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BIM Applied to Bridges: Single-Cell Box Deck Modelling Supported by Dynamo Programming

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Abstract

The adoption of the Building Information Modelling (BIM) methodology in different sectors of the construction industry has recently received government support worldwide as a way of increasing the level of digital transformation in the development of distinct building activities. In the field of the bridge design, the implementation of BIM presents some limitations due to the difficulty of defining suitable parametric objects that can be adjusted to different specific cases. This study addresses the generation of parametric models of viaduct decks of the box girder type. To support the modelling process of the deck, a script was developed using Dynamo visual programming. The script aims to generate a new family of parametric objects, representative of the bridge deck's girder shape, with a rigorous definition of the cross-section, the longitudinal geometric variation of the deck and the track layout of the road. The proposed parametric modelling strategy of bridge decks was applied to a specific case and its efficiency was evaluated. The study presents an innovative contribution, in the context of the implementation of BIM methodology in public constructions, in the support of the design of bridge decks, driving the required digital transformation of the sector.

Keywords

BIM, BIM Modelling, Box-Shaped Viaduct, Dynamo Script, Family of Parametric Objects

1. Introduction

In the perspective of the digital transformation of the Construction industry, promoted by the government and with a growing trend in the global spectrum of the sector, the Building Information Modelling (BIM) methodology is currently recognized as the integrative and collaborative mode of work, required in the multiple facets of the activity. The adoption of BIM meets the requirements demanded in the industry by sharing information concentrated in a single digital representation, the BIM model, leading to increased production efficiency and quality of the building or infrastructure [1]. The innovative work methodology can provide a variability of solutions, meeting the demands required through the sharing of information concentrated in the virtual model. This model is a digital representation of a building's physical and functional characteristics, referring to its geometry, spatial relationships, and construction components. The model contains a complete, organized, and easily accessible database, allowing engineers to conceive an adequate interdisciplinary collaboration, contributing to the streamlining of processes and the optimization of the final product [2]. In the various activities encompassed by the construction industry, important benefits have been identified related to the rationalization of procedures, the reduction of project costs and time of execution, the control of material waste, the study of sustainability, and the decrease in building timelines [3].

Regarding bridges, it is necessary to carry out thorough control and inspection with regular scheduled periodicity, involving public entities, engineering offices, and external organizations. Life-cycle bridge maintenance is highly multi-disciplinary oriented [4]. In each country, the national company concerning the infrastructures is responsible for the construction and maintenance of a considerable volume of bridges and viaducts [5]. This type of engineering work requires the collaboration of different specialists, involving the production and consultation of various types of documents related to the project, the construction stage, and the subsequent life-cycle, ensuring a recorded history of solutions, changes, and replacement of components, equipment or materials [6]. However, in the specific field of bridges, BIM adoption is not yet common. Its adoption requires, as a first step, the generation of a BIM model with the required geometric and physical information supporting the recommended integration of specialists. BIM can promote a high level of communication between partners, contributing to enhance the quality and safety of the infrastructure.

Concerning the BIM bridge context, also referred as Bridge Information Modelling (BrIM), just a few relevant literature was found. Ahmad *et al.* [7] investigates the role of BIM implementation in the bridge sector to avoid and mitigate risks and improve sustainability, demonstrating that its adoption significantly enhances the efficient management of hazards in bridge projects. Kaewunruen *et al.* [8] adopted the 6D BIM modelling procedure, developed in an early stage of the life-cycle of bridges, supported on BIM aptitude of adding distinct type of data into the 3D BIM model, referring to time schedules, cost estimations, and carbon emission analysis. Fanning *et al.* [9] studied the main impact of BIM implemented on bridge projects, analyzing the substructure costs, the maintenance and rework procedures, and the inspection schedules. Wei *et al.* [10] consider that for bridge engineers, BIM adoption can improve several aspects as the construction simulation of the bridge, the important assistant to the stockholders involved in the processes of managing bridge construction and maintenance, and the 3D visualization of alternative structural options during the design stage. Wu *et al.* [11] illustrate the use of BIM parametric techniques to create suitable bridge components and assemblies, and discus the design improvement in effective collaboration and in the control of costs.

However, the main problem to be solved still lies in the correct definition of the geometric shape of the bridge, namely, the deck of the bridge or viaduct. Within the current context of BIM adopting in distinct construct domains, the application of the methodology have been well integrated into the construction companies, with some exceptions. Following this context, BIM methodology application in the bridge design sector undertakes an important limitation related to the creation of the three-dimensional (3D) model. In order, to achieve better performances in bridges' design, some BIM software houses have been developing BIM applications, extensions, and Dynamo and Python plug-ins, easily accessed from the BIM modelling system in use [12]. Supported on the advanced technology of the available BIM software, its application in bridges becomes an important challenge for engineers. In this regard, the present work aims to positively contribute to achieve an improved performance in the process of modelling bridge decks.

As noted, the construction, inspection, and maintenance of bridges constitutes a sector of construction, where BIM methodology is not yet very common. Although BIM can be applied in a large range of building projects, its use on bridge design has currently been limited. In order to input some knowledge in the development of bridge projects, using the BIM environment, the BrIM concept has been considered in bridge engineering work [13]. The principal purpose of BrIM is to provide a complete and accurate representation of the physical and functional characteristics of a bridge, associated with a database easily consulted, allowing engineers to retrieve the necessary data to support its entire life-cycle activity. The physical 3D BrIM model intends to provide a perfect graphical and functional representation of a bridge, improving design quality, constructability, and collaboration. The present study aims to contribute to the development of a parametric modelling process of BrIM models. The generation of the geometry of the bridge deck is the basis for the development of the bridge project, so this proposal regarding the design of the Dynamo script contributes to the adoption of BIM in the bridge sector as well.

The BIM-based modelling systems available on the market allow the generation of 3D BIM models, representing the building or infrastructure under analysis, linked to all the information collected during the design, construction, and maintenance phases [14]. However, the libraries of parametric objects used in the representation of buildings are not applicable in the modelling of viaduct's decks. Modelling bridges requires the creation of specific families of arch stones, deck's shape, pillars, and junctions. Recent works indicate that parametric modeling could represent a solution providing greater design efficiency and interoperability, but the literature on the subject remains extremely sparse [15].

In the context of this study, a script was developed oriented towards the generation of BIM models of viaduct's' decks of the unicellular box typology. In the BIM context, the greatest difficulty lies in the rigorous representation of its geometry. The present research only refers to the bridge component related to the deck. Since the geometry of the deck presents internal variations of the angles and its height along each span, the modelling proposal based on the created Dynamo script solves is the major BIM problem.

The bridge engineer must be able to interact with the program in order to model the required deck during the design phase, manipulate its configuration and database in the perspective of planning its construction, and subsequently support the inspection activity.

2. Materials and Methods

Preliminary bibliographic research was conducted aimed at cross-sections of real cases, of the type of single-cell deck, in order to establish a generic, parametric, and complete configuration of the cross-section, as well as the modes of longitudinal variation of the height and the thickness of the flanges and webs of the section. A script, programmed in Dynamo software, was developed allowing to represent BIM models of the bridge deck of the selected structural solution type.

The new script was tested over a real viaduct case. The generated deck model presents an accurate geometry allowing engineers to analyse its aesthetic impact and to obtain the quantification of the applied material (Figure 1). Other studies can be performed concerning the structural analyses [16] or the design of the prestressed concrete required in the bridge deck [17]:

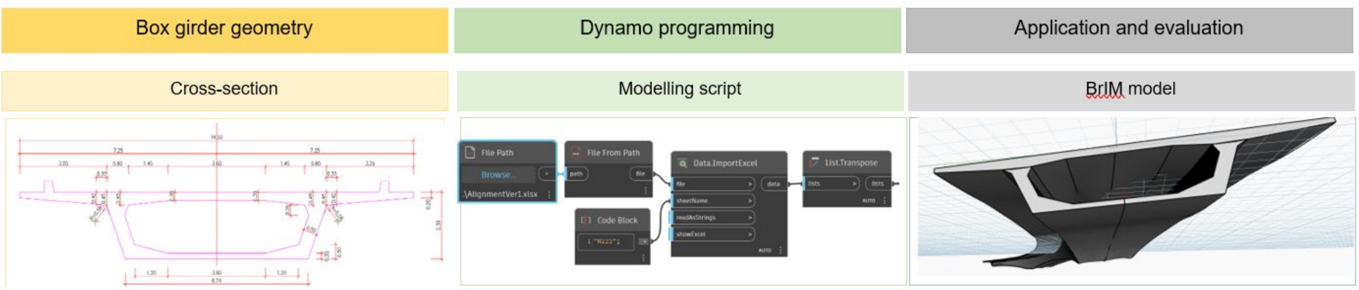


Figure 1. Sequential steps of the applied methodology.

- **Box girder geometry**: The geometric shape of the bridge deck concerning the single-cell box type is defined based on the shape of its cross-section. Along the longitudinal axis of the deck, the shape of the cross-section operates changes in its height and in relation to the thickness of its lower flange and both side webs. Thus, the geometry of the deck is based first on the shape of the cross-section and then on the longitudinal geometry of the deck and the layout of the roadway in which the bridge is inserted.
- **Dynamo script development**: The BIM modelling tool used in the study, Revit

(Autodesk) software, include multiple functionalities, for the global application of the methodology in buildings. However, concerning bridges modelling it requires specific challenges that can be supported by using a Revit extension, the Dynamo visual programming software. This capacity has been little used and explored in BIM adoption. In the study, and considering it as the main innovation of the present research, a complete script was developed involving the re-organization of the geometric data of the cross-sections, the generation of longitudinal segments of the BIM model limited by two consecutive cross-sections, and the representation of the entire deck adapted to the roadway layout. The script was developed in such a way, with geometric parameters, that it can be used in other concrete situations of the same type of bridge. The systems versions used were Revit 2025 [18] and Dynamo v2.13 release [19].

- **Application and evaluation**: The script was then triggered, requiring the input of the geometric data related to the position and shape of each cross-section that forms the deck. The data corresponds to a real case study selected to be used as an illustrative example of the script application. As a result, the complete model of the deck is visualized, which can be observed from different points of view, allowing the bridge engineer to assess its aesthetic value and the correctness of the structural solution in analysis.

The geometry of the deck is the basis of the project, so the aspect related to structural analysis and maintenance corresponds to a future step that will be studied in a future research proposal. In the current state of BIM development, only the geometry has been considered, supported on the development of an application to automate its geometry. Throughout each span of the board, the shape of each section is obtained automatically, allowing the representation of a parametric BIM object corresponding to a deck segment.

3. Dynamo Applied in the Context of BrIM Methodology

The growing technological evolution experienced in the context of the modernization of the construction sector worldwide has been driving the development of BIM studies, with work focused on analysis and real-world testing to assess the capabilities and potential of implementing the BIM methodology, as well as assessing its limitations or application difficulties. However, the specialized literature on bridges is scarce regarding the application of BIM in the sector.

The implementation of BrIM methodology, related to the design, construction and management of bridges has shown recently some encouragement, concerning the modelling process of prestressed beam bridges, cable stayed bridges or metal arch bridges. However, BIM is not only applied on the design of new bridges, but also on the support of the inspection and repair activities of existing bridges. Currently, it is possible to obtain point cloud data supporting the modelling of existing structures for renovation and extension of bridges. BIM can also consider the modelling of the necessary reinforcement, including the prestressing detail, and the required extraction of design documentation (drawings, tables of quantities and cost estimation). Doing a breve review of the most current literature about the topic BrIM related to Dynamo programming, a concise list of the most important achievement is presented below:

- The maintenance and management of large infrastructures must be supported in an adequate regular inspection schedule, but these are normally time-consuming and labour-intensive, reducing the ability to quickly provide synchronized responses. Cavier *et al.* [20] focused their proposal on the monitoring and the maintenance of bridges in order to guarantee the safety and operation over time of these infrastructures, by linking Revit modelling functionality with the inspection data, listed in the form of an Excel spreadsheet, achieved through the use of Dynamo programming. In it, the authors allows the BIM model to visually reflect the condition of the elements, depending on their damage, consolidate the inspection information, and generating a visual management tool. In this direction also Sampaio *et al.* [21] used Dynamo to visually over the railway model, presented with distinct colours (red, yellow and green), the degree of degradation detected in a traditional inspection task, also listed in Excel spreadsheet.
- Other perspective is programming Dynamo on the centralization of the inspection data into a single source, reducing the risk of information loss and improving the maintenance management and associated tasks [22]. Currently, monitoring data obtained from a structural health monitoring (SHM) system is a recurrent strategy allowing engineers to provide the most realistic information and associating theses type of data to BIM models. Also Zhou and Sun [23] refers to monitoring structural health of cable stayed bridge, investigating the mechanisms of thermally induced variations in girder length and mid-span deflection through plane geometric and finite element analyses.
- Dynamo programing supporting BIM environments is currently frequently applied facilitating high-quality architectural and engineer solutions minimizing manual input through the use of Dynamo for Revit. Rocha, and Mateus [24] convert point cloud data into accurate BIM models, enhancing productivity and reducing the potential for errors in the architectural context. Concerning the analysis of embodied carbon in construction materials, Alzara *et al.* [25] propose the integration of Revit, to produce the 3D model, and Dynamo script to support an efficient interoperability between a carbon analysis system, related to the Structural Engineers 2050 (SE2050) commitment to net zero.
- In a bridge context, the analyses of the semantic structure of BIM models and the use of digital twin-BIM technology are current research topics. Park *et al.* [26] propose a methodology to generate 3D point cloud model together with semantic information, referring to the automation of the specification of the identified structural components. Tita *et al.* [27] studied the development of digital twin-BIM technology and demonstrated its various applications for existing bridge structures where the implementation of health monitoring is planned. The application of BIM in infrastructures is effective in the manage-

ment of their life-cycle, encompassing tasks from the design stage to maintenance. Implementing BIM in infrastructure has considerable potential to add value to asset the facility management task [28].

- Recent works specify that parametric modelling could represent a solution providing greater design efficiency and interoperability, but the literature on the bridge subject remains extremely sparse. In Revit software, the bridge model is not accurate enough due to the need to manually pick the location of the bridge structural components. In order to improve the accuracy of the bridge model, the 3D model of the bridge is accurately established by using the open source tool Dynamo [29]. Girardet and Boton [15] developed a parametric file that is able to generate several types of bridges from a single parametric file, using a parametric algorithm for modelling bridge elements in a design software application.

Thus, the present study presents the innovative concept of defining a common configuration in bridges, with the single-cell box deck, in a parametric way based on Dynamo programming.

4. Geometric Characteristics of the Bridge Deck

Bridges and viaducts are structural solutions designed to allow the crossing of people moreover, vehicles over watercourses and lower roads [30]. The type of infrastructure adopted can have an arch or girder configuration, or be composed of tension rods, and the materials used can be masonry stone, metal structures, or reinforced and pre-stressed concrete [31]. In the context of the present work, a single-cell box section deck made of reinforced and pre-stressed concrete was considered.

As software associated with bridge project development, Civil 3D and Allplan Bridge 2025 can be referred to as the most commonly used, parametric 3D modelling software. The Allplan Bridge 2025 software has been tailored for bridge engineering, allowing engineers to create complex geometries along with a higher level of detailing. However, these systems only address geometry [32]. Although undeniably important in supporting the design of the geometry of bridge decks, they are not BIM software. BIM software is significantly richer in information and allows the association of other data related to structural calculations, inspection, or management of the constructed bridge. The development of the Dynamo script presents an accurate modelling process of the bridge deck shape, allowing for the representation of families of bridges of the same typology, as the script enables the introduction of values related to the parameters associated with the BrIM model representation. This option is innovative, as the software Allplan and Civil 3D only allow for the representation of the unique geometric shape of the case under study.

The software Allplan Bridge and Civil 3D are not BIM. The present work allows the correct representation of the shape of bridge decks, creating a BIM model. This model allows users to develop the multitasks associated with BIM dimensions, 4D, 5D, and others up to 10D. The other models developed with the software Allplan Bridge and Civil 3D do not allow the elaboration of these activities associated with the project because they are only capable of representing graphic or geometric models, not allowing for the association of costs (5D) or planning (4D).

A box girder bridge is a type of bridge known for its hollow, box-shaped girder beams, which give it a unique blend of structural integrity and efficiency. The box girder are hollow channel-shaped beams containing two or three side webs and two flanges. The box shape can be either trapezoidal or rectangular. Widely used in engineering projects for highways, railways, and river crossings, these bridges are designed to handle long spans, heavy loads, and challenging environmental conditions [33].

A careful analysis of the box girder deck shape was carried out. Based on a deep evaluation of the cross-section shape, a necessary set of geometric parameters, required to a full definition of the 3D model shape of the deck, was identified. Both in relation to the deck cross-section and to the deck longitudinal configuration. In order to establish an adequate script programming structure, concerning the parametric BrIM bridge modelling process, it was necessary to identify some common features in this type of bridges [34].

The identification of the geometric characteristic of the cross-section and the longitudinal variation of the height of the deck, related to single-cell box bridges, was supported on the provided Computer-Aided Design (CAD) drawings, concerning distinct real bridge projects [35]. This consult sustained the collection of a full set of geometric parameters necessary to describe a generic cross-section shape, and its evolution along the longitudinal axis of the deck [36]. The geometry control, for each study case, is supported by the parabolic variation algorithm, as well the internal transition of the squares.

4.1. Cross Section Geometry

The information about the shape of the cross-section and its change in the longitudinal direction of the deck formed the base for programming the Dynamo script. The bridge modelling script presents a parametric geometric process allowing users to encompass the modelling of the selected case study and other cases of bridges of the same typology. For that, a generic parametric shape of the cross-section was established.

The deck of the selected bridge case is composed of three spans and it is characterized by a parabolic evolution of its depth. The shape of the cross-section, located in the middle point of the central span of the viaduct, includes distinct geometric dimensions elements, namely, the upper and lower slabs, the lateral consoles, the side webs, and a set of internal squares, which describe it in its completeness [36] (**Figure 2**). This full geometric characterization of the cross-section shape allows the bridge engineer to identify the dimensions that should be considered as dynamic geometric parameters in the script [37].

The longitudinal evolution of the cross-section shape, along each span, is determined by structural needs. The increase in the effective height of the section, in the region near the supports over the pillars, is followed by an increase in the thickness of the bottom flange [37]. This thickness variation is necessary in the presence of high compression values during the construction stage, occasionally being a limiting factor, throughout the construction process of the deck. Along the longitudinal axis of the deck, the shape variation can be verified observing the thickness increment of the lower flange of the deck (**Figure 3(a)**), of the bottom slab, the web in the zone of its connection to the lower flange and its height (**Figure 3(b)**).

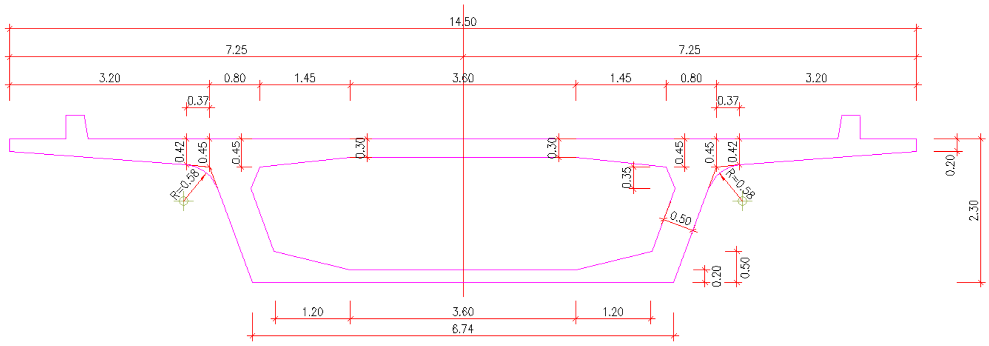
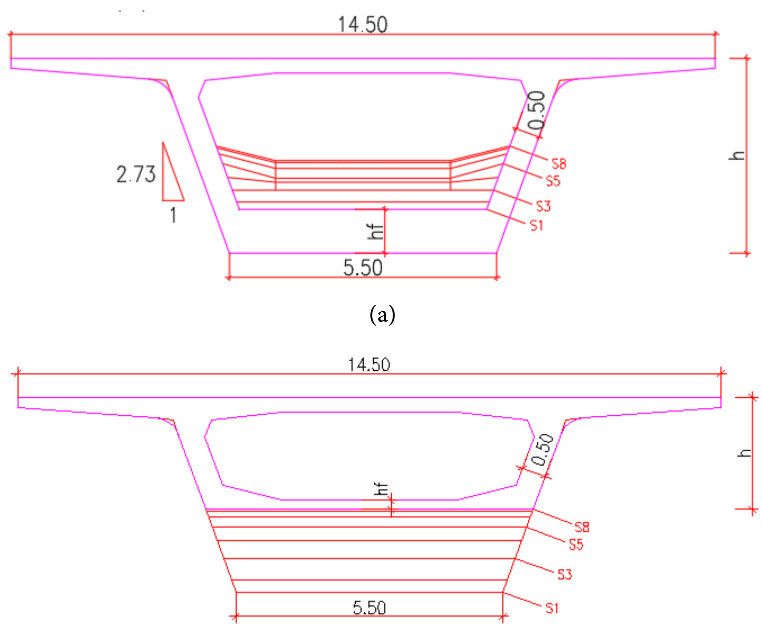


Figure 2. Cross-section of the bridge deck of the unicellular box type.



(a)

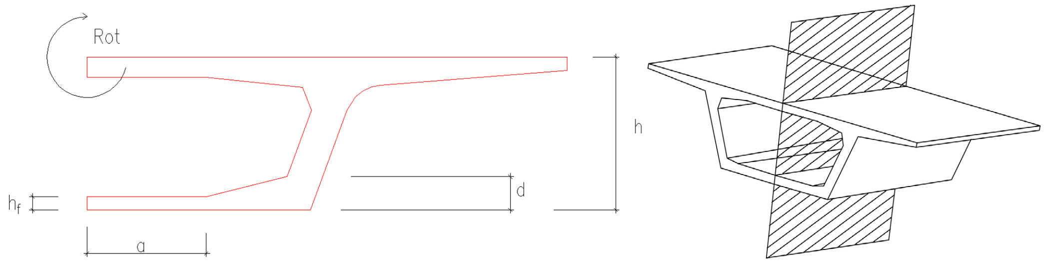
(b)

Figure 3. Variation of cross-section shape of a single-cell box: internal brackets (a) and height of the cross-section (b).

4.2. Variation of Deck Height and Lower Flange Thickness

The modelling process of a deck longitudinal segment family requires the establishment of restrictions and conditions applied over adjacent straight segments. It aims to identify geometric parameters for the dimensions that prove modifications, such as the cross-section height, the internal squares and the thickness of flanges and webs. Observing these constrains, five variables were considered, keeping the remaining dimensions fixed. A sufficient set of geometric parameters was demarked (**Figure 4(a)**): height (h); thickness of the bottom slab (h_f); interior brackets shape (a and d); rotation angle of the section as a whole (rot).

The parameters are only considered for a semi-section, as a cross-section always presents symmetry with respect to the central vertical axis incorporated in a cut orthogonal plane (**Figure 4(b)**).



(a) (b)

Figure 4. Geometric parameters associated with the cross-section (a), presenting symmetry (b).

Due to its infrequency, no variable was considered to represent the thickness of the upper slab, although sometimes the induction of this thickness variation is done to accommodate the layout and anchoring of pre-stressed cables [38]. A bridge deck segment can be seen as a solid geometric element defined by a cross-section sweeping along the deck's longitudinal axis. The shape of the initial and central cross-section is modified when it goes through along the longitudinal axis of the deck, namely, its height and its lower slab thickness [37] (**Figure 5**). The evolution of the deck configuration and the layout of the road geometry influence the overall deck shape.

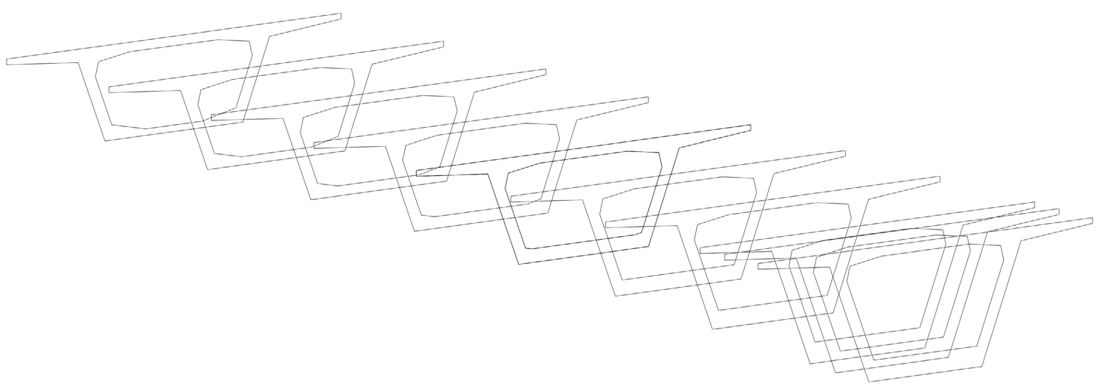


Figure 5. Set of cross-sections generated along the deck.

The geometry related to the shape of the deck in a curved situation is studied in relation to the geometric parameters of the road where the bridge is embedded. The values of transverse rotation calculated for each kilometre point are considered in the rotation parameter associated with the parametric object developed by the Dynamo script.

4.3. Geometry of the Road Alignment

The preliminary project of a bridge or viaduct provides the geometric characteristics of the road alignment layout and the respective longitudinal profile. The geometry of the alignment and the elevation is associated with the road's kilometric reference, as well as with geometric parameters and alignment lengths, both, in plan and altimetry. The initial information also includes the transverse slopes of the road and the widening of the road width [36].

The present bridge is inserted in curved alignment composed of a circular arc and clothoid transition path. The use of clothoid or transitional arc ensures a progressive variation of angular velocity for a constant vehicle speed when transitioning from straight alignment to circular curve, thus playing a fundamental role in a homogeneous road layout. For the definition of the circular arc, it is necessary the coordinates and the direction of the initial alignment point, and the data of the arc centre of the associated radius.

The selected deck case, with a total length of 154 meters, is composed of three spans presenting lengths of 70 meters (central) and 42 meters (laterals) [37]. Each lateral span is defined by 10 cross-sections and the central span by 16 (**Figure 6**). The project includes eight types of cross-sections that are staggered and located according to the respective kilometric point. The longitudinal parabolic variation of the deck along each span is performed externally within the script, with the results presented in an Excel file for each section. The geometry verification is controlled by algorithms representing the parabolic or linear form.

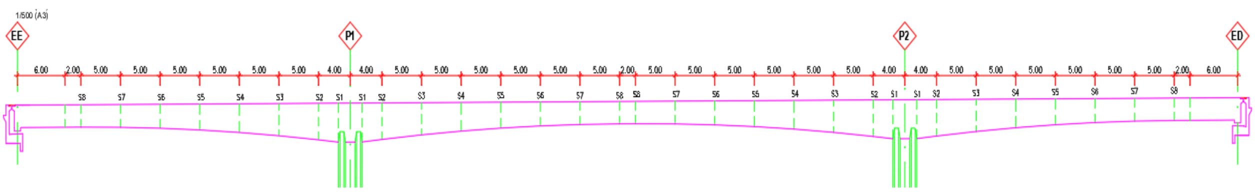


Figure 6. Cross-sections identified along the deck.

A correct definition of the deck requires the identification of a suitable list of points that characterize the path's layout. This description should encompass the points where variations begin or end, ensuring a correct and smooth transition between consecutive cross-sections. By fulfilling this requirement, a correct modelling of the deck is guaranteed. The insertion points for each cross-section are established based on their kilometre point. The calculating of spatial coordinates of the road layout, relating to each point, is required in the new reference system adopted for the modelling of the deck.

The example presented does not require the road parameter related to overwidth or overelevation. The script can be enhanced with this geometry in a future development of this work.

5. Dynamo Programming on the Deck Family Generation

The definition of a new family of parametric objects in the Revit system is obtained in the form of a .rfa extension file. This process corresponds to the development of a new specific BIM model, to be inserted in the modelling of bridge BIM projects. In the present study, the new family represents a deck segment limited by two consecutive cross-sections. A simplification, supported on the symmetry condition of the cross-section, was used in the process. In addition, since the configuration of the deck segment to be modelled has an interior closed section shape, a hollowed configuration, it was necessary to fragment this form into three parts. A proper analysis of the shape division was made, allowing to identify all descriptive variable parameters.

The Dynamo script was applied with the data related to the selected case study. However, the programming was based on the identification and association of specific geometric parameters, which, when realized with values related to other case studies, can also correctly represent those other bridges. The innovation lies in the definition of a script with a parametric character, capable of representing other deck cases referring to the same typology. The deck height geometry can be constant, linear, or parabolic. However, for aesthetic reasons and optimal strength, the most commonly used longitudinal geometric morphology is parabolic.

The development of the modelling script for the deck segment was carried out using an adaptive component, allowing an easy control of the linear variation of the parameter values between consecutive cross-sections. Thus, a new family was created using a generic metric adaptive model provided by the Revit family library. In order to establish a frame family that could encompasses all the parameters subjected to a geometric variation, like the thickness and internal squares, a subdivision of the cross-section into three parts was considered. The parametric variability and the necessary restrictions for their definition make the programming process considerably time-consuming.

5.1. Rotation

Regarding the definition of the transversal slope required along the road, related with the layout geometry, the angle due to elevation can be imposed over each cross-section of the deck by its rotation as a rigid body (**Figure 7**). In it, the cross-section behaves as a whole, and thus, the entire section undergoes the same rotation in order to respond to the transverse slopes [36].

In the script programming, the rotation parameter was the first defined variable. The constraints imposed over the section are related to the orthogonal axes rotated in relation to the road geometry. Thus, subsequently, the entire section rotates around the upper reference point, where the road alignment information will be associated.

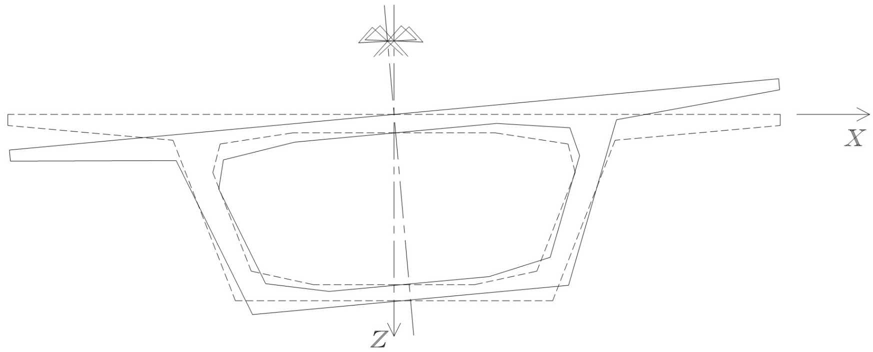


Figure 7. Cross-section submitted to a rotation as a rigid body.

5.2. Upper and Lower Flanges

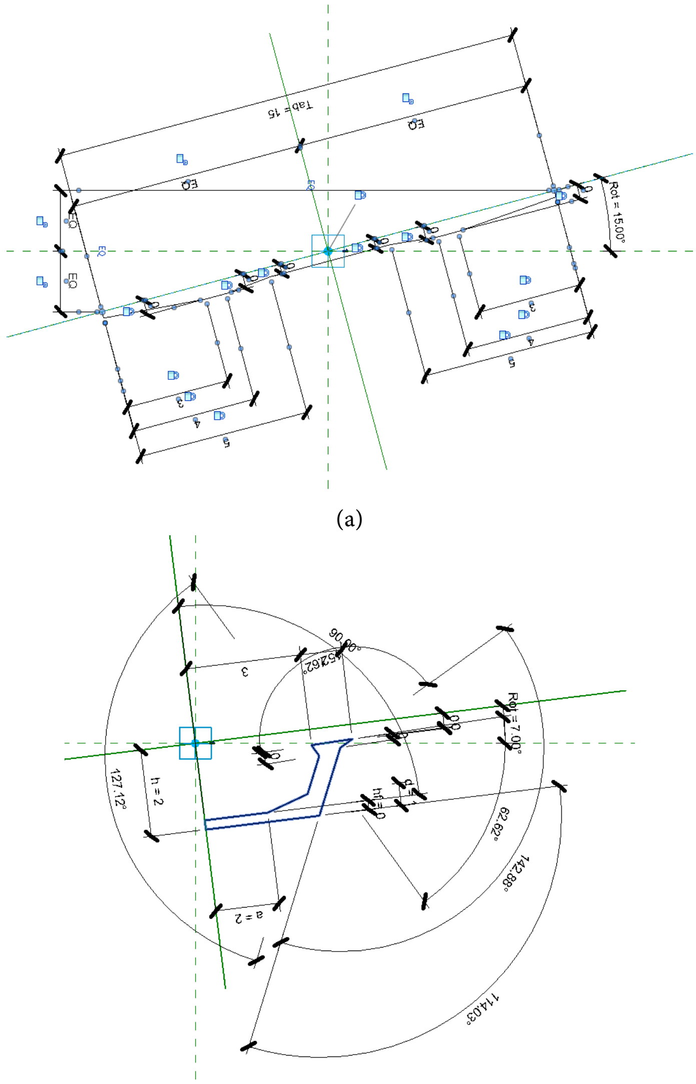
Given the complexity that the cross-section presents, it was considered a subdivision of its shape into three parts. The creation of the element corresponding to the upper flange of the deck was easy and quick to define, while the two elements representing the lower flange and the webs of the section were more demanding to define.

In the present case, the upper slab has a constant height. Thus, the restrictions applied regarding the height of the section do not allow the introduction of input values in the creation of the model. Thus, it ensures that this component of the cross-section has a constant configuration throughout the deck axis (Figure 8(a)). The height of the section is defined based on its location along the guideline layout, associated with the respective kilometric point.

The development of the lower flange configuration requires a phased definition. The lower flange section, along with the webs, has been subdivided into two components, with symmetric positioning relative to the section vertical axis. The thickness of the lower flange shows variations. As so, for a complete definition of these elements of the section, it was necessary to consider two more parameters, a and d (Figure 8(b)). Regarding the complementary cross-section shape of the lower flange, it was represented by symmetry.

The parameters considered assume that some thicknesses or squares remain constant without variation, such as the thickness of the webs or the upper slab. In a future version of the script, parameters related to these geometric components of the cross-section may be added. The developed script only requires compatibility with the Excel file containing the data necessary to correctly represent the external and internal shape of the deck. Subsequently, as future work, the IFC classification necessary to increase the interoperability required in the development of subsequent tasks within the scope of bridge design should be considered. The script can be enhanced with more aspects of the deck geometry following the described work.

The study is ground-breaking in the field of BIM applied to bridges. The literature consulted only mentions the use of software CAD, which, although intended for bridge modelling, is purely CAD. Dynamo programming is naturally more time-consuming than CAD modelling, but its reuse on decks of the same type is naturally faster than CAD modelling, with the advantage of obtaining a BIM model and not just its geometric shape (CAD model) [39].



(a)

(b)

Figure 8. Families of the upper (a) and lower (b) slabs defined in the .rfa file.

6. Results and Discussion

With the definition of the cross-section shape and the assignment of geometric parameters, it was possible to achieve the total characterization of each cross-section, necessary for the representation of the all bridge deck. For it, instance-specific is stated by the user in each case of the deck and the variable type correspond to values calculated based on a parabolic formulation of the deck height variation.

6.1. Development of the Script

As Revit is a BIM tool with multiple benefits for the global application of the methodology, concerning bridges the challenge of modelling fell on the use of Revit's Dynamo extension. Currently, it is still a functionality little used and explored within the BIM performance, which leads to difficulties related to obtaining viable information for its direct application in the bridge project, as required in the present study. In the research, the principal use of Dynamo software concerned the creation of operating routines to support the modelling process of some specific components of the deck, thus circumventing the aforementioned limitation of Revit.

Dynamo extension features a friendly and intuitive usable interface, and programming proves to be easy to handle. The developed script is intended to be able to generate BrIM models of decks of the selected bridge deck type. The last version of Dynamo, Dynamo v2.13 release [19], was used to create the modelling script of the deck.

Dynamo plug-in is a visual programming that has been used by BIM designers, integrating and adding computational design capabilities into Revit. In Dynamo programming, it is possible to group actions by identifying blocks and sub-blocks, making the main document easy to interpret and manipulate. For the generation of the deck modelling script, the input data, related to the position and geometry of a set of cross-sections, were re-organized in a Excel table. When Dynamo script is executed, each element is directly transposed to the Revit workspace and the respective solid model is created, allowing the visualization of the required 3D BrIM model.

6.2. Data Organization

After processing the required geometric information, it is possible to obtain the characteristic values of each parameter. In the development of the script, the definition of two new nodes. These codes allow the input of data, into the script, related to the road layout (position of each cross-section of the deck) and the geometric values of the parameters calculated in conformity to the variations that are operated over the deck.

Regarding Dynamo programming, the nodes organization and links between action, can become complex given the necessity of defining and use a large number of nodes. In the programming process, it is possible to group actions and represent them as sub-blocks, making a main document easier to interpret and manipulate. Dynamo programming proceed with the definition of nodes of combined actions, allowing to input data, related to the position and parametric values of each cross section. Providing the insertion of the Excel table, the deck model can be generated and visualized in Revit software. To achieve this performance the generated Dynamo script is directed activated from Revit. All elements of the deck are, then, directly transposed to Revit workspace, defining the solid representation of the complete bridge deck model. After, the user is able to develop future phases, such as the association of materials to the model and proceed to the calculation of reinforcements and pre-stressed cables, detailing in a 3D representation. The longitudinal geometry is controlled by an external algorithm supporting the generation of the required Excel file. The example presented does not require the road parameter related to over width or overelevation. The script can be enhanced with this geometry in a future development of this work.

This procedure corresponds to obtain a suitable organized geometric data, in order to allow its direct introducing into the script. The data must is listed in an Excel table format. However, it was previously necessary to modify the input indices, of both of the parameters and the coordinates of the kilometric points. This programmed stage is composed of the necessary sequence of actions represented by nodes, related with data import from the excel software and the transposition of data to the script (Figure 9).

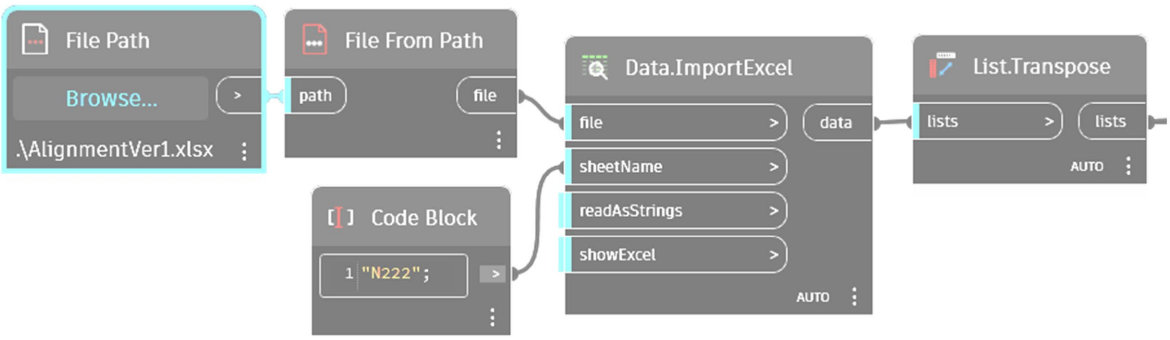


Figure 9. Dynamo programming nodes for data insertion in excel format into the script.

It is possible to identify specific node responsible for data retrieval as well as the nodes for data manipulation. Using the created code block, the input indices can be edited and provide the insertion of coordinates (Figure 10).

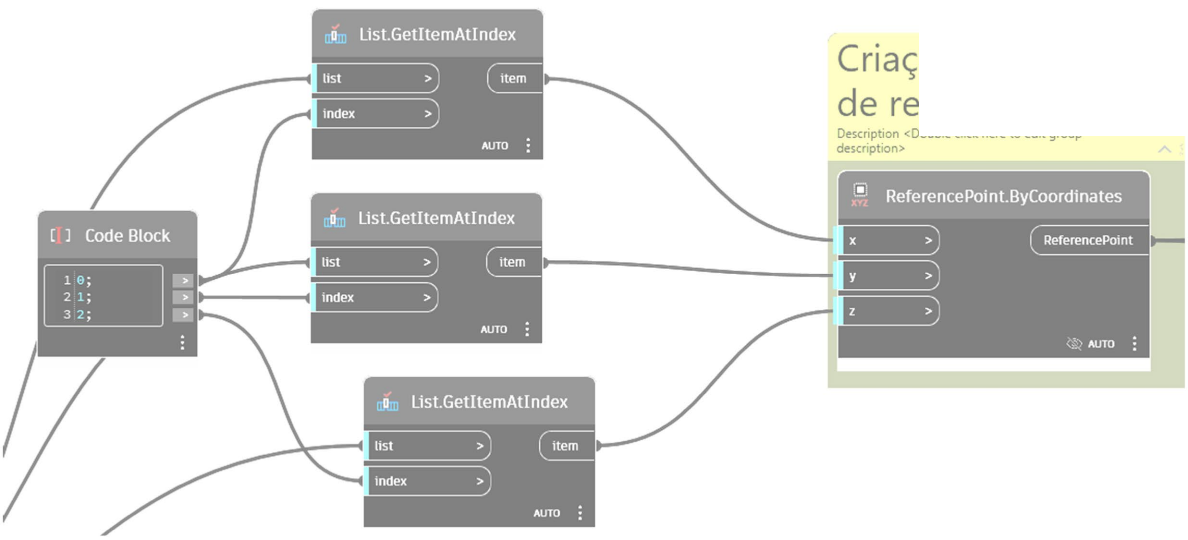


Figure 10. Programming nodes related to data organization and generation of reference points.

In order to achieve these objectives, BIM tools like Revit, and its extensions, Dynamo, is the most used complementary tool. These BIM software allows designers to import road alignments manually and automatically, using data obtained from civil engineering and infrastructure solutions, correspondent to its axis or alignment, as the new bridge is implemented on the designed road. Although Revit is not oriented for road design, it can import CAD files containing a 3D straight or curved representation of the alignment and the associated side corridors. A Dynamo plug-in can be used to directly read the spreadsheet in Excel of the alignment, composed of a set of points defined by X, Y, and Z coordinates.

The Excel file created to be inserted into the script, can present, for each real case, an is independent number of rows, but it is required a complete definition of each row, including null values if required. Table 1 presents a list of the geometric parameters values and the related spatial coordinates, referred to the necessary sections selected to compose a longitudinal segment of the deck case.

Table 1. Excerpt of values corresponding to the definition of cross-sections of the deck case.

sections	x	Y	z	h_f	h	d	a	rot.
S8	0.00	0.00	0.09	0.20	2.30	0.50	1.80	−4.46
S7	4.35	0.43	0.18	0.20	2.30	0.50	1.80	−4.69
S6	5.73	0.59	0.27	0.20	2.30	0.50	1.80	−4.92
S5	9.04	0.98	0.36	0.20	2.34	0.50	1.80	−5.15
S4	12.19	1.40	0.45	0.20	2.46	0.50	1.80	−5.38
S3	15.20	1.83	0.54	0.20	2.66	0.50	1.80	−5.61
S2	18.07	2.28	0.63	0.40	2.94	0.50	1.80	−5.85
S1	20.83	2.75	0.72	0.60	3.31	0.60	1.80	−6.08

In Table 1, the columns corresponding to the x, y, and z coordinates, refer to the geographic position of the section in the road, considered the new coordinate system established in the modelling process. The other columns of values listed the parameters characterize the shape of each section of the deck segment. The column of the rotation parameter shows negative values due to orientation of the defined axes. Thus, the development of any model or desired board segment can be entirely achieved through the definition and adjustment of the Excel table.

Some Dynamo programming diagrams are presented, with the essential objectives of each programming scheme. The diagrams sufficiently clarify the objective of each programming step.

6.3. Application to the Deck Case

Once the family files, data table, and the script necessary for their reading were created, the script code was executed to build the model under study. It is directly performed by acceding the Dynamo icon included in the proper Revit menu. Figure 11 represents the Dynamo environment where it is possible to visualize all the programmed script, overlaid on the generated 3D BrIM model of the complete viaduct deck.

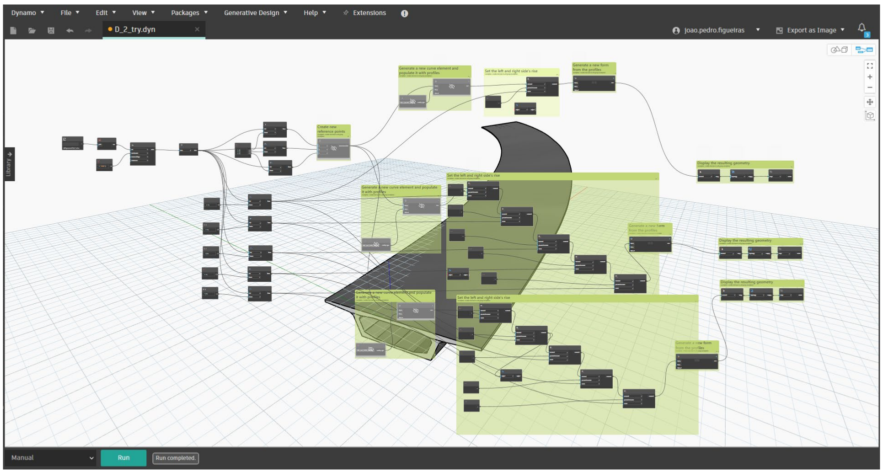
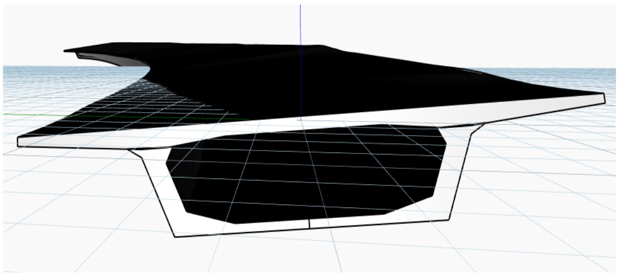
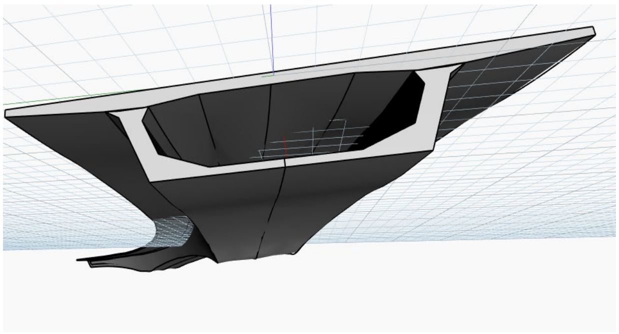


Figure 11. Dynamo environment of the modelling script and the generated BrIM model.

The model can be observed from a top perspective (Figure 12(a)) or a bottom view (Figure 12(b)). In both images the modelled deck presents the first cross-section identified in the first row of Table 1. Both images refer to the BrIM model created, highlighting the clear visualization of the interior of the deck, which is composed of distinct internal squares that allow for geometric variation along the axis of the deck that follows a linear evolution, alongside a parabolic change in the height of the deck.



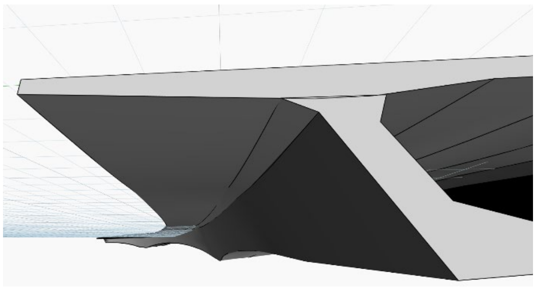
(a)



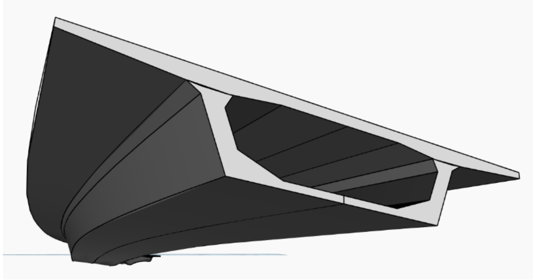
(b)

Figure 12. Perspectives of the model created from the top view (a) and the bottom view (b).

In the perspectives included in **Figure 13**, it is possible to identify the link between the upper flange and the lower half-flanges associated with the lateral webs (a) and the connection between the three elements considered in the representation of the cross sections (b). Regarding the way to divide the cross-sectional shape, it includes partitioning the shape into three parts: the upper deck segment and two symmetrical components of the cell. The joining of the three parts is perfectly identified in the images.



(a)



(b)

Figure 13. Identification of connections between the upper slab with the later web (a) and the segmentation operated in the deck family (b).

The developed modelling script imported by Revit environment, using the Dynamo option, ensures the generation of the deck defined in the form of an Excel table. The deck model of bridges can be observed from distinct viewpoints, supporting the designer to analyse adequately its configuration. The deck model can be presented in the form of segments (**Figure 14**), allowing a detailed analysis of the inner shape, or the complete deck (**Figure 15**), permitting its insertion into the surrounding virtual environment of the real construction. The images clearly show the shape of the cross-section at both ends of the longitudinal segment of the board. Additionally, the parabolic evolution of the modelled midspan is observable.

The engineer can easily assess the correctness of the structural solution, established for the viaduct, by adjusting the descriptive data Excel table of the deck shape. The contribution of the new script is thus quite positive and innovative in the present stage of BIM implementation in the bridge sector. Finally, the complete deck can be presented, modelled using the developed script, where the composition of the deck is perceptible, consisting of three spans with a parabolic external evolution for each span (**Figure 15**).

The evaluation of the geometric details of the cross-section and its longitudinal morphologic changes along the deck axis can be easily understood observing the model from distinct perspectives and zooms. In more advanced stages of the modelling process of the all bridge, with the integration of structural elements such as pre-stressing cables, the possibility of obtaining multiple views and zooms of the section views ensures a careful assessment of overlaps and compliance with parameters in a facilitated manner.

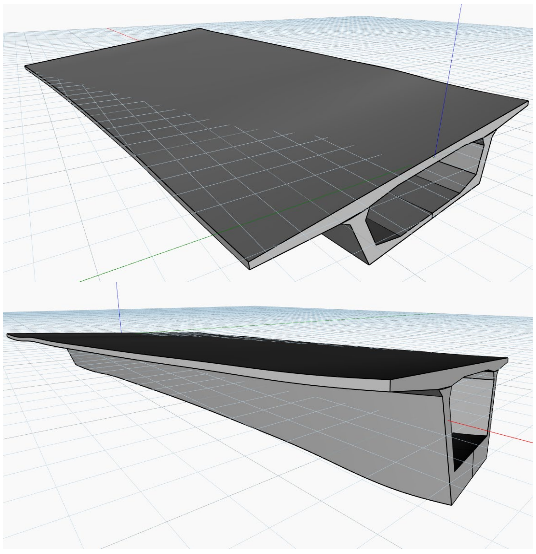


Figure 14. Distinct viewpoints of the model presenting a half-span of the deck.

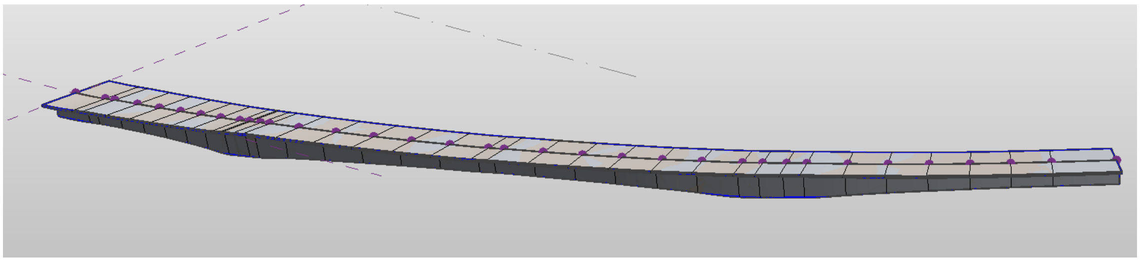


Figure 15. Perspective of the complete deck model.

The generation of the model offers advantages related both to the structural assessment of the designed model and to the integration of the various dimensions of BIM that can be worked out over the model database. By adequately handling the Revit model, it is possible to develop task such as the planning of the construction of the deck (4D), cost estimation (5D) supported by the quantification of material volume applied, CO_2 emission assessment (6D), and the execution of inspection and maintenance (7D).

Concerning a future perspective of the script capacity it can be enhanced with this control of its robustness, requiring its application of other cases. For the extrapolation of the BrIM model to other tasks such as structural calculation or inspection data association, it is necessary to adjust the parametric model (*i.e.*, the script) in order to associate the IFC identification of bridge objects for structural calculation and new parameters related to the type of inspection required. Previous work related to the first and second aspects has been duly studied by the same authors in [40] and [21].

7. Conclusions

The text describes the development of a BIM modelling script for decks of single-cell box type viaducts. Within the BIM framework, the study contributes to the adoption of the methodology in the context of bridge projects. Specifically, in the design phase where the developed program allows to create BIM deck bridge models of the project in elaboration, supporting the analysis of successive adjustments to its shape, within the perspective of a collaborative multidisciplinary team.

Revit modelling system does not contain the bridge parametric objects that are required to model the box girder bridge type. In order to overcome this limitation of Revit, the Dynamo extension was used, accessed directly through the Revit system. Dynamo extension of Revit has emerged as a work option that complements the already great capacity of Revit. The present text describes the development of a new application with the goal of modelling box girder decks. A new family of objects was then generated. The elaboration of the Dynamo new script is presented in detail, illustrating how to insert data, how to calculate values to be associated with the geometric parameters of the cross-section, and how to organize and import Excel files into Revit.

Throughout the presentation of the illustrative deck case, it was possible to highlight the main challenges encountered in the development of the script, its application and evaluation. The strategy established for the representation of the cross-section is sufficient for the generation of the complete deck model. For that, an adequate division of the cross-section shape into three elements, was worked out. This procedure was conceived in response to the difficulty of applying the constraints that ensure the parametric design in the development of the desired family file.

BIM methodology can be used in bridge projects. However, it requires that specific families of objects should be generated and represents a considerable time-consuming. Revit system has sufficient capabilities and functionalities for generating new families of objects for the representation of different types of bridges and decks. One of the functionalities with enormous potential to add value to the performance of the Revit software, is the use of Dynamo extension. Its application in BIM work is currently considered as a strong aid in the digital transformation of the construction sector.

As mentioned, in BIM the greatest complexity corresponds to the geometric representation of the deck. The proposed solution refers to the development of a script that allows the rigorous representation of the case used as an example, but also of any bridge of the same type. The script is easy to use in any bridge design office, contributing to the adoption of BIM in the sector. A bridge is a public work, so the adoption of BIM is mandatory. The first step to consider in a bridge project is naturally the design of its shape. At this point, this work is essential for the beginning of the design of the new bridge. The study is oriented towards BIM modelling and not CAD, so CAD work is unnecessary. Geometry control is supported by the parabolic variation algorithm and the internal transition of the squares. In addition, and in a future perspective of the work aspects such demonstration of more geometric parameters that can cause failure, like self-intersecting webs or negative thickness, can be analysed, improving the script functionality.

The script development plan follows a study logic that begins with understanding the shape of the board to be modelled, in this case, the coffin board, followed by the definition of a segmentation model of the section so that it can be approached in terms of Dynamo programming. This working logic can be used in other typologies. Without obtaining the rigorous geometric model of any type of bridge, it is not possible to develop other tasks, such as structural calculation, detailing of reinforcements or restressing, or even aspects of management and maintenance.

In the present context of most of the countries, the public construction project requires the obligation of complementing the official delivery of viaduct projects with a BIM model. As so, the conclusions of this study are currently of great relevance in the global state of the internationalization of the construction industry, focused on the bridge sector.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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