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Novel Parametric Knowledge Modelling approach applied to Viaducts

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Abstract

This paper presents a novel approach to modelling and documenting design knowledge: to use parametric technology to explicitly store knowledge which exists in a group of people (such as a company), so that it can be reused over many projects and grow over time when more projects are designed. This approach has been applied and tested on a test case of common concrete viaducts. The outcome constitutes the first iteration of the development of a parametric viaduct design platform, aimed for architects and structural engineers. The motivation was to counter the fragmentation of the Architecture, Engineering & Construction (AEC) industry, where each discipline encapsulates different knowledge areas, which results in miscommunication and the loss of valuable information and time. The suggested methodology aims at combining the BIM principles [1] with the concepts of parametric and associative design, as well as visual programming [2] to develop a common design platform for the architect and the structural engineer. Such a platform ensures that both disciplines are working on the same design and merges their different knowledge areas into one model. The knowledge model evolves from a top-down UML diagram into a user-friendly, parametric platform for viaduct design implemented in Dynamo [3].

Keywords: concrete viaducts, conceptual design, parametric design, associative design, knowledge model, BIM

1. Introduction

This research project investigates the development of a knowledge-based, parametric platform and the extent to which the knowledge around an infrastructure project can be integrated and stored on such a platform. While Building Information Modelling (BIM) aims at resolving the miscommunication within the project design team, BIM technologies are often characterised by a limited design flexibility, which discourages the practitioners from adopting an integrated design approach from the early design stages. To tackle this, the knowledge model of this research project is based on BIM principles, considering associative modelling with local and global design parameters, in an attempt to identify patterns, create links and produce an efficient, computational design approach and a final 3D visualisation of the viaduct.

This research project focuses on defining the recurrent steps of the design and tracking the implicit information, which is usually hidden behind the project's requirements and the designer's intuition [4].

The resulting platform enables the engineer/architect to access, interpret and act on the available information. The infrastructure project under investigation is a common concrete road viaduct over traffic. This project type is chosen for its repetitive design process, which restrains the architectural freedom and the available functional choices.

2. Methodology

The methodology for this research project is based on an ontology, composed of various systems and subsystems (components) which have their own requirements and goals in a local level, but are also connected to each other, so as to meet global requirements. As an ontology, the viaduct includes a set of concepts, entities, properties and functions, as well as relationships and semantics [5]. The output of this approach is a generic viaduct design template which can serve as a starting point for similar projects. In the aforementioned template, the abstract needs and requirements of a project can be converted into functional and technical input, processed on the platform and the final output can be visualised.

The first step of the research project is to define how the viaduct components are related and the requirements which steer the design. As a second step the translation of the aforementioned knowledge into an associative, parametric model is attempted. The structural analysis of the bridge is also integrated into the platform, so that the communication between the architect and the structural engineer can be facilitated. An outline of the process can be seen in Figure 1.

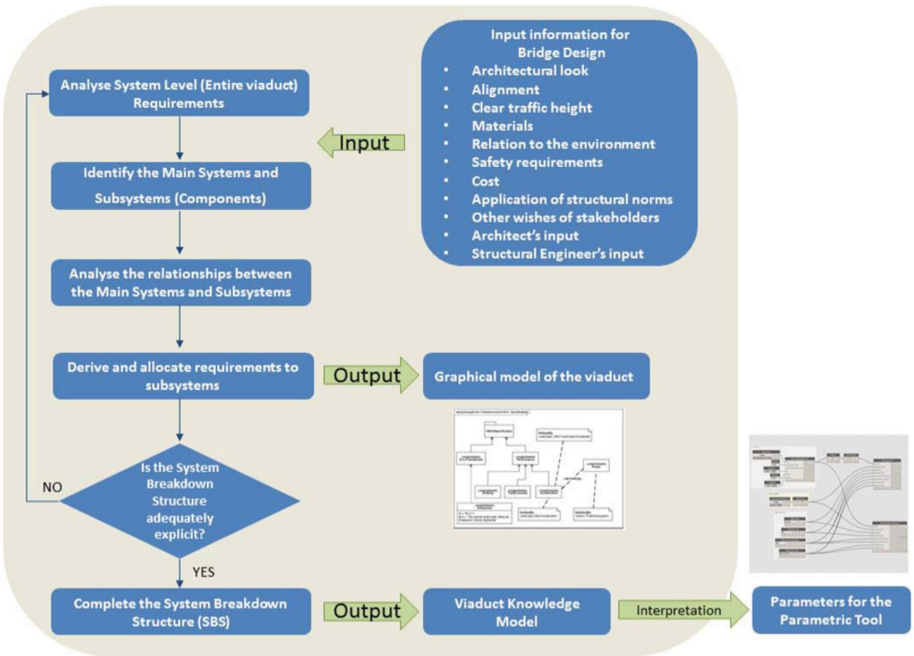

Figure 1: Development of the knowledge model and its relation to the Parametric Model

2.1. Development of the Knowledge Model

The aim of a knowledge model is to capture, formalise and implement the knowledge of the AEC practitioners into a digital design tool, incorporating automated, as well as semi-automated tasks [6]. One of the most important, yet elusive elements, associated with a knowledge model is the experience of the design team. In order to capture the latter, the parameters defined in the model are specified after discussion with practitioners at BAM A&E, the architectural and engineering department of a major Dutch contractor.

One of the objectives of the knowledge model is to define which information is relevant during each design phase and therefore request the right level of input from the designer. For instance, in preliminary design the choice of the deck prefab beams type is not required, since it can be decided at a later stage.

The knowledge model of this research project focuses on three main components: the deck, the abutments and the pier. Those components function as a system, since the design needs of one influence the design needs of the others. The knowledge model documents the interaction between those components by introducing a generic viaduct design, which includes all possible designs within the set design space.

2.2. UML diagram

Initially, the viaduct is seen as a system with a top-down structure and a UML [7] model is developed to outline the relationships between the components on a higher level. The UML model contains the main components of the viaduct, as well as their main design parameters. Through this model the propagation of the design changes and the influence of each design choice on the rest of the model can be monitored. An important step in establishing a connection between the UML model and the parametric/associative model is to clarify the semantics of the relationship between them.

2.3. Parametric Model

The strict top down structure of the UML model facilitates the definition of the system components and the interaction among them. The findings of this step, along with a further investigation of the topological interdependencies of the components, are used to develop a parametric model, based on a bottom up approach. Parametric design is by essence non-destructive, meaning that one model contains all the previously explored solutions, as well as the ones yet to evaluate [8], which can highly benefit the design process, by enabling an interactive feedback loop. This parametric model is developed in Dynamo [9].

The development process requires a constant re-evaluation of the defined parameters, namely specifying the shape and qualities of each component, so as to address the design needs of the viaduct. The Dynamo model constitutes a fully parametric design algorithm, where the user is able to create numerous designs, within an expandable design space. The whole viaduct model is built around two alignments, the 3D alignment of the viaduct and the 2D alignment of the road underneath, which are part of the initial input. A user interface is added to the model in order to guide the user through the parameters that need to be defined. The visualisation of the final design can be seen in Figure 2.

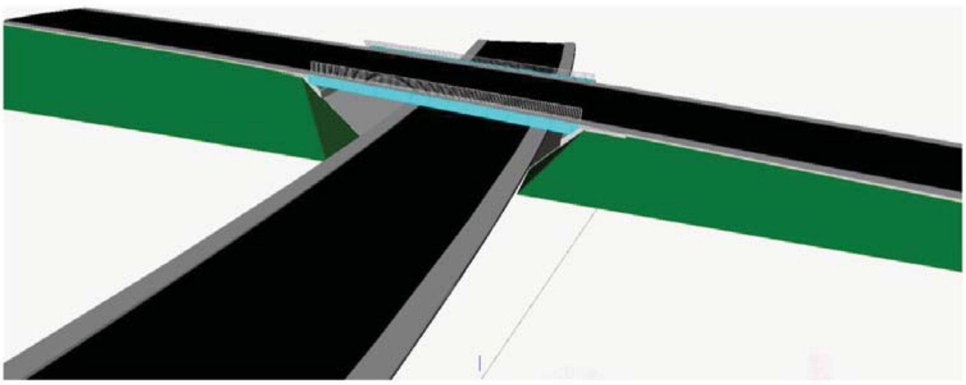

Figure 2: Visualisation of viaduct in Dynamo

The development of the script is incremental, in order to ensure that the complexity is gradually introduced to the model and ensure the credibility of the final parametric model. Two main tools are employed: Visual Programming (Dynamo) and Python. The connection between the applications is illustrated in Figure 3.

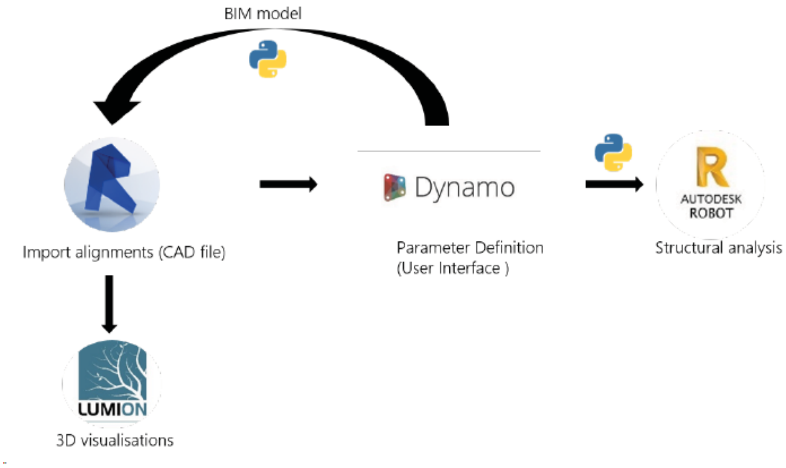

Figure 3: Overview of linked applications

2.4. Design Parameters

The design parameters of this research project have been derived from the study of the requirements and the input of the AEC practitioners. The total number of parameters is 82 and a list of them is presented in Table 1.These parameters are divided in three categories, according to the level to which the designer can influence them. Those categories are the following:

User-Defined parameters: User-defined parameters reflect the level of design freedom in the model. This parameter type can be seen in Table 1 (no colour). A number of user-defined parameters can be symmetrical, which means that the same design choice can be applied for both (or more) instances of one object, which reduces the overall design complexity. E.g the cornices on both sides of a viaduct are usually the same, so the designer needs to define the object only once.

Default parameters: The default parameters do not have an impact on the design. The values of those parameters can be predefined, as they refer to standardised components or standardised dimensions of components. This parameter type is denoted with light grey in Table 1.

Immutable parameters: This category is closely related to the scope limitations of the platform. The user cannot influence these parameters, as they define the scope of the research. For instance, the abutments of the viaduct can only be of type bankseat, therefore the abutment type is an immutable parameter. This parameter type is denoted with dark grey in Table 1.

Table 1: Parameter list

Element Name	Number of Instances	Parameters
Viaduct	1	Alignment
		Slope (side 1)
		Slope (side 2)
		Road width underneath the viaduct
		Pier
Deck	1	Width
		Slab Thickness
		Crossfall
		Tolerances
		Asphalt Layer
		Clearance Height
		Curved/Straight Edges
Railings	2	Position on Curb
		Inclination
		Shape of Vertical and Horizontal Bars
		Distance between Vertical Bars
		Number of Horizontal Bars
Edge Elements	2	Shape
		Size
		Length of each element
		Tolerance
		Position
		Cutting at Wing Walls
Abutments	2	Type
		Shape (6 parameters)
		Vertical Translation
		Location
		Angle of Skewness
		Cut for Approach Slabs
Bearings	n	Dimensions (3 parameters)
		Position
		Number
Approach Slabs	2 arrays	Dimensions (3 parameters)
		Position
Wing Wall	4	Shape
		Dimensions (3 parameters)
		Position
Pier	0 or 1	Position
		Number of Columns
		Diameter of Columns
		Dimensions of Pier Beam (2 parameters)
		Pier Beam Cut to Skewed Angle
Surroundings	-	Embankment angle

The percentage of each parameter type in relation to the whole parameter set can be seen in Table 2.

Table 2: Design parameters

Parameter Category	Number	Percentage of Total Parameters
User-Defined (non-symmetrical)	42	51.2%
User-Defined (symmetrical)	30	36.6%
Default	30	36.6%
Immutable	10	12.2%

3. Structural Analysis

The structural analysis of the viaduct is also considered at a conceptual level, by linking the parametric model directly to the structural analysis application. This eliminates the need for each practitioner to develop individual models on multiple applications. To achieve this, Robot [10] is linked to the

Dynamo model via Python. All structural analysis parameters, the generation of the FE model and the linear analysis execution are defined and controlled in Dynamo and the structural engineer uses the Robot environment simply to assess the analysis results.

The scope of the structural analysis is limited to the deck of the viaduct, considering prefabricated beams. The output of the structural analysis provides an overview of the resulting forces and the behaviour of the slab. The Robot model can be seen in Figure 4.

From this model the following can be derived:

1. Effect of prestressing on the slab.
2. Behaviour of the viaduct under the applied loads
3. Reactions at the supports and shear reinforcement in the beams.

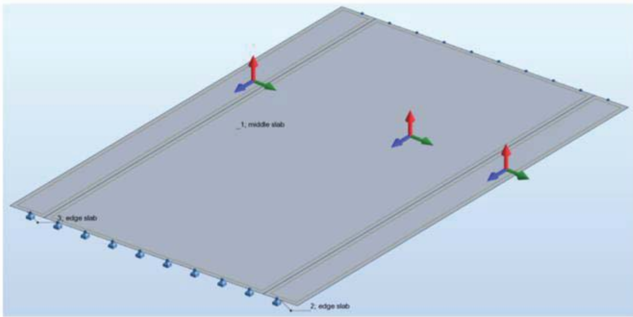

Figure 4: FE deck model in Robot

3.1 Structural analysis assumptions

The following assumptions have been made for the structural analysis.

3.1.1. General assumptions

The structural analysis is conducted at the full service stage of the viaduct ($t = \infty$). The prefab beams and the in situ concrete layer are assumed to work together as one composite section. The deck of the bridge is modelled as orthotropic plate elements.

3.1.2 Supports

Point supports which restrict the vertical movement are employed, in order to simulate the effect of the bearings. The location of the supports is defined automatically in Dynamo, based on the dimensions of the abutments.

3.1.2. Loads and load combinations

The loads are automatically placed on the deck, according to its geometry and distribution of notional lanes. The following loadcases are considered:

Dead Load: The dead load is considered for the whole model.

Asphalt Load: The asphalt load is applied on the carriageway as a uniformly distributed load.

Edge Load: A line load is applied at the edges of the viaduct to include the loads of the curb, the edge elements, the parapet and the railings.

Traffic Loads: Uniformly distributed loads and a tandem system are considered according to EC2 [11]. The location and magnitude of the loads are automatically generated in Dynamo.

3.2. Structural result validation

The result validation of this conceptual study by the researcher is limited to the following three verification methods, since the goal of the research project is to conduct a first iteration towards the development of a knowledge model for parametric viaduct design. Those methods are:

1. Visual Verification: Check whether the viaduct has the expected behaviour under the applied loads.

2. Sum of reactions: Check whether the sum of the reactions equals the sum of the applied loads.

3. Comparison with analytical solutions: The Guyon-Massonnet method [12] was employed to define the load distribution on the beams and verify the results of the structural analysis in Robot.

4. Test Case

The platform is tested on an actual project to assess its efficacy and the value it can bring to its execution. The Hoevelaken project (designed by BAM A&E) includes the construction of new common concrete viaducts in the area of Hoevelaken (the Netherlands), as well as the expansion of existing ones. The outcome of this research has been assessed, using the Hoevelaken Quality Team requirements for the new viaducts, which provide guidelines about the conceptual design. These guidelines focus on the function of the viaducts, the visual impact of the design, the relation to the surroundings and the user experience, as well as ensure that the design is cohesive.

The total number of requirements in this category is 56, of which 24 could be met by the platform. This proves that the platform can be an important asset during the design phase, since the interpretation of the requirements by the designers can be visualised easily, discussed and agreed upon. In Table 3, a list of the met requirements is given, along with their subdivisions.

Table 3: Requirements met by the platform

Category	Number of Requirements
Cohesive Design	3
Span and Clearance Height	2
Deck Curvature	2
Viaduct - Environment relation and Abutment Type	2
Detailings of Edges	7
Pier Location and Design	4
Slopes	4
Total	**24**

5. Conclusion

This research project investigates a novel approach to viaduct design, in an attempt to facilitate the communication among the team members and develop a parametric design platform which encapsulates their accumulative knowledge.

The results of this conceptual study indicate that the designers can highly benefit from such an approach. Indeed in the case of a symmetrical viaduct design the number of user-defined parameters are 30 out of 82 (36.5%). This means that the design time can be drastically reduced, since 63.5% of the design issues considered in this study are automatically addressed by the platform. Testing the platform using actual design requirements, further underlines the benefits of this approach, since 24 out of 56 (42.8%) requirements could be addressed using the platform.

A more automated design process, supported by parametric design, allows the designer to focus on the creative and challenging parts of the design process and drastically reduce the amount of time needed for the mundane parts of it. Moreover, through visual programming, the parametric model's logic is transparent and available to the designer, rather than hidden in a "black box".

An important constraint are the tools that were used in this research project, since the increased complexity of the model and the dense relationships between the components reduce the computational speed. This could be resolved by changing the tools that were employed in this research project and moving the knowledge model to the cloud, in order to fully benefit from the suggested approach.

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