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Features of Visual Programming for Designing Bridge Structures Based on Information and Parametric Modelling

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ABSTRACT

The widespread adoption of Building Information Modelling (BIM) in construction project management has been greatly facilitated by technological advances. Despite this, the BIM approach has been mainly applied to building construction projects, with limited attention paid to infrastructure projects such as bridges.

The projects of this kind often present significant geometric and semantic differences between structures, making it difficult to leverage existing BIM data schemas. Recent research suggests that parametric modelling can provide a viable solution to improve design efficiency and interoperability. However, the number of existing scientific sources on the topic remain extremely scarce. The objective of the study presented in the paper is to address this knowledge gap by developing parametric bridge elements capable of generating all types of bridge structures from a single parametric file.

The parametric scripts used in this study were developed using Grasshopper, a visual programming language, and subsequently integrated into Tekla Structures, a popular Building Information Modelling (BIM) software, for modelling purposes. The resulting BIM integration enables exploration and creation of advanced designs with complex geometries, ultimately leading to cost-effective solutions. Compared to traditional design methodologies, the results obtained demonstrate significant improvements in terms of time savings, increased design flexibility, and optimised structural performance.

Keywords: transport infrastructure, BIM, bridge, parametric modelling, bridge element, programming, Tekla Structures, Grasshopper.

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INTRODUCTION

The technologies used in the architecture, engineering, construction and operations (AECO) industry are constantly improving, but development of new requirements for them is also accelerating. Large infrastructure projects such as bridges are becoming more common, requiring development of new technologies for creating plans and documents, as well as handling changes and incoming information during the design process.

Previous drawing software (e.g., AutoCAD) made it possible to create design documents, store them electronically and make the necessary changes. However, this approach is being replaced by information modelling, which offers significant advantages in terms of data integration. As a result, BIM systems generate an object-oriented 3D model linked to a database of all elements and materials. Architectural design (geometry of building elements, spatial relationships, connectivity), structural design (design documents, structural diagram) and information about construction and maintenance processes of the building are all included in the information modelling system [1].

The design of bridge elements is a critical aspect of infrastructure development, requiring careful consideration of various factors such as structural integrity, durability, aesthetics and environmental impact. The traditional manual design process can be labour-intensive, error-prone and result in long design cycles. A review of several publications (e.g., [2]) has shown that a parametric design approach is one that improves the efficiency of this process and interoperability.

Building information and parametric modelling technologies are increasingly used in infrastructure design thanks to BIM design tools [3]. The use of building information and parametric modelling improves the design process by reducing time and effort [4; 5]. The method is based on the introduction of parameters and numerical dependencies between elements to create flexible models. The geometry is implemented in parametric modelling using a programming language, and most parametric modelling situations are centred around visual scenarios [6].

The *objective* of the study is to develop parametric bridge elements capable to generate all types of bridge structures out of a single parametric file.

RESULTS

Methodology. Advantages of parametric modelling

In parametric modelling, the script developer enters parameters that serve as the basis for creating geometry and then performing all the necessary analyses and calculations. To simplify the process, complex structures can be divided into manageable components, such as the main bridge, approach bridges and auxiliary structures. Then, by combining these individual sections, a single visual model can be created that provides a comprehensive view of the overall structure.

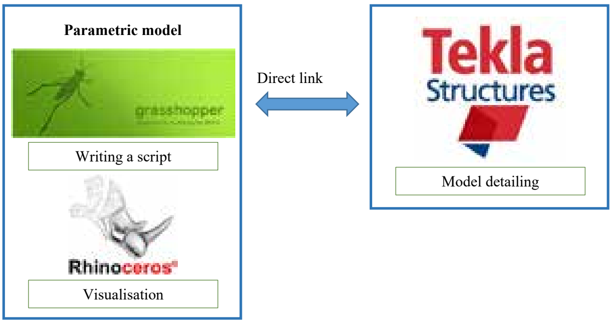
The methodology described in this article aims to overcome the limitations that arise in the design process by using the tools available in the Grasshopper environment, which uses visual scripts and does not require the designer to have programming skills.

The article also discusses examples of developed parametric bridge elements, using which it is possible to speed up the process of creating and modifying parametric models of a structure without the need for manual adjustment of individual components. This innovation is aimed at optimising the design process, increasing work productivity and reducing the likelihood of errors. The parametric elements required in the project are developed in the BIM environment and then connected to form a single structural organism. The direct link between Grasshopper and Tekla Structures enables the entire process to be completed. With direct links between software such as Tekla Structures and visual programming tools such as Grasshopper, designers can implement the workflow without programming experience. The process of interaction between information modelling and visual programming software is briefly presented in Pic. 1.

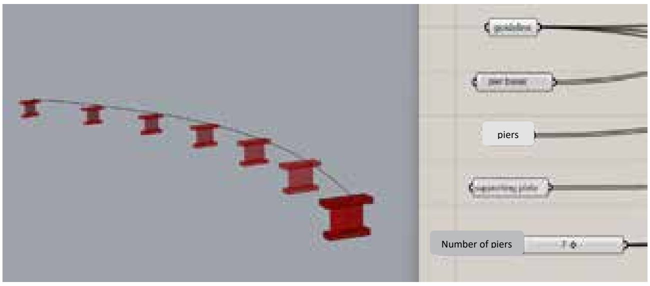
Stages of creating parametric elements

The application of algorithmic design in bridge construction offers promising opportunities for innovation. To illustrate this potential, let's consider the example of creating parametric elements for a bridge in the Republic of Myanmar.

A bridge is always built from scratch, from the piers to the deck [7]. This is well suited for modelling. In the Grasshopper environment, the user can define the bridge axis by specifying three points (coordinates of the start, middle and end



Pic. 1. Workflow between Grasshopper and Tekla Structures [performed by the author].



Pic. 2. A simple Grasshopper script for concrete bridge piers [performed by the author].

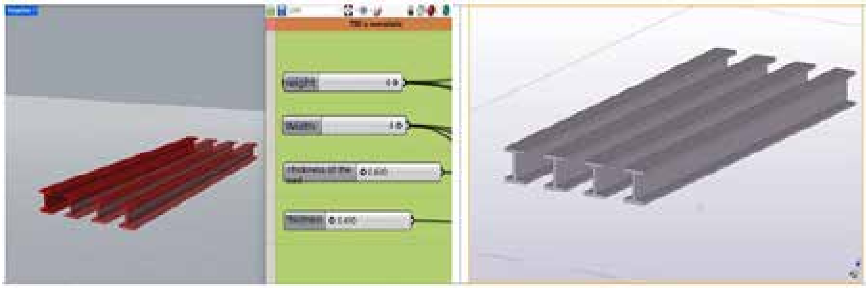
points) or directly extract a curve from the bridge axis by re-parameterising the geometry obtained from direct modelling using the «curve» element. The user can then simply create a script to build the piers according to the bridge axis. To obtain a stable and convenient model for the designer, users can split the model into several sub-models associated with each bridge element (deck, piers, guardrails, etc.). Pic. 2 shows a script developed for bridge piers.

The next step is to design the bridge beam elements. The beams provide the primary support for the bridge deck and transfer the weight to the piers. Since the «I» shape is structurally efficient, the beams are often shaped like this. The top and bottom flanges of the «I» shape provide horizontal support and resistance to bending, while a vertical web connects two flanges and provides resistance to shear pressure. In Grasshopper, I-beams are created by first defining a profile and then using various elements to build the geometry. The beams are designed in such a way that the user can modify the section specifications as desired.

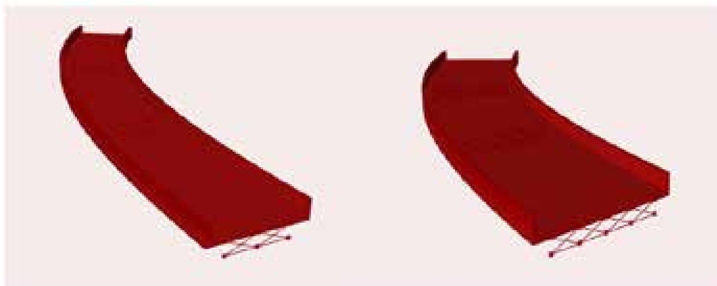
The beam is created using polylines, which are then segmented based on connection points or length specifications. Regions can be defined in the structural model where the beam properties change, such as the effective width of concrete elements or the cross-sectional properties of a solid beam. These parameters can be modified using a parametric approach. For example, a parametric I-beam was created using a BIM-based algorithm (Pic. 3), demonstrating the potential of this approach.

The creation of a bridge span is usually one of the challenging aspects for designers due to the uniqueness of the input data, which is the guide curve for the bridge [8]. The length of the bridge and other characteristics are considered when arranging the piers. The script allows creating piers of different lengths and connecting them to the main beams or cross beams [9]. During the modelling process, it is possible to select different types of cross beam profiles and their number depending on the features. To prove the adaptability to changes in parameter values and conditions, the geometry generation process goes through several stages. Once the Grasshopper bridge model is completed, it can be used as a template for other projects by connecting it to the database [10; 11]. The result of using the bridge deck width parameterisation and how it changes when the parameter related to the number of beams changes is shown in Pic. 4.

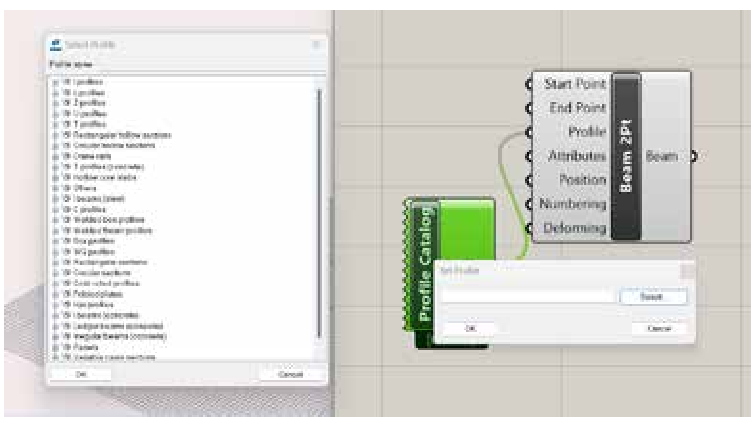
With direct connections between BIM software such as Tekla Structures and visual programming tools such as Grasshopper, designers can implement a parametric workflow without prior programming experience [12].



Pic. 3. Parametric I-beams in Grasshopper and Tekla Structures [performed by the author].



Pic. 4. The number of beams determines the change in the deck of the bridge [performed by the author].



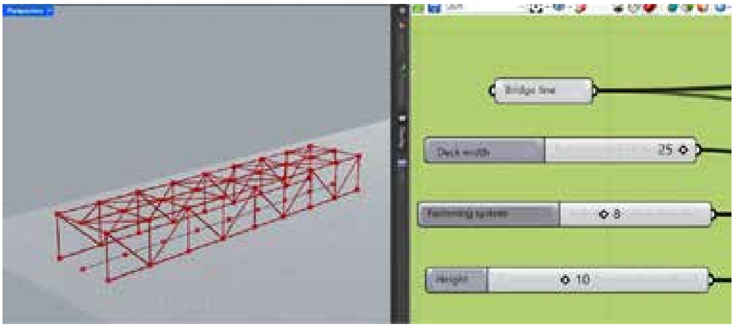
Pic. 5. Large number of profiles in Tekla plugin in Grasshopper [performed by the author].

If desired, the user only needs to generate a Grasshopper-based element, add it to the Tekla component catalogue, and use it with ease. Since Tekla offers an extensive library of profiles for different sections (Pic. 5), the software is particularly effective in developing parametric parts for bridges [13].

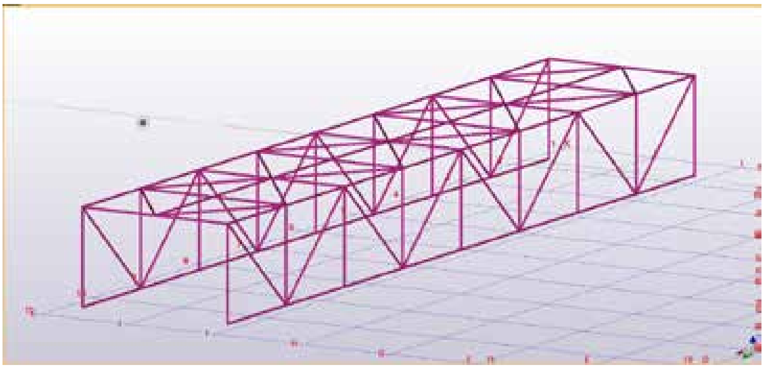
By working on computer-aided design using algorithms, designers can overcome the limitations of standard CAD software and 3D computer graphics tools, achieving a degree of complexity beyond the ability of humans to interact with digital objects [14]. To take advantage of these capabilities, the operator must be familiar with the basics of programming languages such as C# or Python.

A simplified parametric design of a steel truss for a bridge is shown in the final section of this study. Developing a simple and efficient process that is useful during conceptual design, early reviews and decision making is the goal while we continue to work on parametric elements for all the many bridge types that Grasshopper offers.

Creating a parametric frame in Grasshopper involves using a variety of elements and tools to define parameters, relationships and geometry. To create such a design, it is necessary to define key parameters, establish algorithms or mathematical relationships that govern the frame geometry and structural elements, and use Grasshopper elements



Pic. 6. Parametric truss section in Grasshopper [performed by the author].



Pic. 7. Parametric truss section in Tekla Structures [performed by the author].

to transfer these rules into a parametric 3D model. Through this iterative process, designers can refine and optimise the design according to the stated goals and constraints. The final result is a parametric truss that is easily adaptable to changing design requirements and is automatically updated in Tekla Structures (Pic. 6; 7).

CONCLUSIONS

The integration of modern technologies into design, construction and operation of transport infrastructure allows finding effective and optimal solutions at any stage of the life cycle of the structure [15; 16]. Using plug-ins to combine specialised software with information modelling, operators and designers can minimise the likelihood of errors and optimise the design process. The implementation of additional programs and plug-ins facilitates creation of an information model of the bridge, as well as execution of necessary calculations at any stage of the facility's operation, considering the results of monitoring. In addition, parametric modelling allows engineers to work with complex geometry, automate repetitive design tasks and create customised workflows, thereby optimising the design process and increasing overall efficiency.

In the presented work, parametric elements for bridges are created using Grasshopper add-in, a visual programming language and environment that enables creation of a flexible generative model ready for testing in Tekla Structures. The algorithm generates the geometry of bridge elements based on parametric input parameters, where each structural element has its own set of input values that define the dimensions of the geometry. By changing these input values, the width, height, length, and inclination of individual structural elements can be changed. An operator query determines which values need to be parameterised, allowing for efficient and targeted design changes. The proposed visual scenarios demonstrate improved performance in terms of computational costs and resource-efficient design and analysis, outperforming traditional incompatible processes. This approach enables the efficient creation of bridges with complex geometries and facilitates the optimisation of design parameters, ultimately reducing the time and resources required for design and analysis.

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