Development of bridge model variations for sensitivity analysis using a parametric building information modelling approach

Erstellung von Brückenmodell-Variationen für Sensitivitätsanalysen unter Verwendung eines parametrischen Modellierungsverfahrens

Project Work

TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Civil Engineering

Institute of Construction Informatics

TU Dresden, Germany

Written by

Gulshat Zaripova

Supervisors:

Prof. Dr.-Ing. Raimar J. Scherer

Dr.-Ing. Peter Katranuschkov

Dipl.-Ing. Al-Hakam Hamdan

Date of submission: 20.03.2017

Declaration of independent work

I confirm that this assignment is my own work and that I have not sought or used unacceptable help of third parties to produce this work and that I have clearly referenced all sources used in the work. I have fully referenced and used inverted commas for all text directly or indirectly quoted from a source.

This work has not yet been submitted to another examination institution – neither in Germany nor outside Germany – neither in the same nor in a similar way and has not yet been published.

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TECHNISCHE UNIVERSITÄT DRESDEN

Fakultät Bauingenieurwesen Institut für Bauinformatik

Technische Universität Dresden, 01062 Dresden

Prof. Dr.-Ing.
Raimar J. Scherer
Institutsleiter / Director of the institute

Bearbeiter:
Telefon: 0351 463-32966
Telefax: 0351 463-33975
E-Mail: Raimar.Scherer@tu-dresden.de
AZ:

Specification of the Project Work (module BIWO-08)

for Gulshat Zaripova, Master's study programme ACCESS,

matriculation no. 4573497

Topic:

Development of bridge model variations for sensitivity analysis using a parametric building information modelling approach

in German:

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Objective:

Correct identification of structural system behavior is an important part of the bridge monitoring and retrofitting process. Sensitivity analysis is thereby often used to identify the parameters that have strongest influence on the bridge behavior. For that purpose, a method to create variations of bridge models that differ only by a small number of parameters needs to be provided. A promising solution approach here is the use of parametric modeling through which different models can be almost fully automatically generated by varying specific attribute values. However, in order to use those models in specialized analysis and simulation software tools, they should be provided as standardized model data using the Industry Foundation Classes, IFC specification (ISO 16739).

The objective of this project work is to develop parametric bridge models for selected bridge construction types, which can be exchanged in IFC and are capable to support the required parameter change functionality.

Tasks:

1. Investigation of the state-of-the-art in parametric modelling and the advantages of this method for building information modelling (BIM) based analysis and design
2. Selection of two different construction types for bridges taking into account curved alignments, characterization of their specific features regarding model parameterization and parameter variations and conceptualization of the respective parametric models
3. Development of the parametric bridge models using appropriate CAD and parametric modelling software tools (recommended: Dynamo[1], Revit[2] & Excel); The instantiated parametric bridge models must be exported from CAD as standard IFC files
4. Evaluation of the flexibility of the developed solution for parameter changes on selected examples
5. Documentation of the achieved results in a written report (appendix is allowed)
6. Preparation and public presentation of the results

The work can build upon a previous project work on parametric bridge modelling using Dynamo and Revit, which has been performed at the Institute of Construction Informatics in 2016. The bridge alignment project of buildingSMART should thereby also be taken into account[3].

Day of issue: 28.11.2016 Day of delivery: 20.03.2017

Tutors:

Dr.-Ing. Peter Katranuschkov

Dipl.-Ing. Al-Hakam Hamdan

Supervisor:

Prof. Dr.-Ing. R. J. Scherer

Student:

Gulshat Zaripova

28.11.2016

[1] Dynamo, see http://dynamobim.org/download/ ;

[2] Autodesk Revit, see http://www.autodesk.de/products/revit-family/overview,
Free student download at: http://www.autodesk.com/education/free-software/revit

[3] buildingSMART Bridge Alignment project: see http://www.buildingsmart-tech.org/infrastructure/projects/alignment

Abstract

Traditional ways of design and planning the infrastructure are insufficient to provide object-based and data-rich models intended to be the basis for the sensitivity analysis of bridges. Being widely recognized as a mature design methodology in the building industry, Building Information Modeling (*BIM*) the application for infrastructure is rapidly increasing today, implementing more accurate engineering representations of the design model. The parametric modelling approach is one of the aids to create object oriented bridge models.

In this work, two specific bridge structures using the BIM tool Autodesk Revit 2015 and Dynamo Revit visual programming extension were developed in order to vary of bridge models that differ only by small number of parameters. Challenges during design process such as: repetitive operations, non-standard geometry (a particular case with curved road alignment was considered) or interaction with another infrastructure design software are solved using visual programming language.

Recent developments extend the IFC concept into the domain of infrastructure modeling by developing the IFC-Bridge format, therefore bridges modelled in this work are exported as standard IFC files.

Keywords: BIM, Revit, parametric bridge modelling, Visual Programming, Dynamo.

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1 Introduction

1.1 Problem description and aims of the project.

In comparison to the commercial sector, the bridge design process is not commonly used in terms of full BIM orientation, and traditional methods are still preferred. Thus, it is appropriate to assess how BIM-tools' lacking ability to design complicated bridges can be remedied and how BIM to a greater extent can be used as a resource in bridge design. By evaluating the process as it is done today and comparing it to a more BIM dominated process, one can gain knowledge about the possibilities and limitations concerning a change in the bridge design process. One of the biggest problems lies in the fact that a bridge's geometry is often described in parametric terms, using geometric constraints and mathematical expressions to describe dependencies between different dimensions.

This project work aims to develop different bridge instances meeting the requirements of the BIM-oriented models possessing parametrically dependent properties in order to generate a variation of bridges. Created bridge instances could be further used for sensitivity analysis or load simulations, therefore exportation to Industry Foundation Classes is considered.

1.2 Choice of Software

The implementation of BIM-oriented technology implies a number of software bringing the working process to the new level of collaboration between all the construction participants. Owners of civil infrastructure do not want to miss out on those benefits and they are increasingly mandating the use of BIM on their projects. By utilizing three-dimensional, real-time, dynamic building modeling software such as Revit, the designer is provided the opportunity to design a structure and its components in 3D, annotate the model with 2D drafting elements, and access building information from the building model database. Fig. 1 illustrates the stages of construction where a 3D model is necessary.

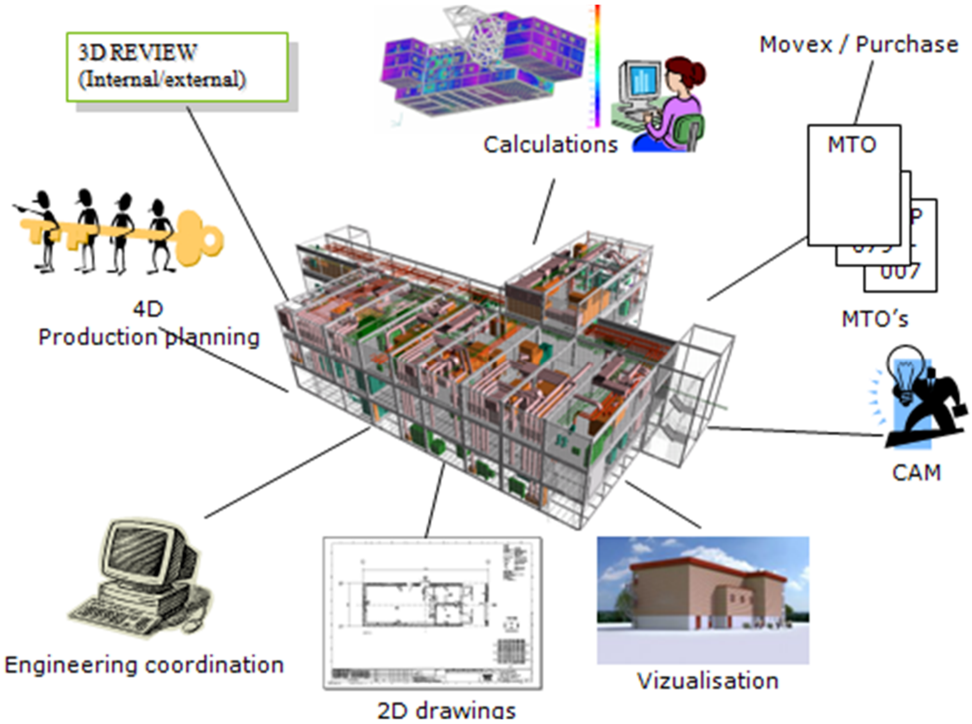


Fig. 1 Fields of 3D model's use in planning process. [9]

Since the parametric properties are essential for bridge modeling assigned to sensitivity analysis, the bridge itself is assumed to be designed by means of parametric tools. This capability delivers the fundamental coordination and productivity benefits of Revit: change any variable, dimension or other data at any time in the model, and Revit coordinates that change through the entire project. Therefore, Revit was chosen as the main modelling tool for this project work.

Being mostly developed and successfully implemented for civil structures, Revit has no Infrastructure Project Templates or Families of the bridge structural elements built in. However, there is a Bridge Modeling Autodesk® Revit® Extension, which can generate bridges based on the user's parameters including a road profile, a deck, abutments, piers and railings.

The road profile may also be imported from a LandXML format file.

Nonetheless, bridges generated by Bridge Modeling Autodesk® Revit® Extension have limitations in the choice of the deck's profile, type of girder and the alignment is only possible to define by one radius, namely, there is no possibility to create a road aligned to spline (see.Fig. 2).

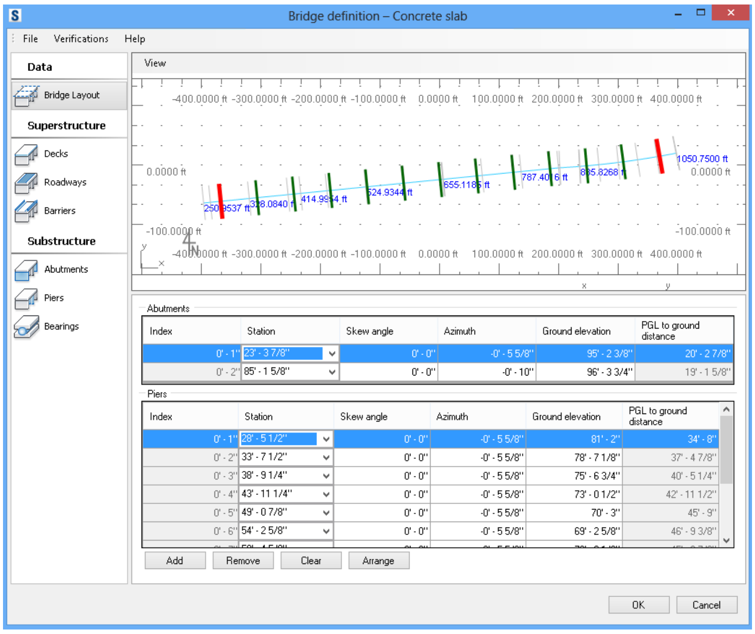


Fig. 2 Bridge Modeling Autodesk® Revit® Extension Screenshot

To extend the functionality of Revit, there is the addition of visual programming considered. Most of the BIM software have auxiliary visual scripting components, and a in case of Revit there exists the open source graphical programming language Dynamo. This free application is very convenient in its installation and intuitive in use as an add-in, Dynamo is launched atop the main *.rvt* of *.rfa* (Revit project or Revit family) files (see Fig. 3 Dynamo Revit interfaceFig. 3).

It extends building information modelling with the data and logic environment of a graphical algorithm editor. Dynamo can be extended easily through a large library of user-created packages, Python scripting, and through directly importing *dll's* to create nodes.

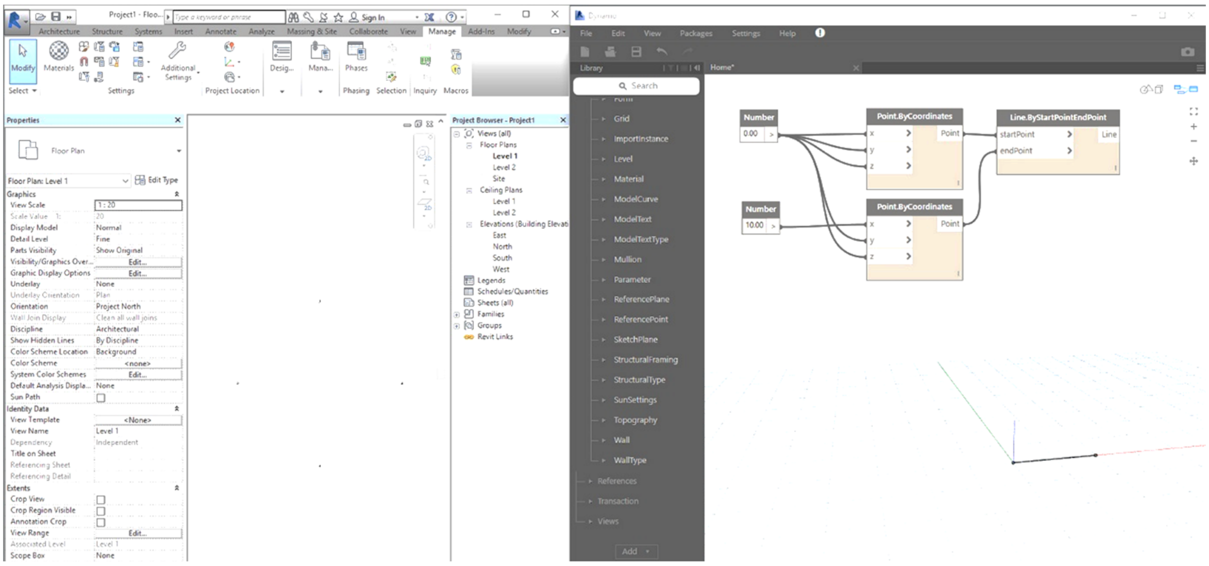


Fig. 3 Dynamo Revit interface.

The principle of coding with Dynamo implies replacement of "methods" in classic object-oriented programming languages by nodes, which already contains both method and object, so there is no deep programming knowledge from the user expected. All the nodes are divided into categories of use, for example: "Geometry", "Math", "Core", "Revit" etc., and have a short description of the operation they execute.

Dynamo offers a whole suite of nodes specifically designed for Revit, as well as third-party libraries from a thriving AEC community. Revit hosts a comprehensive API (Application Program Interface), allowing third-party developers to create custom tools and programmers have been using this API for years, but text-based scripting is not accessible to every engineer or architect. Dynamo seeks to democratize Revit data through an approachable graphical algorithm editor, and this project work demonstrates some of the possible solutions.

1.3 Project outline

Chapter 1: In this part introduction to the problem and motivation are given, as well as an explanation of the software choice, their limitations, and capabilities.

Chapter 2: This chapter represents the state-of-art in parametric modelling and its influence on bridge design today. The application of BIM methods in construction in general and BrIM development, its advantages and challenges are covered.

Chapter 3: Here is a detailed description of two different bridge modelling procedures were given and the issues existing in conceptual design workflow or bridge element positioning. This chapter introduces the used software tools and possible optimizations achieved with visual programming and gives an overview of the developed models.

Chapter 4: This part gives an introduction to IFC format data and its role in BIM development, IFC property sets, and IFC alignment.

Chapter 5: A summary of the work is given and an analysis of the performed methodology is reviewed.

2 State-of-the-art in parametric modeling

2.1 Bridge design today and BrIM

The main idea of Building Information Modeling (BIM) is to create 3D models and store the information on a construction project across the project's life cycle in a database so that this information can easily be extracted and viewed from these objects. By creating 3D-models and adding information related to all the different disciplines involved (Plumbing, Electrical etc.), all the information which previously had to be coordinated after they were made (sheets describing the bridge used in the construction phase) can be incorporated into the model immediately. This way, one obtains an overview of the project early, which in turn means that problems or improvements can be identified early in the design process. In contrast to traditional drawing and the use of CAD-tools, where the drawings are independent of each other, the BIM is a 3D-model with 3D-objects and elements with parameterized properties and relations to each other. Parameterized properties means that the objects are assigned with certain parameters (e.g. dimensions, offset from original placement, slope etc.) easily altered through a property palette. Once the information representing the object is altered, it will be altered everywhere in the BIM, which renders tedious changes in the documentation obsolete [12].

The commercial construction sector has more or less employed full BIM, however, Bridge Information Modeling (BrIM) has been slower to develop the infrastructure sector in the same volume. Bridge Information Modeling (BrIM) refers to an advanced modeling approach that is based on the generalized definition of the "objects" that make up the physical asset. It is a holistic digital representation of physical and functional characteristics of the facility, which provides an information to support a reliable basis for decisions during its life-cycle. Using a standard for representing bridge information in a digital format which can be rapidly adopted by software tools will offer the opportunity to use digital project delivery, 3-d visualization, virtual assembly, automated machine control, fast routing and permitting, network-level study, smart inventory, and more, as a routine part of project development and asset management [21]. Two of the key differences between BIM and BrIM are:

- Geometric definition for buildings is developed in a rectangular grid system, whereas bridges are defined with horizontal curved or straight alignments (stations and offsets), vertical grades and curve profiles (elevations), and varying cross-section definitions.
- The number of disciplines and construction trades involved in building structures is significantly higher than for bridges [5].

There are some of the reasons that decelerate BrIM implementation:

- Existing CAD-tools are considered sufficient.
- The BIM-technology still has problems, especially concerning non-standard geometry. The problem with bridges constructed with concrete cast-in-place is an example of this. Curvatures are often needed in two planes as well as a variable cross section.

To evaluate the potential role of BIM in infrastructure projects, and in this case bridge design, one has to address the shortcomings of the present work process. At the same time, one has to assess the potential of a new digital process. This includes, among other things, to evaluate the programs used and how they can be integrated into infrastructure projects.

There are several software vendors who have developed BrIM based interfaces.

•Autodesk Revit, BIM 360

•ArchiCAD (Hungary, 120,000 users, IFC)

•Bentley

•CodeBook (UK, database add-in)

•Data Design System AS

•GRAITEC Advance BIM

•IDEA Architectural (full IFC compatibility)

•Tekla Structures and BIMsight (Finland, IFC compliant)

•VisualARQ (Spain, IFC).

Software that are not intended to be used in BIM, such as AutoCAD or Microstation, deal with these challenges in a superior manner as they only create the correct geometry without regard to the relations between elements in the model. However, they lack the object orientation. In connection with increasing interest of customers to BIM oriented tools in the design of bridges, in 2015 Autodesk University published an Online Class [6], in which the creation of detailed bridge model using mainly Revit software was taught, as well as Dynamo software, and AutoCAD Civil 3D software as a data source for alignments and profiles. The advantage of this method is its compatibility of software and opportunity to be applied in such regions as DACH (DACH region = Germany / Austria / Switzerland) because existing bridge extensions for Revit do not meet the industry's requirements. There is a need to assess the applicability of Revit for bridge design where the geometry of the bridge is non-standard and gain knowledge about the possibilities and limitations concerning a change in the bridge design process.

2.2 Parametric modeling and parametric design approach to bridge structures

Parametric modeling is a well-established methodology in the field of mechanical engineering. It allows the creation of flexible geometric models using parameters for dimensions and makes it possible to define numeric relationships between these parameters by means of mathematical formulas and define geometric-topological constraints between geometric entities. The result is a flexible geometric model which can be steered through the manipulation of its primary parameters. In contrast to explicit geometric models with fixed dimensions, a parametric model can capture the design intent and represent domain knowledge. The use of parametric modeling techniques is particularly beneficial for designing bridges. This is due to the fact that the geometric design of bridges is mainly determined by external constraints resulting from the size and the layout of both the overlying and the undercrossing carriageway. This reduces the effort required for reworking when changes are made, while simultaneously providing a high degree of reusability for the model in other, similar projects, resulting in significantly increased efficiency in the bridge design process [20].

As in case of BIM approaches, there is a dramatic difference between numbers of cases of parametric concepts applied to building design rather than bridges. For infrastructure facilities in the field of civil engineerings, such as roads, bridges and tunnels, only a few examples are well known and developed, although bridge sketches, which are based on implementation of visual programming software, exist.

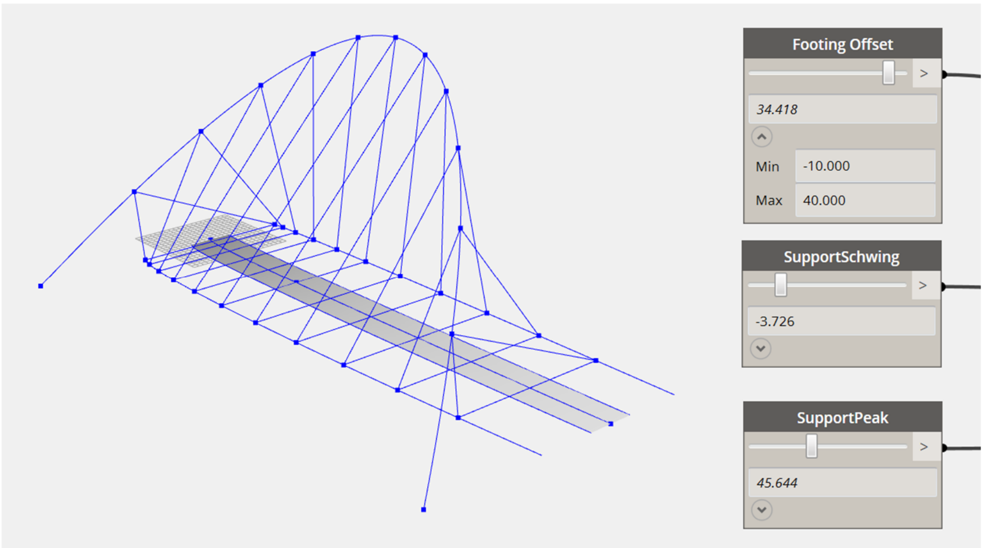
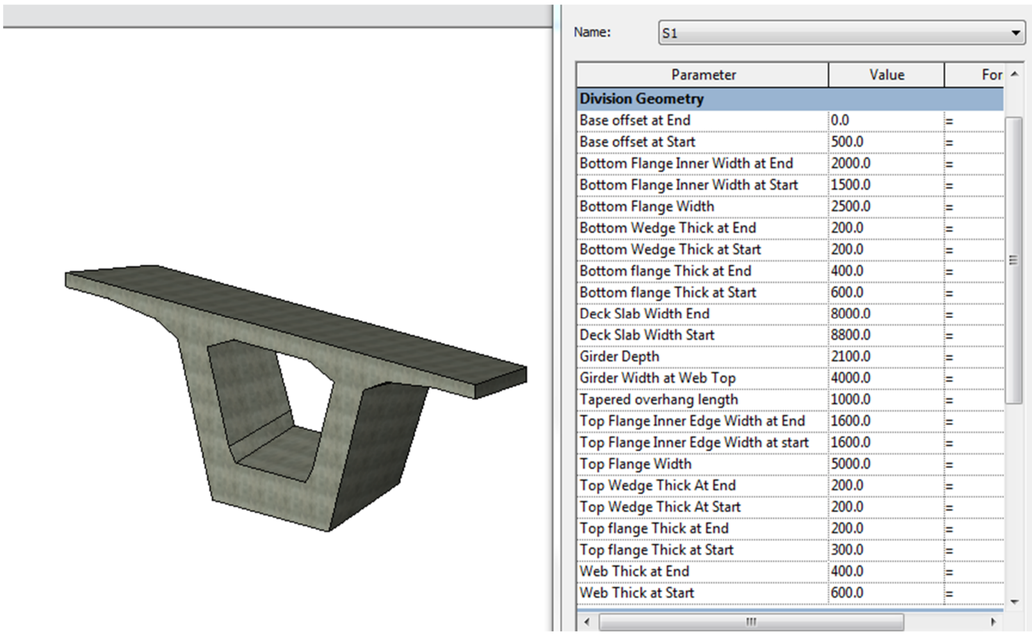


Fig. 4 Bridge from sketch in Dynamo.

More approximate to real case is an example of a box girder element, published by Naresh Kumar in 2015, Fig. 5 shows an example of the parametrically controlled box Girder family instance.



Parameter	Value	For
Division Geometry		
Base offset at End	0.0	=
Base offset at Start	500.0	=
Bottom Flange Inner Width at End	2000.0	=
Bottom Flange Inner Width at Start	1500.0	=
Bottom Flange Width	2500.0	=
Bottom Wedge Thick at End	200.0	=
Bottom Wedge Thick at Start	200.0	=
Bottom flange Thick at End	400.0	=
Bottom flange Thick at Start	600.0	=
Deck Slab Width End	8000.0	=
Deck Slab Width Start	8800.0	=
Girder Depth	2100.0	=
Girder Width at Web Top	4000.0	=
Tapered overhang length	1000.0	=
Top Flange Inner Edge Width at End	1600.0	=
Top Flange Inner Edge Width at start	1600.0	=
Top Flange Width	5000.0	=
Top Wedge Thick At End	200.0	=
Top Wedge Thick At Start	200.0	=
Top flange Thick at End	200.0	=
Top flange Thick at Start	300.0	=
Web Thick at End	400.0	=
Web Thick at Start	600.0	=

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Fig. 5 Example of parametrically driven box girder instance.

2.3 Advantages of BIM in bridge design

Due to the reasons mentioned above, bridge design process is not well defined in terms of full BIM, and traditional methods are still preferred. Therefore, it is reasonable to investigate how BIM-tools' lacking ability to design complicated bridges can be improved and how BIM to a greater extent can be used as a resource in bridge design. By evaluating the process as it is done today and comparing it to a more BIM dominated process, one can gain knowledge about the possibilities and limitations concerning a change in the bridge design process. The model-based approach increases efficiency within the following benefits:

2.3.1 Capture reality

Some projects already include aerial imagery and digital elevation, along with laser scans of existing infrastructure, accurately capturing reality and greatly streamlining project preparations. With BIM, designers benefit from all of that input compiled and shared in a model—in a way that paper is not able to capture [11].

2.3.2 Collaboration

Sharing and collaborating with models is easier than with a drawing sets, as there are a lot of functions that are possible only through a digital workflow. Much of this added project management functionality is now being delivered in the cloud, such as Autodesk's BIM 360 solutions. Here, there are tools for different disciplines to share their complex project models and to coordinate integration with their peers. Review and markup steps ensure that everyone has had input on the evolution of the design and that they are all ready to execute when the concept is finalized and moves forward in construction [11].

2.3.3 Maintain Control

The digital model-based workflow involves aids as autosave and connections to project history so that users can be certain they have captured their time spent working on the model. The connection to the version history of the model's evolution can help you avoid disastrous disappearances or corruption of files that can make blood boil and impinge productivity[8].

Already, advanced technologies are available across the entire spectrum of infrastructure development—from the opportunities big data provides to the analysis of more complex risks and problems to avoid wasting time and money, to the Building Information Modeling (BIM) processes that can stretch infrastructure investment dollars throughout the design and engineering and construction phases along with introducing predictive asset management approaches to prolong the infrastructure life once built. In the European Union and the U.K., BIM is already proving its worth along with asset management frameworks like PAS 55, the British Standards Institute (BSI) publically available specification for the optimized management of physical assets which have been migrated to the ISO55000 standard [11].

2.4 Industry Foundation Classes file format

2.4.1 Introduction into IFC

The Industry Foundation Classes (IFC) file format was developed by buildingSMART®. IFC provides an interoperability solution between different software applications. The format establishes international standards to import and export building objects and their properties.

IFC improves communication, productivity, delivery time, and quality throughout the lifecycle of a building. It reduces the loss of information during transmission from one application to another, with established standards for common objects in the building industry [12].

The specification of the IFC standard includes for each major and minor edition:

- the IFC Specification html documentation (including all definitions, schemas, libraries)
- the URL for the IFC EXPRESS long form schema
- the URL for the ifcXML XSD schema

The IFC specification is written using the EXPRESS data definition language, defined as ISO10303-11 [13] by the ISO TC184/SC4 committee. It is the same data definition language as used e.g. in STEP or CIS/2. It has the advantage of being compact and well suited to include data validation rules within the data specification. The IFC exchange file structure (the syntax of the IFC data file with suffix ".ifc") is the so-called "STEP physical file" format, defined as ISO10303-21 [14] by the same ISO TC184/SC4 committee. It is an ASCII file format used to exchange IFC between different applications.

In addition to the IFC-EXPRESS specification an ifcXML specification is published as well (since the IFC2x release). The ifcXML spec is provided as an XML schema 1.0, as defined by W3C. The ifcXML exchange file structure (the syntax of the IFC data file with suffix ".ifcXML") is the XML document structure. The XML schema is automatically created from the IFC-EXPRESS source using the "XML representation of EXPRESS schemas and data", defined as ISO10303-28 ed. 2. This ensures that both IFC-EXPRESS and ifcXML handle the same data consistently and that the *.ifc and *.ifcXML data files can be converted bi-directionally.

2.4.2 IFC alignment project

It is important to check the list [15] if Revit supports the desired IFC classes before exportation. By the time, there is no alignment class supported in current version of IFC. Therefore, buildingSMART has developed **IFC for Infrastructure** extension project is the P6 "IFC Alignment" project. It will act as a baseline for further projects, such as IFC-Bridge and IFC-Road, and provides the data model with 3D and 2D alignment information for the spatial location of infrastructure assets.

The main scope of the IFC Alignment project is the extension of the IFC4 schema to capture semantically rich alignment information. The alignment definition will be used by other infrastructure extensions for IFC4, such as IFC for Roads, and IFC for Bridges, and referenced by domain specific definitions such as cut & fill, road cross sections, or bridge segments.

Main achievements of the IFC Alignment 1.0 are:

- Ability to exchange alignment information from planning to design, to construction, and finally to asset management phase
- Ability to link alignment information to other project information such as cross sections and full 3D geometry of construction elements (realized by upcoming IFC-Bridge and IFC-Road projects)
- Ability to query alignment information providing data such as linear referencing for positioning
- Ability to allow open data access of alignment information from the asset management databases

- Ability to map IFC alignment models to InfraGML (developed by OGC), and LandXML (latest InfraBIM version from buildingSMART Finland) [17].

The IFC Alignment definition will, therefore, provide a common definition layer for all infrastructure extension schemas. The alignment definitions depend on:

- a well-defined mapping between the geospatial coordinate reference system, in which alignment coordinates are defined (Easting, Northing) and the engineering coordinate system (local coordinates) in which construction projects are defined,
- a spatial reference system for linear construction projects,
- a definition of linear referencing to spatially locate items in addition to the geometric coordinates,
- a terrain model of the existing terrain as a first geometric context for the 3D alignments.

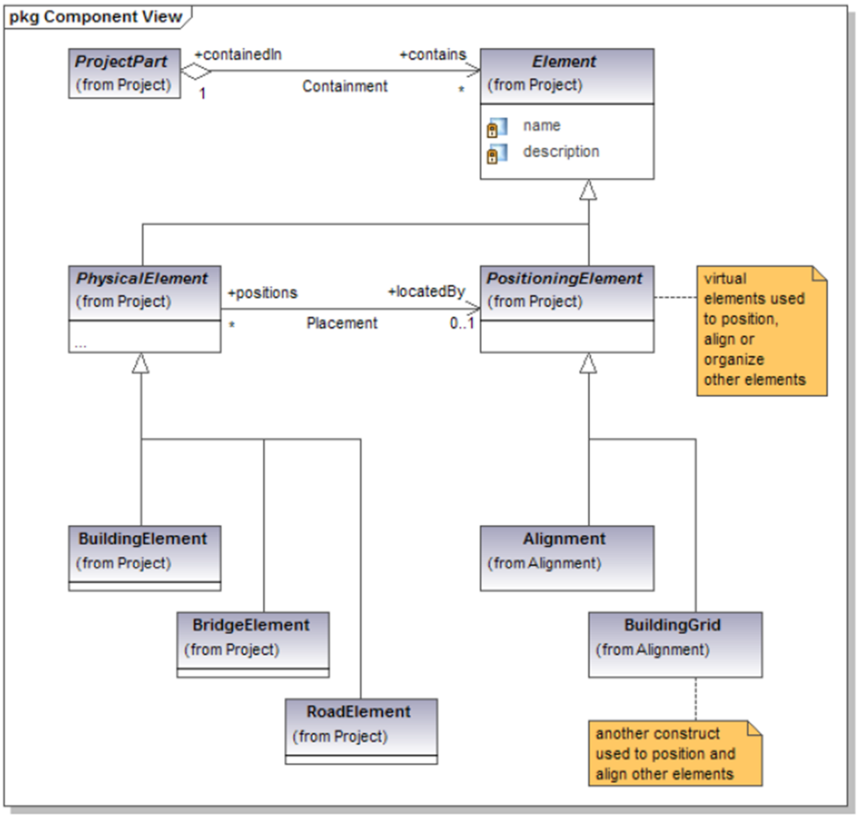

Fig. 6 Class Diagram *Classes Project Elements* [17].

Facilities are defined by its constituting components (see Fig. 6), both physical and virtual components. Physical components are for example building elements, bridge elements, or road elements. Virtual components are positioning elements, such as grid for buildings, or alignments for linear infrastructure works.

2.4.3 IFC property sets

In 2014 buildingSMART published *Property Set* as part of the official buildingSMART IFC releases.

Property sets is a special capability in the IFC Model, allowing the extension of IFCs without changing the model and providing a framework for user defined information. There are the following reasons to use *Property Sets*:

- Capability of thousands different types of components used in building construction to be conveniently grouped into classes;
- A class has common structure and purpose;
- Not all the element types could be translated as a class in the IFC model;

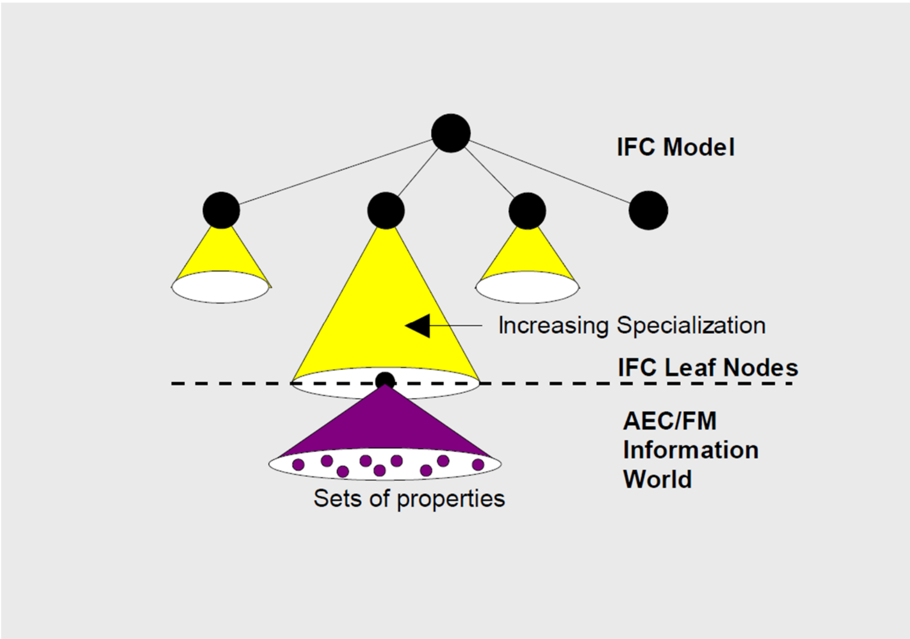

Fig. 7 IFC and the AEC/FM information world schema [50].

A property definition has a name and seven types as follows:

- a single value (with or without units)
- a bound value (with or without units)
- a list value (with or without units)
- an enumeration value (with or without units)
- a range of values (with or without units)
- an object reference
- a complex property

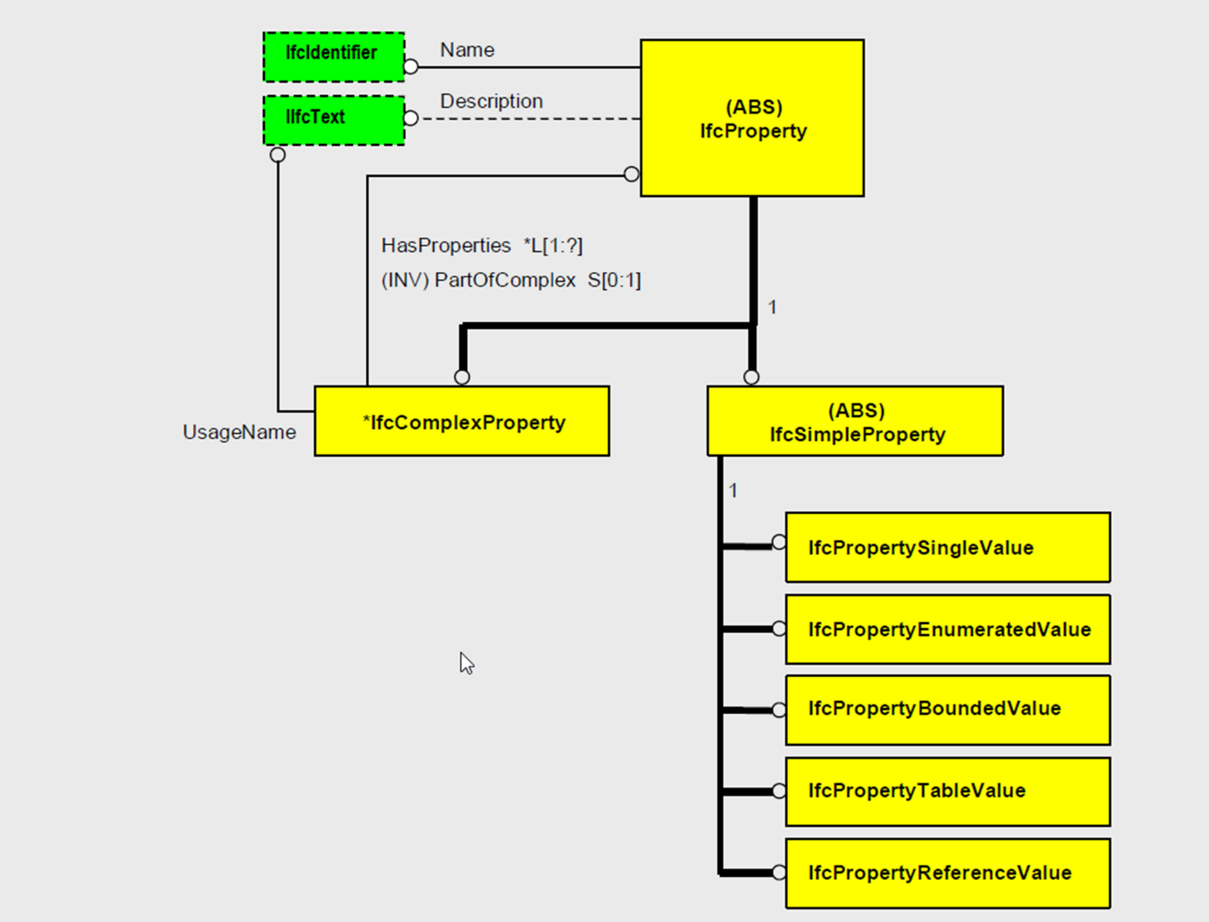

Fig. 8 Property Set Model [50].

A property that can have only *a single* value:

- It has either
  - ❖ a name and a value
  - ❖ a name, a value and a unit
- Provision of a unit is optional
- The value must have data type
  - ❖ The data type is defined in the IfcValue SELECT Type
- The unit must have unit type
  - ❖ The unit type is defined in the IfcUnit SELECT Type.

A property that has *two* values:

- an upper limit (the UpperBoundValue attribute)
- a lower limit (the LowerBoundValue attribute)
- Data type and unit type must be defined as for IfcPropertySingleValue

A property that can have *multiple* values as a list:

- The order in which the values are given is significant
- But the semantics of the values is not specified
- Selection of the values is from a predefined list.

A property that allows reference to objects whose structure is defined within the formal (EXPRESS form) IFC Object Model. Only objects at the resource layer of the IFC Object Model may be referenced.

Fig. 9 shows the basic Property Set in Use.

Property sets can be created with a simple spreadsheet application, can create multiple property sets as individual worksheets, contains a function to automatically generate XML display code on completion, display generated using a style sheet.

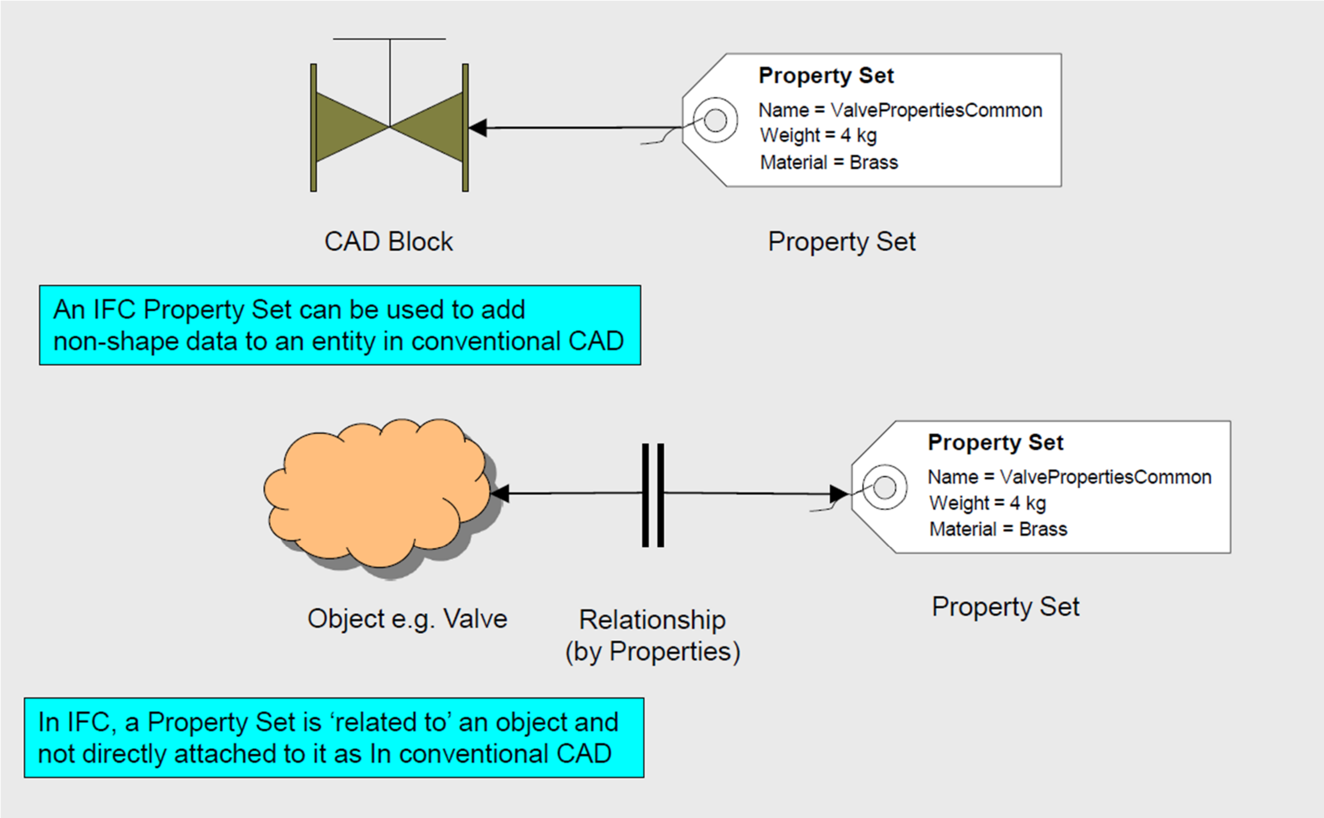

Fig. 9 Basic Property Set Use [50].

3 Methodology of bridge modelling

3.1 Overview of developed models

The first bridge model (Case 1) was modelled in the following steps:

1. **Alignment.** The Corridor Report (represented in Excel file) was read with the help of Dynamo script and then imported in Revit family to obtain the road alignment.

2. **Superstructure.** Superstructure elements were created as profiles in a generic family template. Based on the created spline element the road was generated. Using "*Divide Path*" and "*Repeat*" functions, deck profiles were distributed along the curve. Then using "*Create a Form*" one solid superstructure was shaped.

3. **Substructure.** Support elements with a parametric geometry were created and written Dynamo code simplified their distribution and rotation. Possibility to set different heights to the piers is given by another Dynamo script. Abutment walls are represented by a simple generic model with an opportunity to adapt its shape to the deck's profile.

The second model (Case 2) modeling workflow:

1. **Superstructure.** The Cable-stayed bridge created in this project has a straight trajectory. The road was modeled by the *"Extrusion"* tool with a possibility to change its length. The main beam comprises girders in the shape of a hollow box.
2. **Tower.** The tower serves as a compression element in this model. A front contour was created first, afterward using *"Create Form"* function solid and void elements were extruded, thickness is also might be changed manually after uploading the tower into the project.
3. **Cables.** Cable element modeled as a cylinder with adaptive points at the beginning and at the end, so its length can vary depending on a distance between those two

points. To distribute the cables with a certain distance between them there Dynamo script was written.

4. **Railings.** The railings are based on adaptive component family type as well, and with the help of *"Repeat"* function, they can be copied depending on the road length.

3.2 Case 1. Bridge by the alignment.

Roadways and bridges must adapt to the existing and developed environment through which they pass while balancing the needs for safety and cost effectiveness. As a result, roadways are not always flat and straight – they maintain vertical and horizontal curves in their alignments to circumvent or be compatible with existing constraints.

3.2.1 Special features of modeling bridge by the alignment in Revit.

A balanced roadway design is shaped by following requirements to the horizontal and vertical alignments:

- Existing environmental and other constraints should be identified on the base mapping to assist the designer in minimizing impacts to wetlands, historical and archaeological features, private and protected property, and permanent structures.
- For improvements to existing roadways, geometry should be concentric with and/or parallel to the existing roadway layout so that new impacts to the surrounding area are minimized.
- Horizontal alignment should be as smooth and as direct as possible while responsive to the topography. Flatter curvature with shorter tangents is generally preferable to sharp curves connected by long tangents. Angle points should be avoided.
- Curves with small deflection angles (5 degrees or less) should be long enough to avoid the appearance of a kink. Curves should be 500 feet long for a central angle of 5 degrees and increased 100 feet for each degree decrease in central angle.
- Abrupt reversals in alignment and sharp curvature on long, high fills should be avoided.

- Horizontal curves should be avoided on bridges whenever possible. These cause design, construction, and operational problems. Where a curve is necessary on a bridge, a simple curve should be used on the bridge and any curvature or superelevation transitions placed on the approaching roadway [10].

Due to the reason that Revit is assigned mainly to develop projects in AEC field, the only possibility to obtain a bridge alignment curve is to create a road path inside the *Family* file template. Effectuation of this is possible by the use of "Curve through the points" function. In this case, "points" are curve coordinates and due to the parametric dependencies built in Revit, it is possible to set them directly inside the family file.

Fig. 10 illustrates the curve, further developed into the road. First, 5 adaptive points were created, offsets from OX and OY axis were given manually and the second curve was generated by translating the first one. Afterwards, *"Spline Through Points"* command applied, then the reference lines extruded to get the roadway. Using adaptive points means, that it is possible to upload this element into any project, choosing the position of every point (X,Y offsets are defined as instance parameters, so they are flexible from one project to another) depending on required length and curvature.

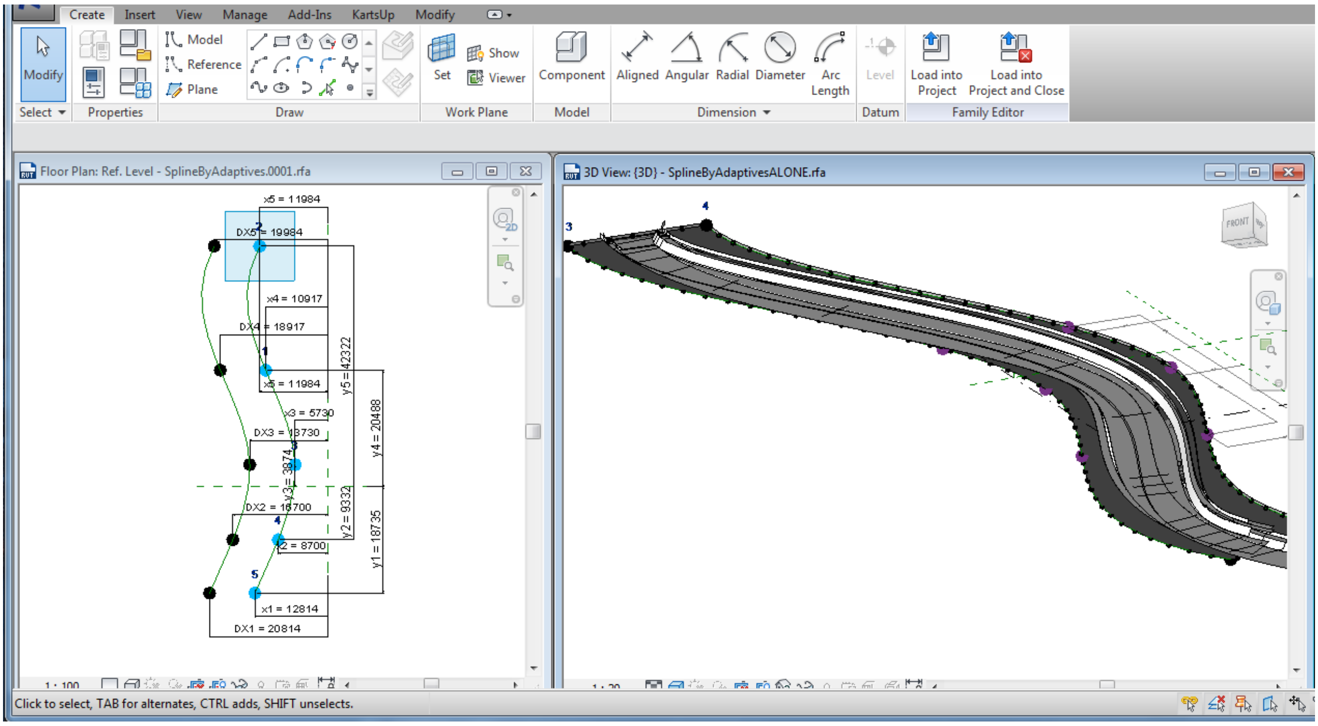

Fig. 10 Creation of spline manually using the *Adaptive components* .

The next step is to distribute the deck profiles and loft them together into the one solid component. For this purpose a Dynamo Code was created: it divides the chosen curve by the number of points, distributes the profiles (which are also made as an *Adaptive Component Family* elements with a possibility to set an offset from roadway edges) along the spline and creates one solid element.

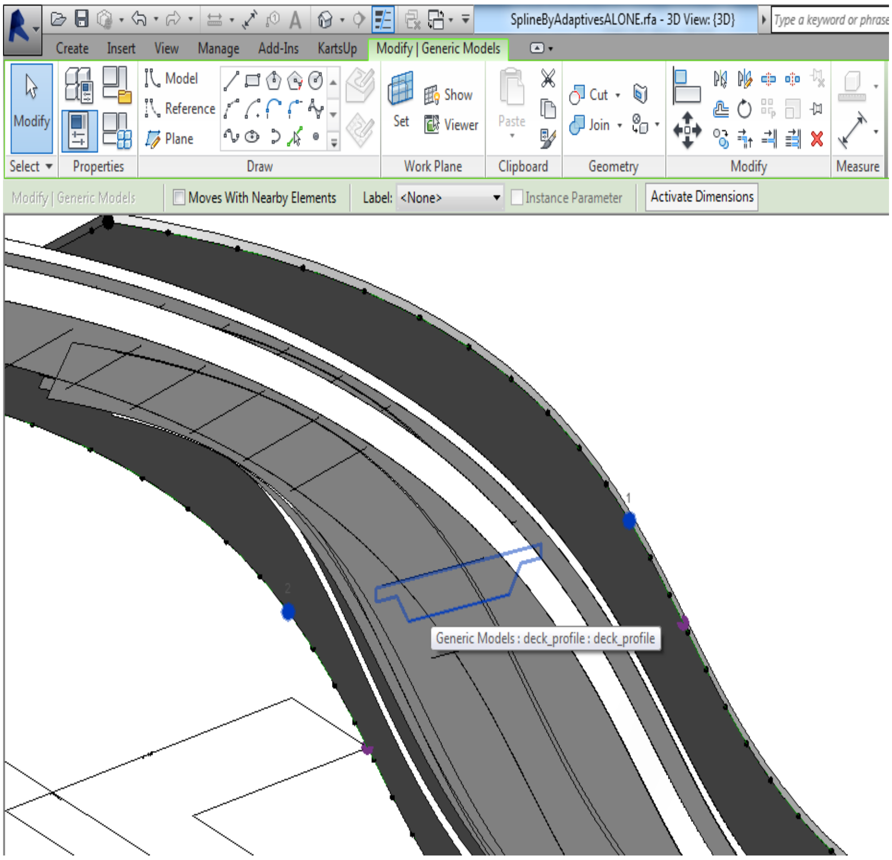

Fig. 11 Deck profiles arrangement by *"divided path".*

However, used Dynamo nodes are not able to create a proper solid family instance and the result has some imperfections (see Fig. 12). In addition, created element is not defined by any of Revit components and represented like "Import Symbol", that is to say, cannot be edited nor post developed (for example, introduce the reinforcement) and inherits the minimum of data.

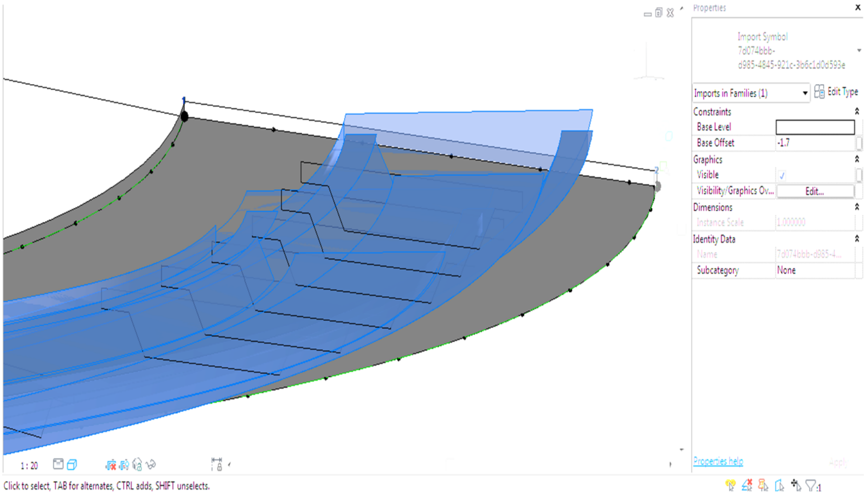

Fig. 12 Lofted solid element.

Another option is to connect Revit with AutoCAD Civil3D - software application used by civil engineers and other professionals to plan, design, and manage civil engineering projects. Civil 3D is used to create three-dimensional (3D) models of land, water, or transportation features while maintaining dynamic relationships to source data such as grading objects, breaklines, contours, and corridors.

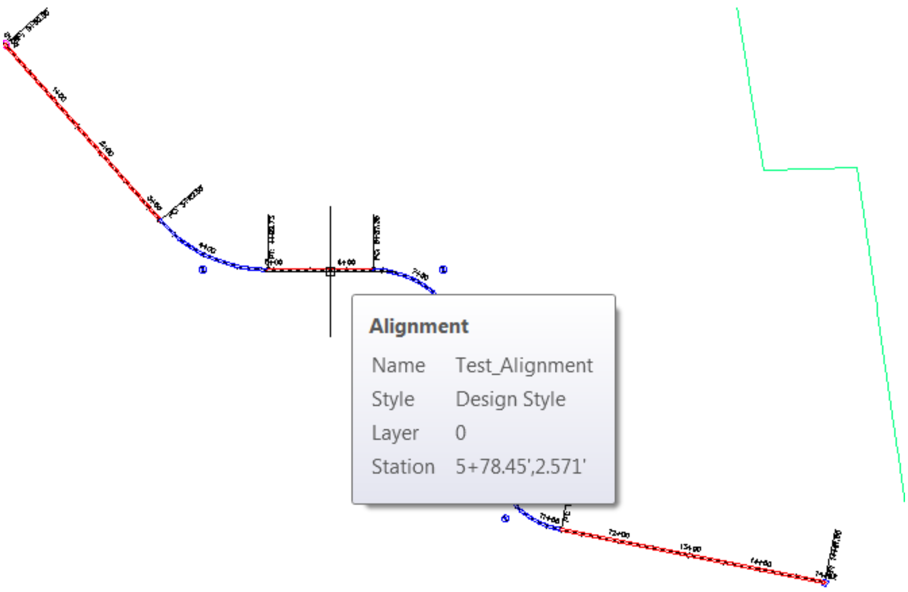

Fig. 13 Alignment element in Civil 3D [49].

Civil 3D includes a function such as an export of Corridor Points in Excel file, in current project this option was further used to create an alignment with the help of Dynamo Revit. As a result, the obtained road spline is more precisely defined.

3.2.2 Modeling procedure:

Importation from Civil 3D was chosen as one of the ways to set the alignment trajectory in this case study. With the help of this software, we can generate a file in Excel format with all the X, Y, Z coordinates of a certain line considering the horizontal curvature and vertical elevation. Since there is no connection between Civil 3D/Excel to read the coordinates and draw this curve Revit in neither the "Project" nor in "Family“ type, Dynamo is a necessary software to meet this challenge.

The first step is to read the Coordinate report from Civil 3D, for which there are nodes already created in Dynamo.

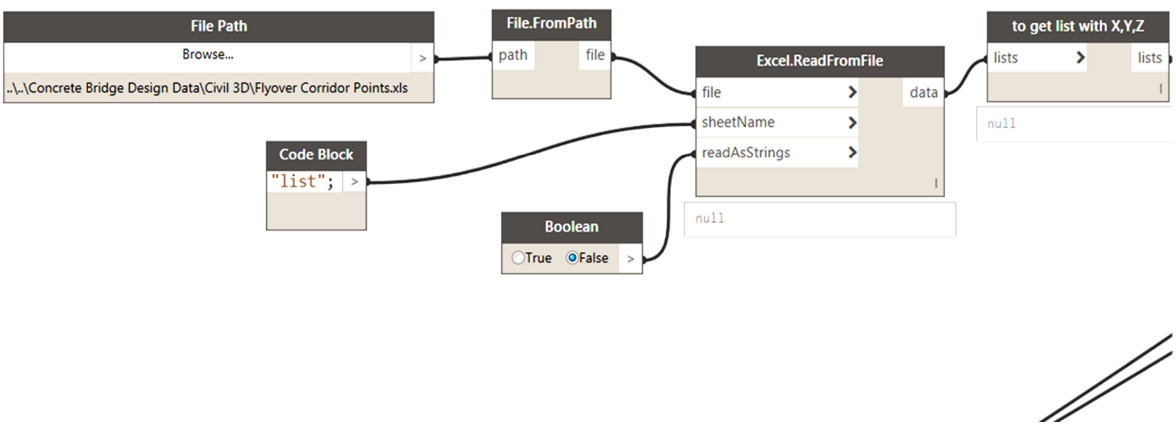

Fig. 14 Reading data from Excel file with Dynamo

Afterwards, with the help of nodes creating reference elements (by the points read from Excel file), the curve will be generated as Revit "Other" component type.

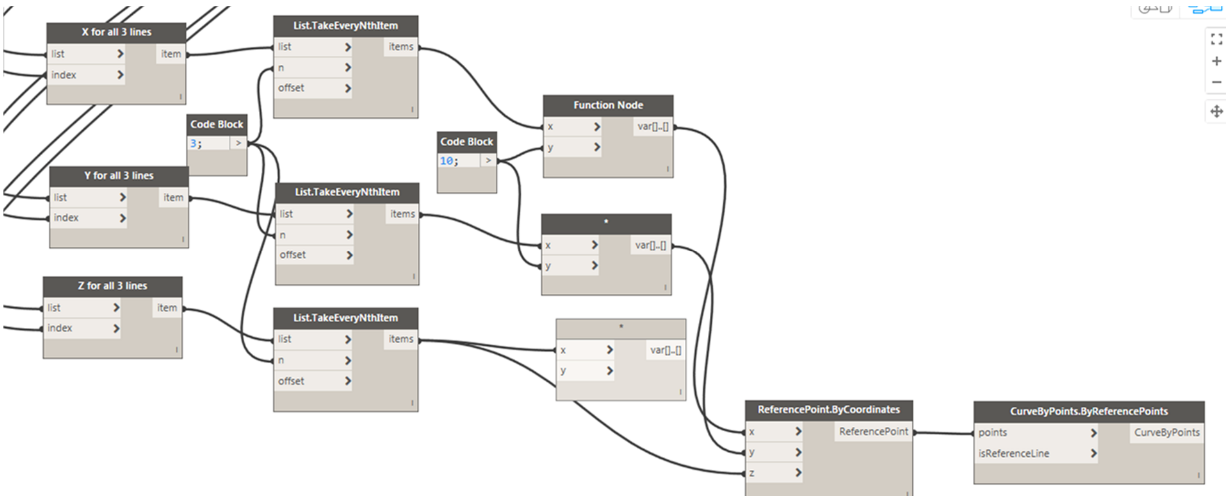

Fig. 15 Creating a Curve by Reference Points.

Having this curve gives an opportunity to use "Divide Path" and "Repeat" functions to distribute the profiles along the line. Therefore, using adaptive components is reasonable. Distributed profiles can be easily lofted in a solid element with the use of the "Create Form" function.

Thereafter, the bridge deck initially created as a profile with parameters to change as the width of the lane and other geometry dimensions composes a template.

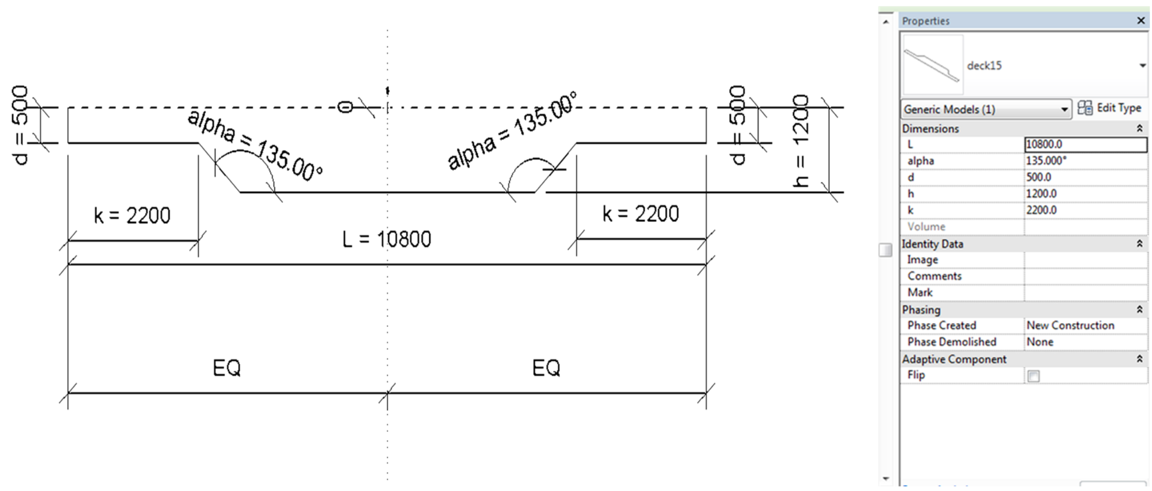

Fig. 16 Deck profile and its parameters

The same technique is used for the creation of auxiliary components like railings or parapets (illustrated on Fig. 17 and Fig. 18). In this case capabilities of Revit are enough to adapt the elements to the curvature.

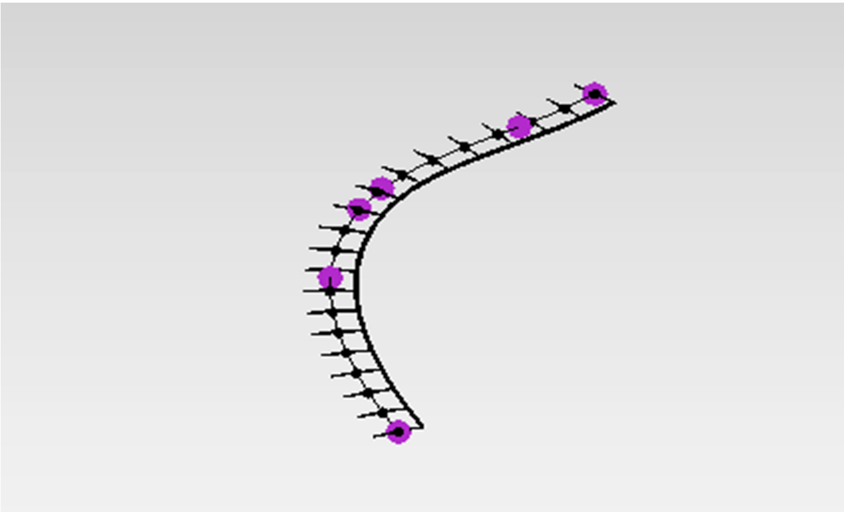

Fig. 17 Distributed deck profiles along the alignment.

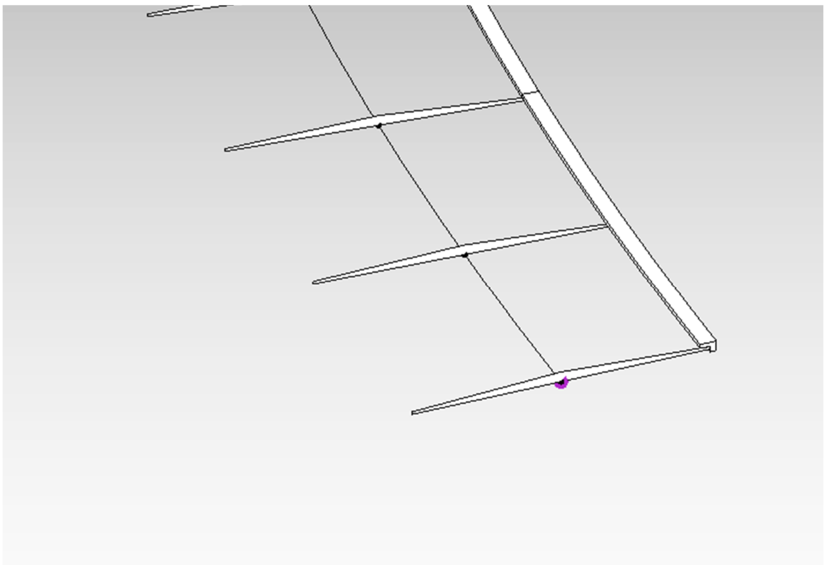

Fig. 18 Creating parapets.

According to this methodology, any horizontal bridge component that has an axis parallel to the alignment (girders, railings, sidewalk, pavement) could be modeled as a new family type and contain necessary parameters.

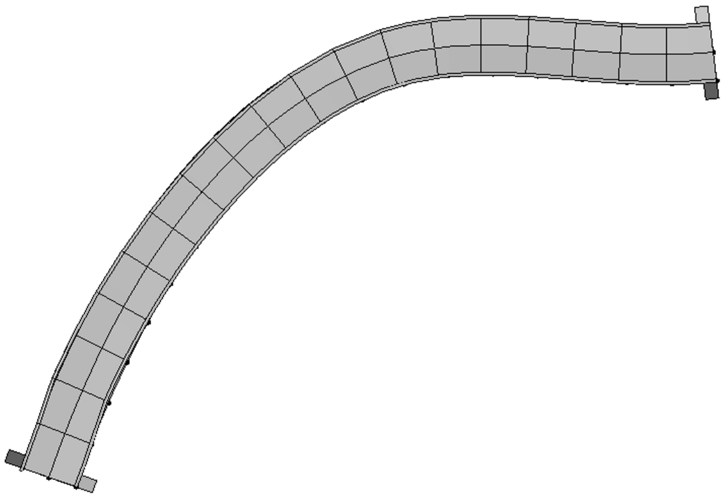

Fig. 19 View from above at the lofted deck.

Those elements are possible to represent as separate families and load into the project one by one or create one massive family containing all the auxiliary elements.

The next step is the creation of substructure elements, represented by hammerhead piers (also based on an adaptive family template) with the parametric geometry.

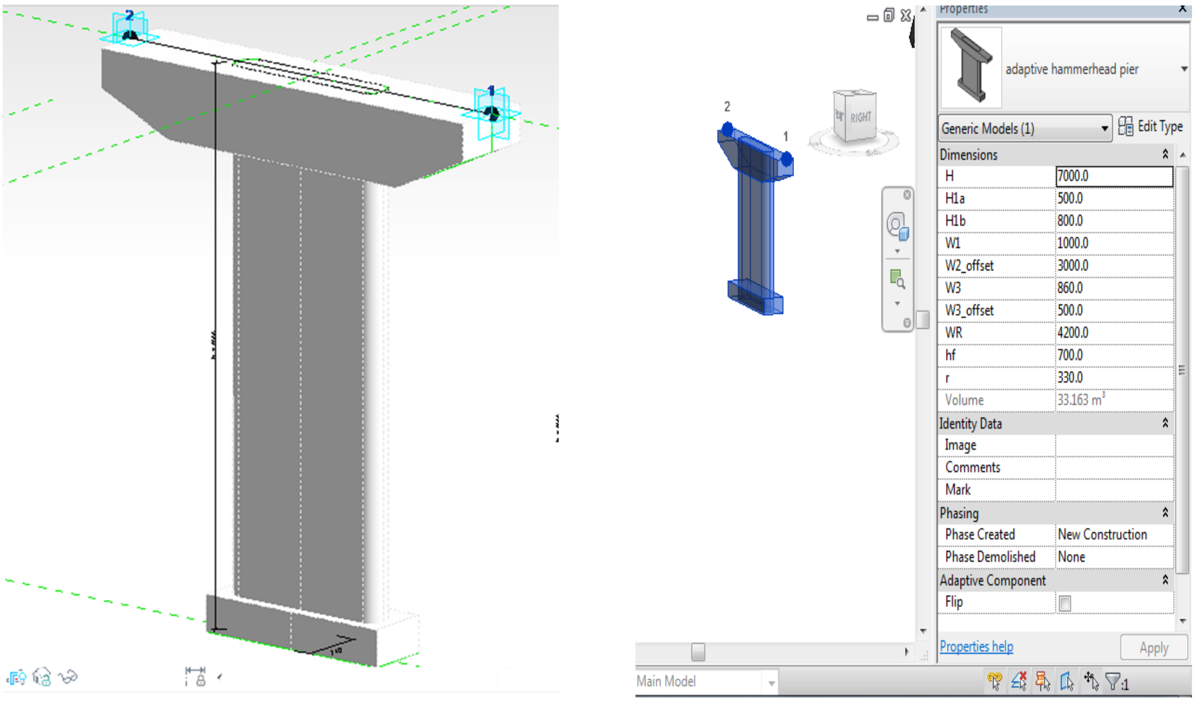

Fig. 20 Hammerhead Pier Family instance by adaptive components family and its parameters.

For the case of a straight-line bridge trajectory, there is no problem with distributing piers or other elements along the road. But since we consider a curved path, the placement of each element and then rotating it would be a time-consuming task. To handle these difficulties a Dynamo code was written, solving the following tasks (Fig. 22):

- number of piers required ;
- aligning of each instance to the plane, perpendicular to the curve at each point;
- consideration of abutment walls placement;

Thus, the distribution of elements along the curve turned into a quick and optimized process. Before running the code it has to be checked if the family instance is already downloaded into the project.

The construction of long span bridges implies to build the structure over the terrain presented by an inconstant ground level, therefore the height of supporting elements may vary. A case study illustrating that is the Longju Bridge which has one of the longest spans in China. The central section alone covers some 220 meters at the height 193 meters (see Fig. 21).

To implement piers with different dimensions, each instance has to be edited manually.

As a solution, there another Dynamo code was developed, which reads the data from a geology profile report of the terrain and assigns the heights according to the depth needed (Fig. 23).

Fig. 21 The Longju Bridge Modaoxi River Canyon, China. [Ошибка! Источник ссылки не найден.]

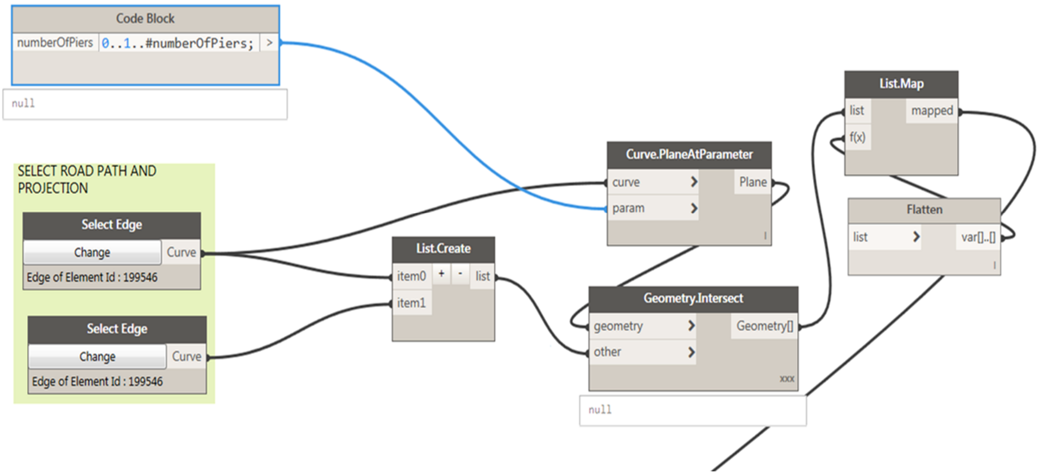

Fig. 22 Dynamo code fragment for creating piers.

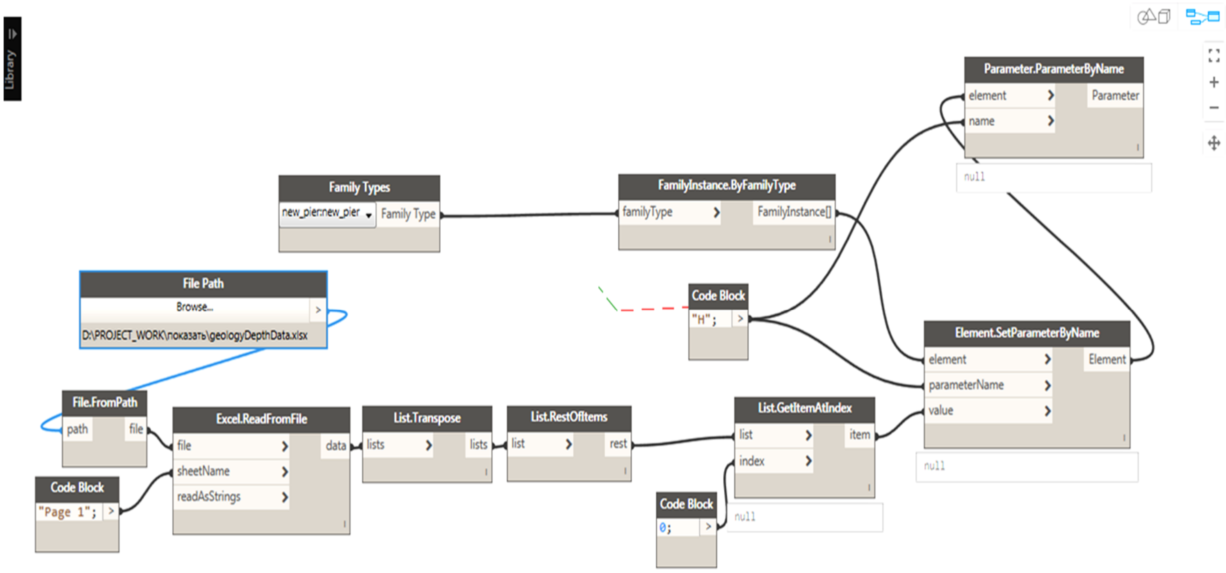

Fig. 23 Dynamo code element to read Excel report and assign different height to each pier.

As a result, we have our support elements with a parametric geometry, adapting to the relief and alignment (Fig. 24).

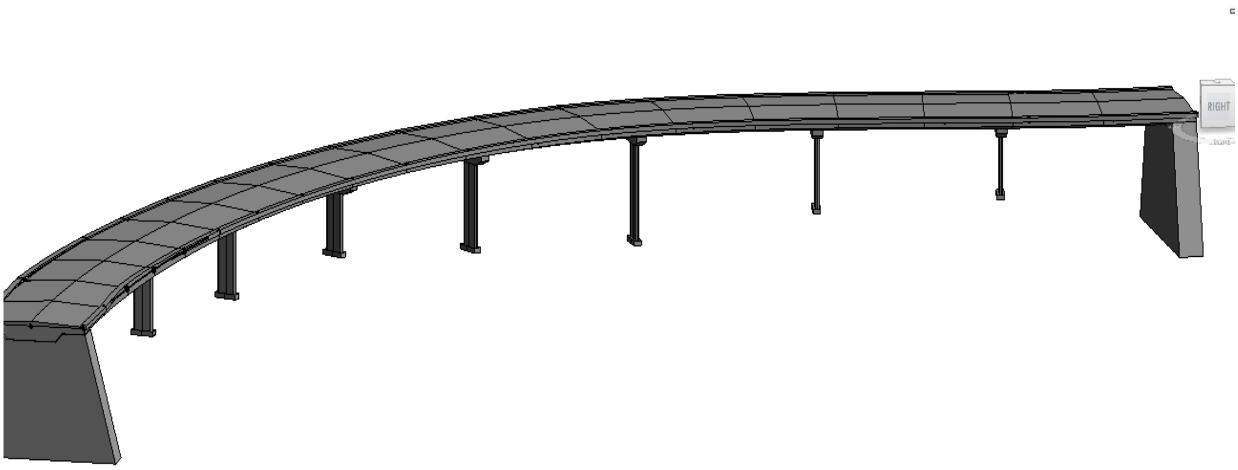

Fig. 24 Final view after the placement of the support elements and their edit.

3.3 Case 2. Cable-stayed bridge.

As a second model, a cable-stayed bridge was chosen. By definition, a cable-stayed bridge has one or more towers (or pylons), from which cables support the bridge deck. Distinctive features are the cables which run directly from the tower to the deck, normally forming a fan-like pattern or a series of parallel lines. The cable-stayed bridge is optimal for spans longer than cantilever bridges and shorter than suspension bridges [4].

3.3.1 Modelling procedure.

The earliest cable-stayed bridges have an orthotropic deck, mainly because the long span bridges were usually built by steel companies. It was considered economical to use composite slabs for spans up to about 250m. Developments in concrete technology allow higher grade strengths to be used. This development, combined with the increased cost of steel, has seen longer composite deck spans being used economically. A box girder is formed when two web plates are joined by a common flange at both the top and the bottom. The closed cell which is formed has a much greater torsional stiffness and strength than an open section and it is this feature the usual reason for choosing a box girder configuration. Spans in excess of 600m are now being built using a steel-concrete composite box girder construction [3].

For this bridge model, two different types of the box's configuration were chosen and created. By downloading both (or more) types of decks into the project, it is easy to generate different types of structure (Fig. 25). Considering that these *family* instances are based on a profile with parametrically driven geometry, different bridge variations might be yield.

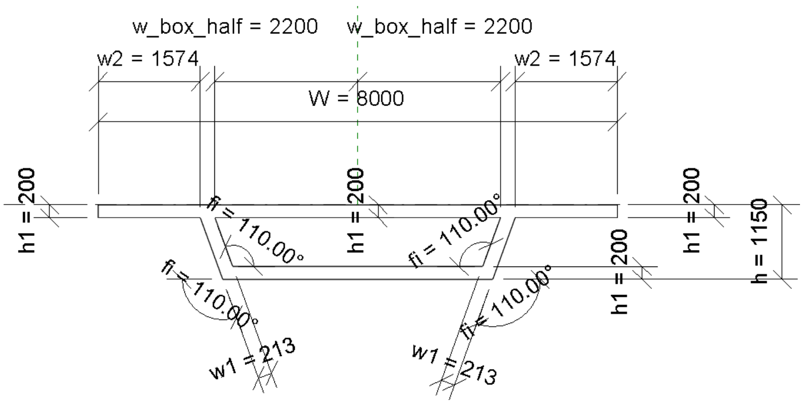

Fig. 25 Box girder profile

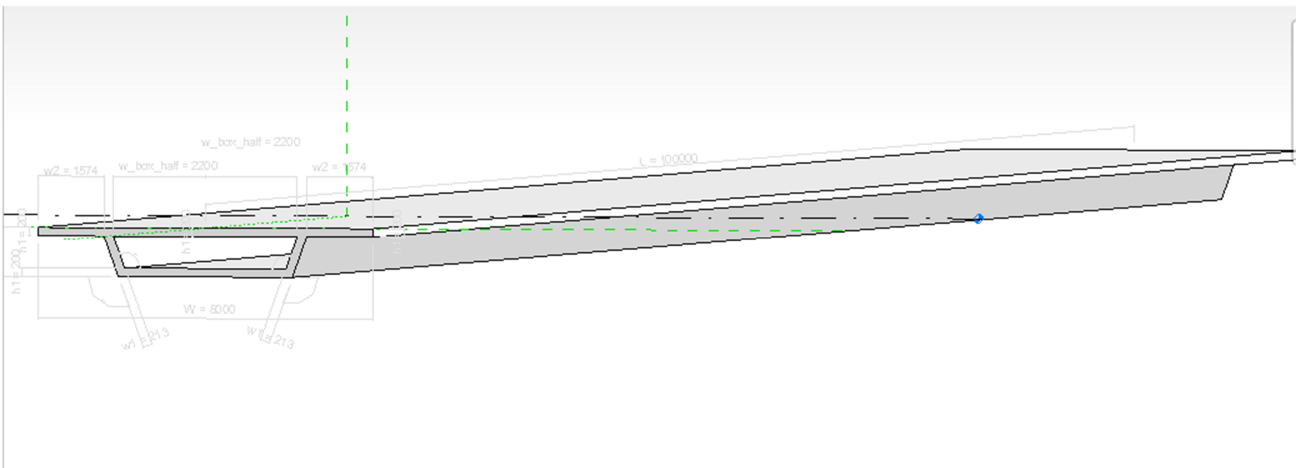

Fig. 26 Extruded box girder.

To create a box girder first the parametric cross section should be created and then by using the "*Create Form*" command the whole deck will be extruded. Here we can also control the length of the deck by assigning "*L*" parameter and Revit presents an opportunity to set dimensions dependent on each other. However, the extrusion operation gets more complicated, if the girder has more cells, due to the repeated "*Create void form*" process.

As a shortcut a Dynamo custom node was created, which sets dependency between solid and void offsets (positive or negative): when the solid's offset value is changed, the same parameter for the void element changes automatically (Fig. 28. Solid and void parts of the girder family instanceFig. 28).

Note: Custom Nodes are constructed by nesting other nodes and custom nodes inside of a "Dynamo Custom Node," which we can think of conceptually as a container. When this container node is executed in your graph, everything inside it will be executed to allow you to reuse and share a useful combination of nodes [7].

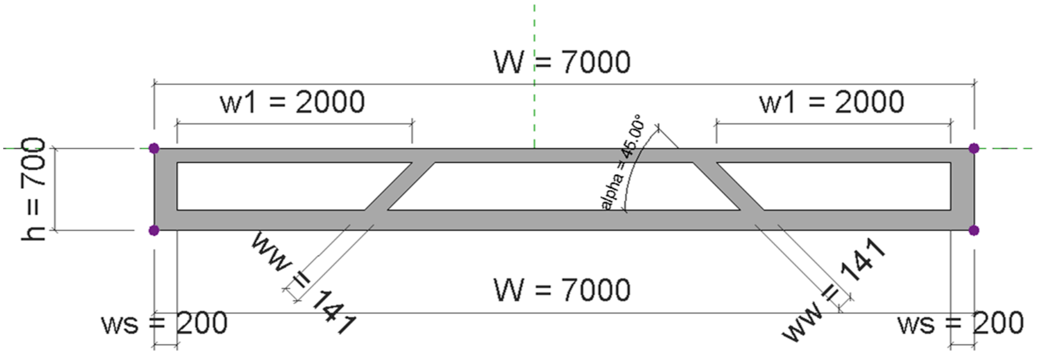

Fig. 27 Cell box girder with inclined struts.

The geometry parameters of profile might be also dependent on each other. That makes possible to use the same *deck family* file in multiple projects.

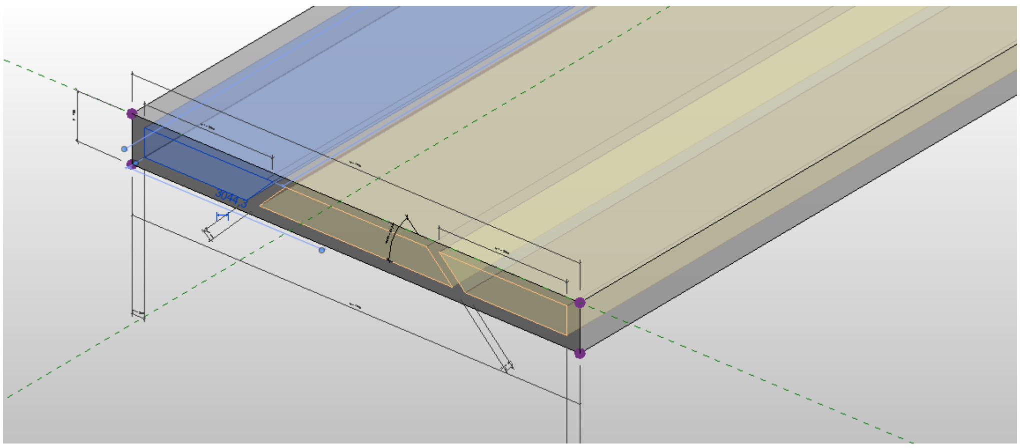

Fig. 28. Solid and void parts of the girder family instance.

Thus, the process of creating a *family* instance containing a lot of void elements is now optimized by means of Dynamo custom node, which we can use while modeling elements such as: frames, pipes, slabs and especially metal structures (which have always been a challenge to reproduce in Revit).

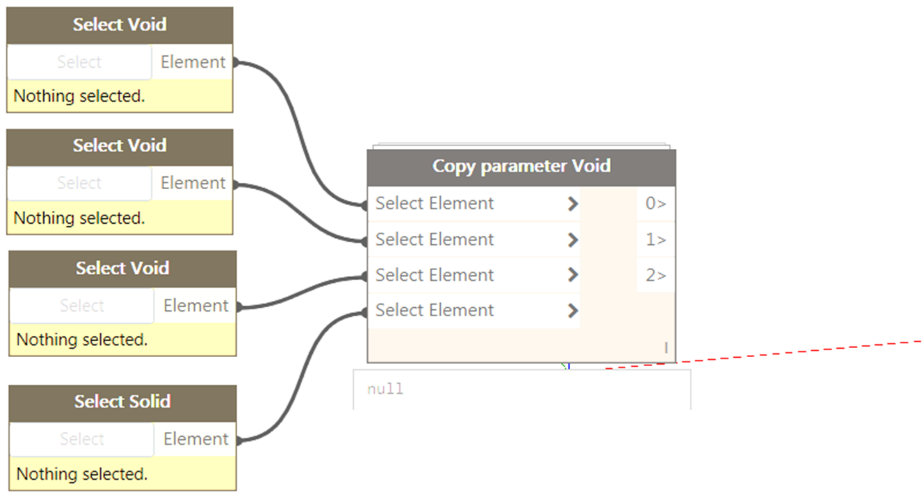

Fig. 29 "Copy Parameter Void" Custom Node in use.

To model this sample of complicated structures, components like *Cables* or *Tower* are needed and they do not exist in Revit. Therefore, new *family types* should be created.

Following procedure considers creating a bridge tower, which being a simple element could be created in a Generic Family template (Fig. 30 Bridge Tower and its geometry parameters to control..

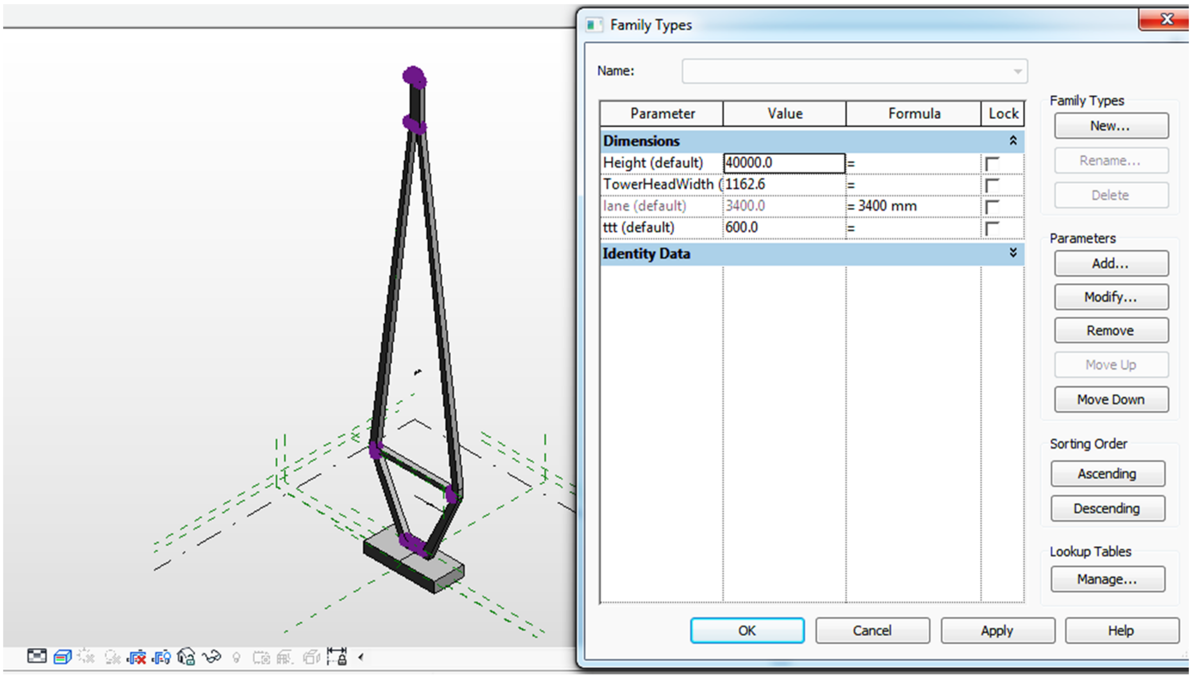

Fig. 30 Bridge Tower and its geometry parameters to control.

The best choice to represent cables is using two adaptive points (Fig. 31), one is anchored at the tower top and the other one attached to the deck. After preliminary design and calculations, the angle of the first cable row in relation to the horizon is known, as well as diameter and distance between the cables.

At first glance, the distribution of cables seems to be another time-consuming task, especially if during the design process geometry parameters change – forcing the user to reattach cables, calculate new offsets due to the reason that cable itself is not built in Revit component and there are no tools and properties for a quick edit of them.

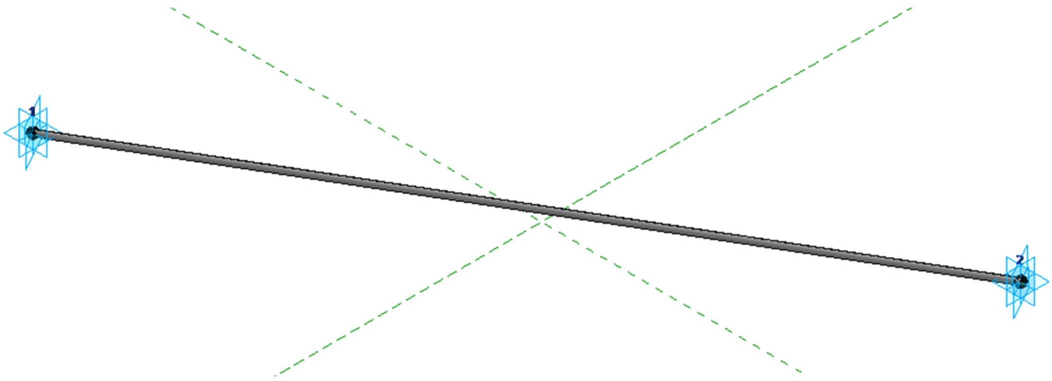

Fig. 31 Cable element created using two adaptive points .

On this basis another Dynamo script turned out to be very helpful tool due to its high capacity to operate geometry. The "Cable placement" script requires to select the tower in the model, define the exact point of anchoring center at the tower head, set the distance between the cables and the distance from the tower to the first cable row and the inclination angle for the front cables, as well as loading adaptive element to the project and then repeat the procedure for the back cable set.

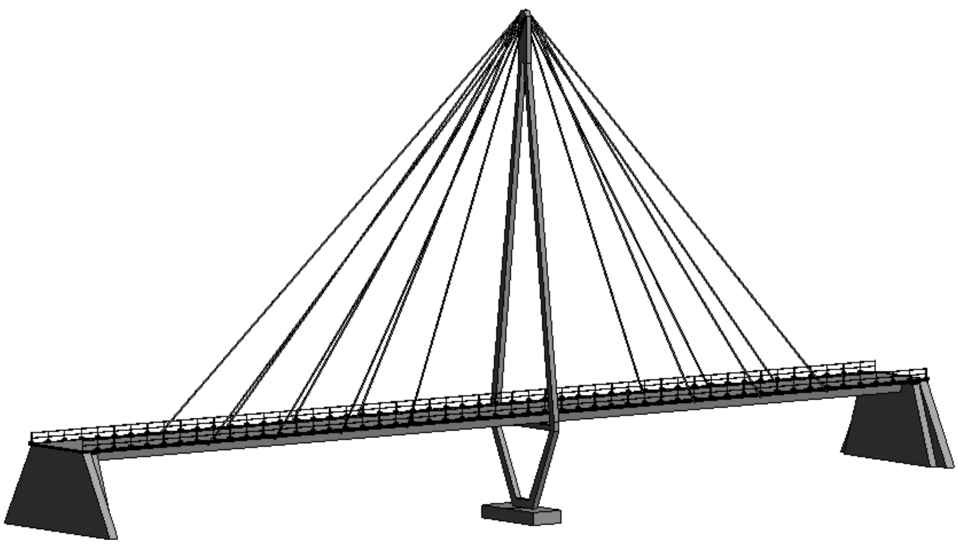

Fig. 32 Final view of bridge.

The next short Dynamo script was written to export data in Excel. For example, it is possible to give a table with a required elements' data, for example, the length and radius of the cables for further calculation of the material consumption (see Fig. 33).

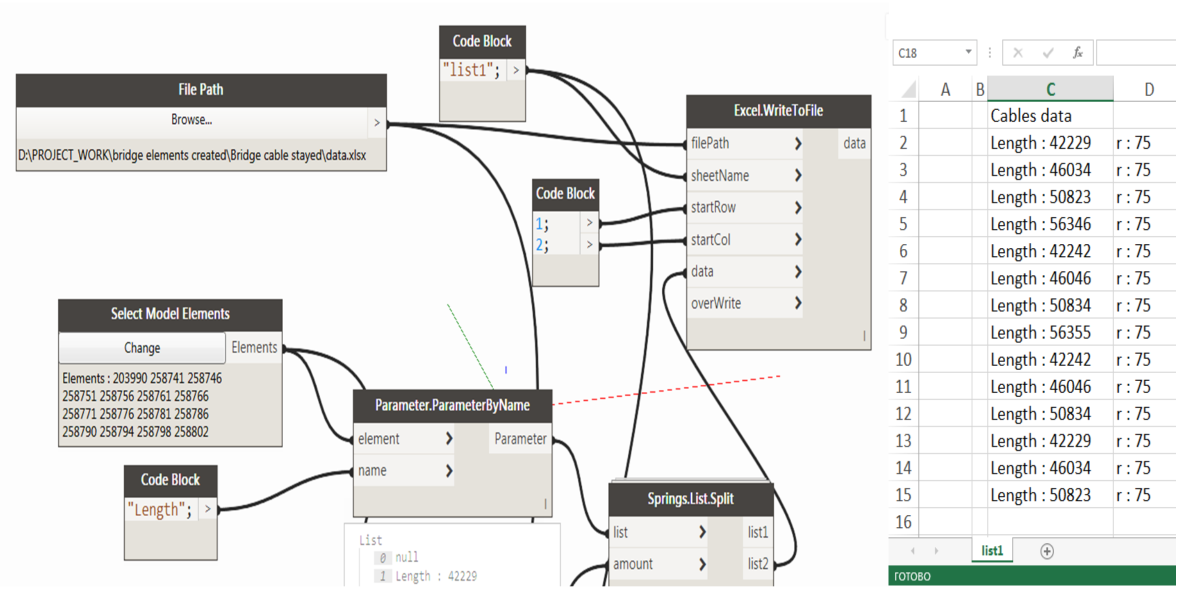

Fig. 33 Data exportation script in Dynamo and Excel Table with an exported data.

3.4 Export to IFC

Some BIM software products include the IFC export option as part of the product, some others are available as separate modules.

Revit provides a fully certified IFC importation and exportation based on buildingSMART® IFC data exchange standards. Bridge instances modeled in this work were exported from *.rvt* to IFC files for the use with an IFC-certified application that does not use the *.rvt* file format.

3.4.1 Export of the model 1

The bridge created for the case study №1 was successfully exported to the IFC format and a saved file was checked with an IFC Viewer called *BIM Vision*.

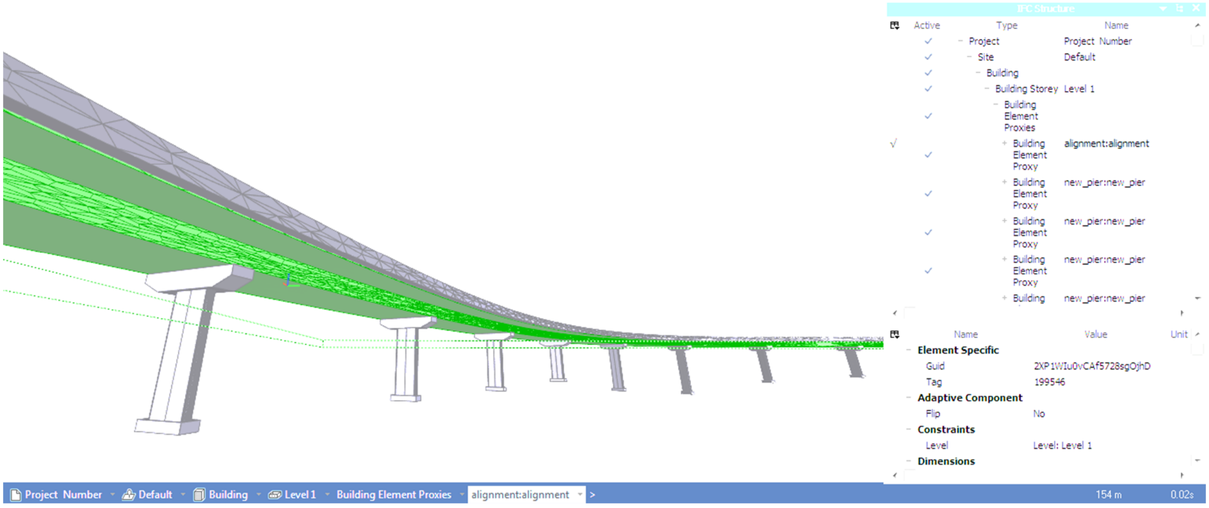

Fig. 34 Bridge for the case study №1 in IFC Viewer.

However, the same type of bridge created by another method, in which the deck was generated directly in Dynamo and then exported into the Revit project, does not appear completely in the IFC Viewer (see Fig. 36). In this case, its deck is missing.

Fig. 35 Bridge for the case №1 generated in Dynamo and exported in Revit project file.

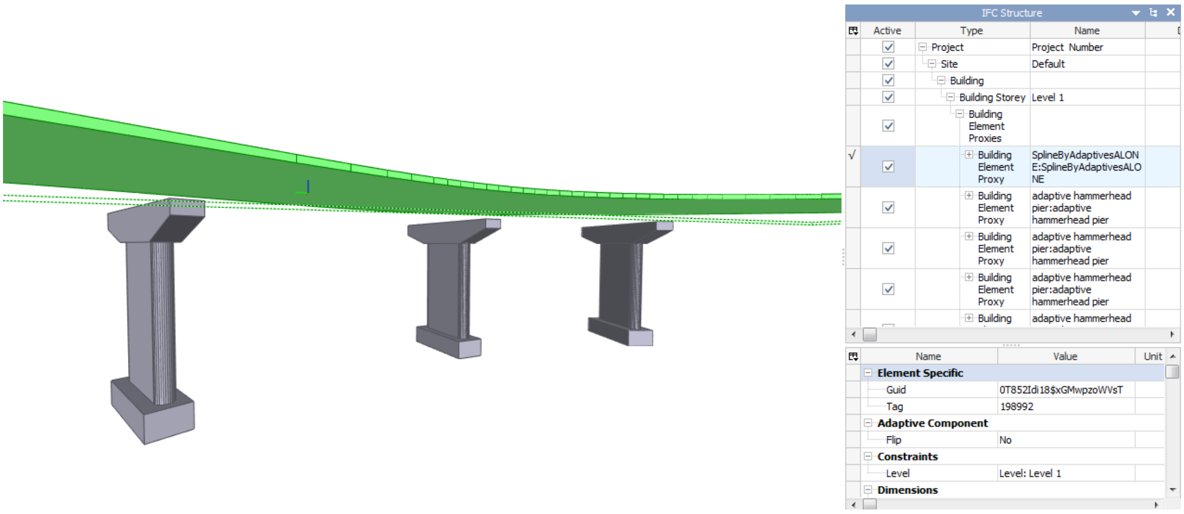

Fig. 36 Bridge for the case №1 generated in Dynamo and opened in IFC Viewer.

As a conclusion, it is not recommended to loft the 3D shapes in the current version of Dynamo due to the lack of data in its IFC representation.

3.4.2 Export of the model 2

Exportation of the second bridge case showed, that the developed model inherits all the necessary data in IFC data format.

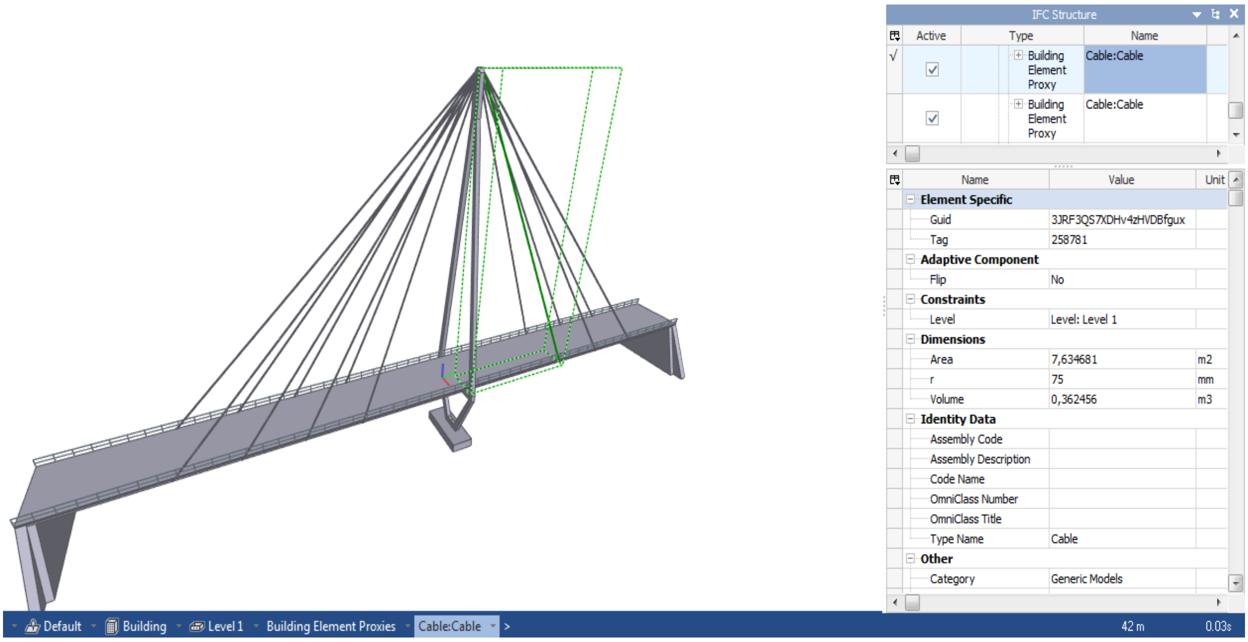

Fig. 37 Bridge for the case №2 generated in Dynamo and exported in Revit project file.

4 Conclusions

In this project work the existing BIM-based methods and necessary software for the creation of parametric bridge models were analyzed and their capacities were discussed. Two different bridge models were developed. Due to the structural or geometry features the design process of them has special issues, which makes design a very time-consuming process or impossible to execute using only Revit software. With the help of visual programming language, those problems were solved, written scripts are possible to modify further to apply to the other types of bridges. Since Revit by its own cannot be used for all the conceptual, design and management phases of the bridge construction, other different software are usually implemented, and the Dynamo add-in gives an opportunity to extend the data import into Revit through reading the Excel files.

However, solid forms which were created only using Dynamo are not amenable to further changes and not visible in IFC Viewer. Therefore, it is preferable to use visual programming as an auxiliary tool to improve already existing modelling tools in Revit, rather than use surfaces and shapes lofted through Dynamo for the extra data enrichment.

The method developed in this work to create the alignment allows building a curved line and then using it as a basis for the superstructure creation, so there is no following change of radius or arc length considered. In case of the cable-stayed bridge, following by straight trajectory, it is possible to adjust the length, lane width, and deck thickness at any moment.

The future work is an advancement of the script for alignment generation, extension of Revit's capabilities to develop reinforcing of the bridge structures and the creation of more data-rich elements for the further use in IFC format.

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6 Appendix

6.1 Dynamo codes

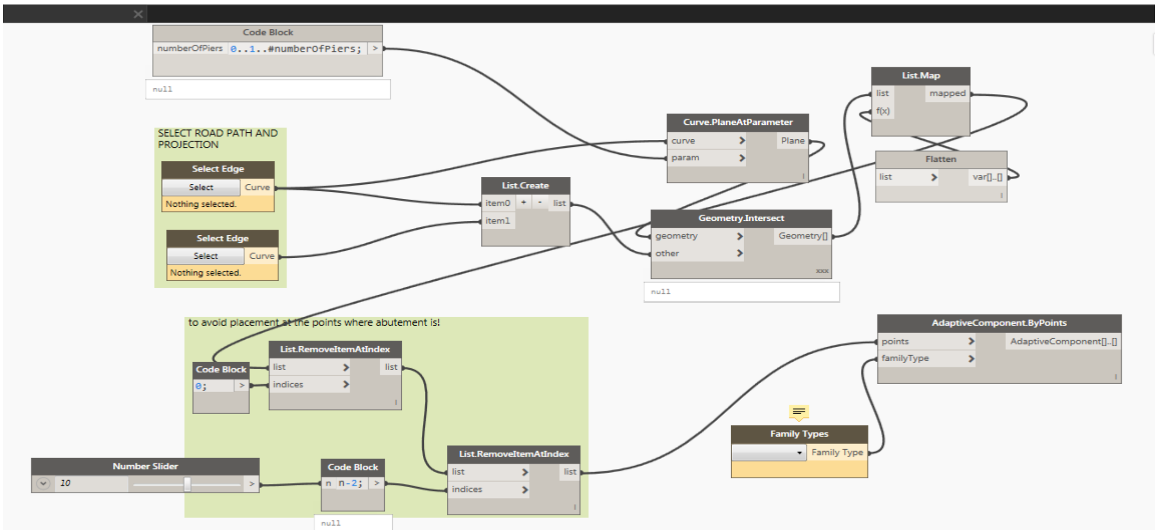

Fig. 38 Script to distribute the piers, Case 1.

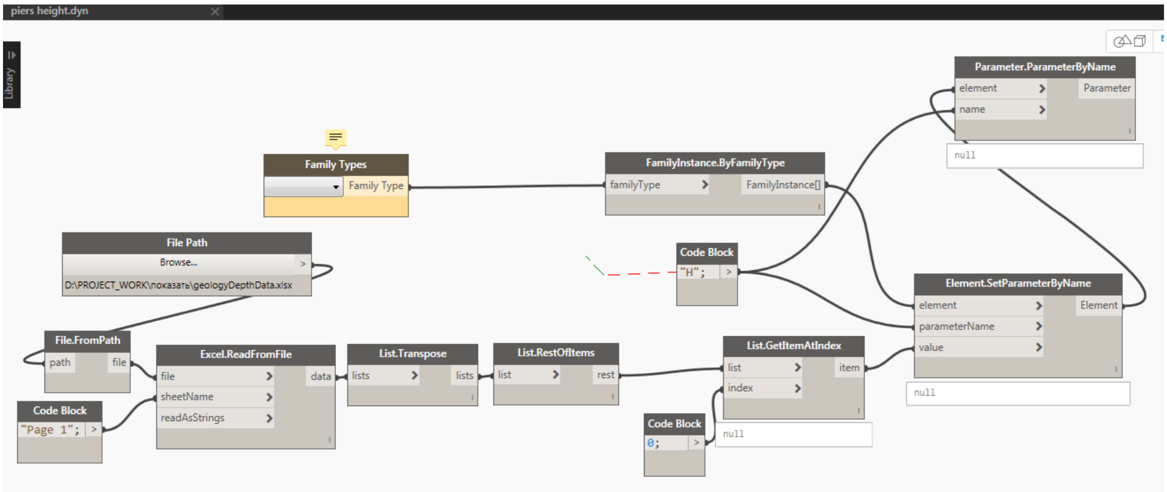

Fig. 39 Script changing the Pier's height, Case 1.

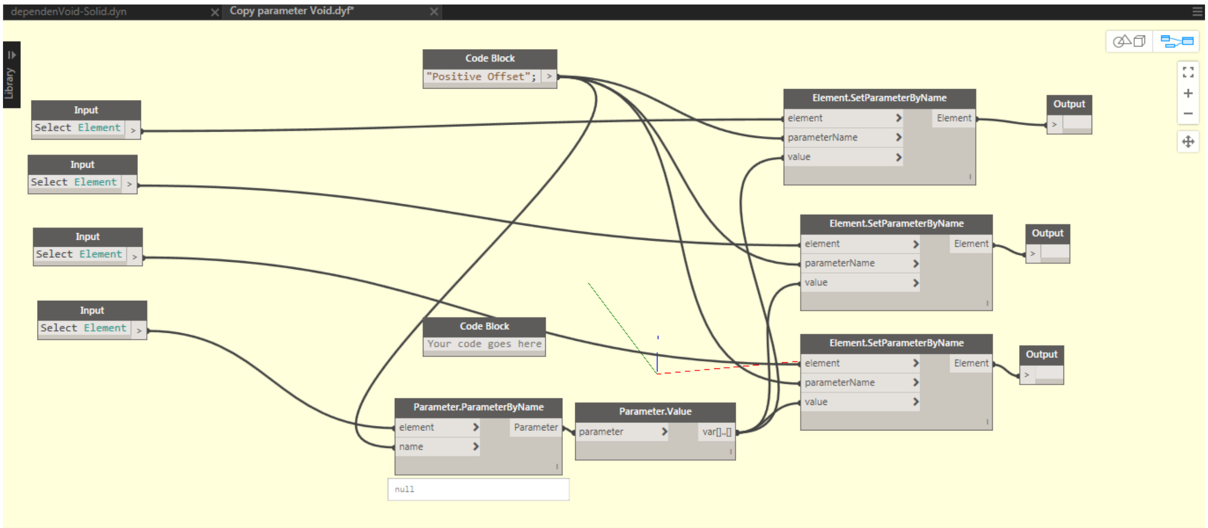

Fig. 40 Code for the Custom Node to simplify modeling of void-solid shapes, Case 2.

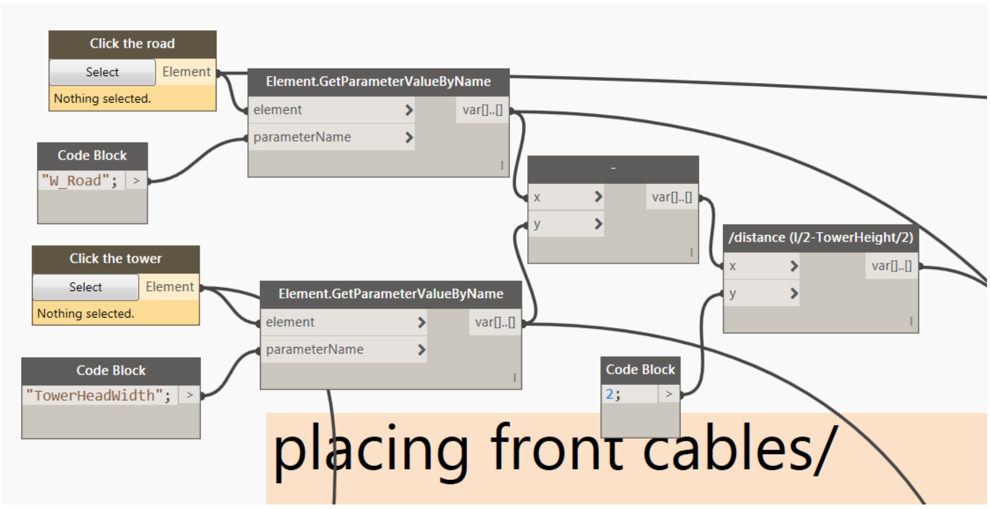

Fig. 41 Part of the code to place the cables, Case 2.

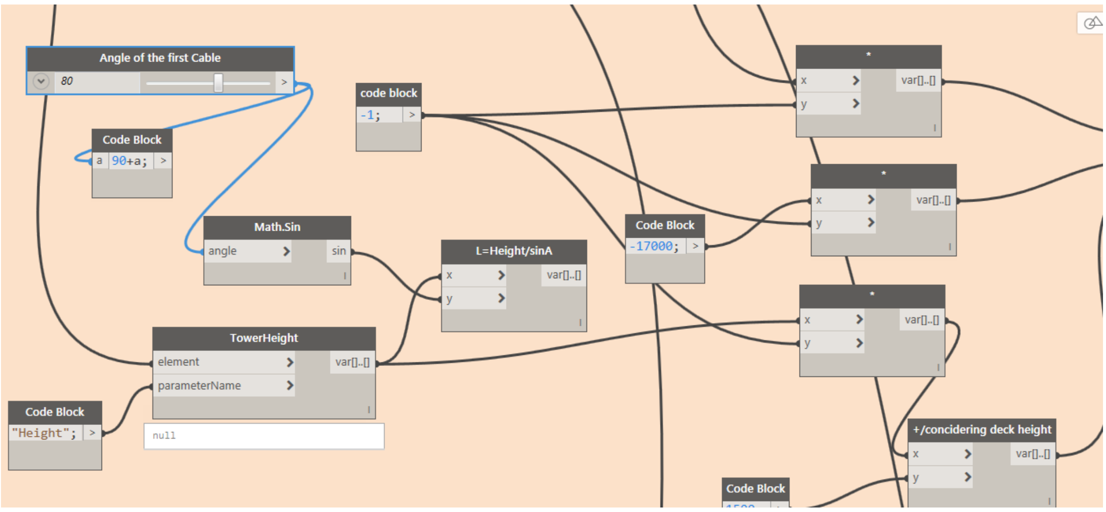

Fig. 42 Part of the code to place the cables, Case 2.

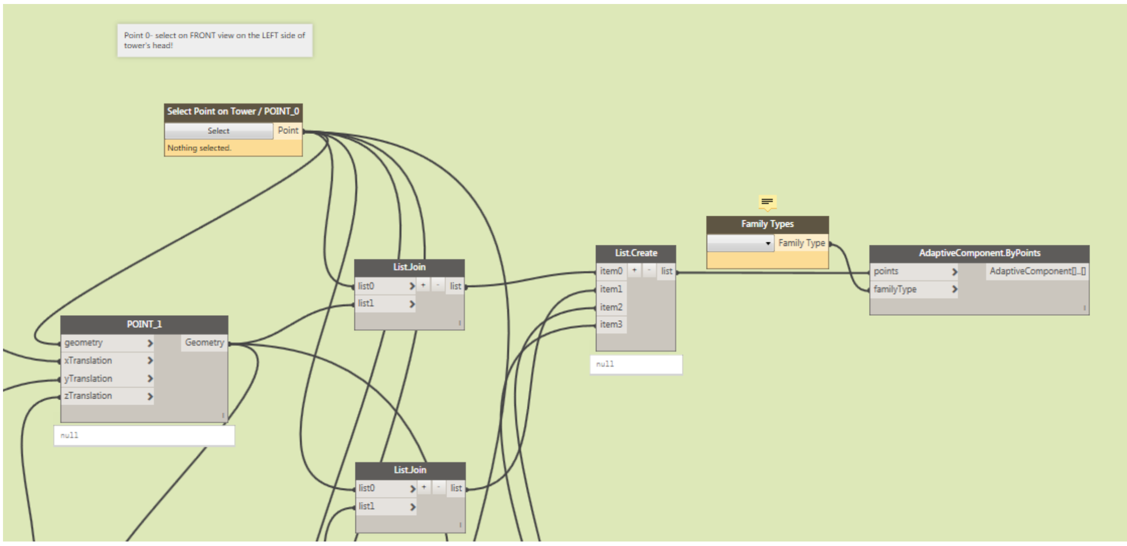

Fig. 43 Part of the code to place the cables, Case 2.