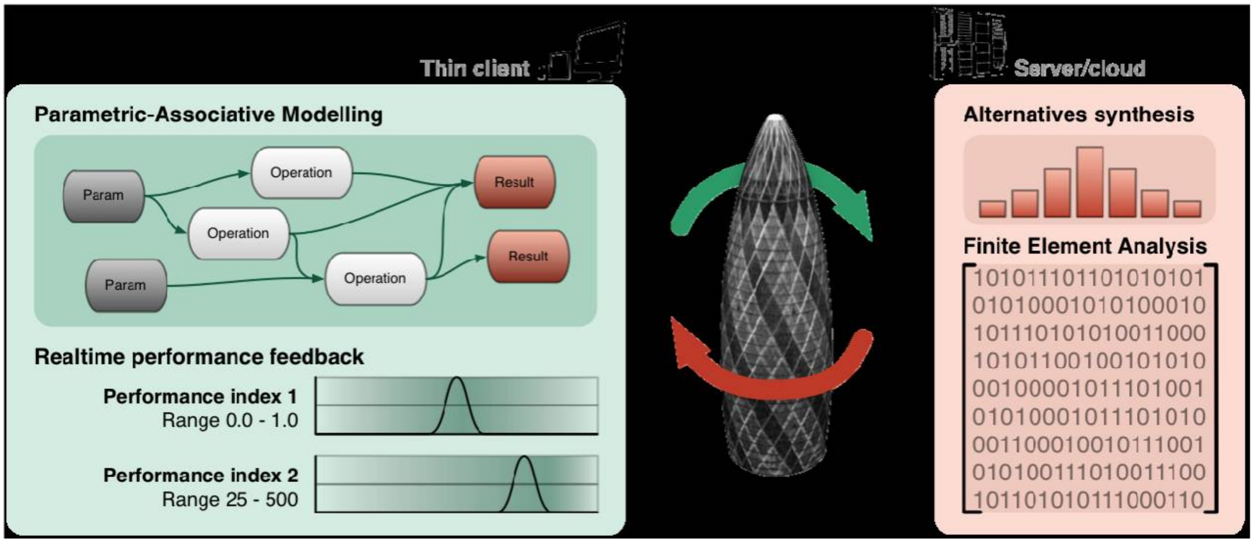

Figure 11. Logic of Structural Components 3.0.

3.2 Smart Asset Management

Linking data about structure to the structure's 3D model and locating these entities in global coordinates can drastically facilitate workflow during project delivery and aid the client to manage the asset throughout its lifecycle.

Imagine a digital terrain model with the bridge abutments and truss members located in proper position with respect to surrounding existing buildings. One click on a truss member would link you to construction shop drawings, inspection photos, etc. The database working behind would have the ability to generate reports and visually display evaluation on the 3D model. An inspector on site takes a picture, and instantaneously tags the photo to the 3D model, along with updating the report through an iPad app.

As the projects get more and more complex, this is the only way to deliver and maintain them efficiently.

4. Conclusion

The information technology revolution is allowing us to visualize, optimize, analyze, and build structures with more speed, efficiency, and accuracy. It allows us the ability to get creative with geometries and provide solutions which were unrealistic with our old approaches. Bridges make a significant impact on the lives of large masses. Embracing this change in our industry is vital in ameliorating the lives of many.

5. REFERENCES

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