TECHNISCHE UNIVERSITÄT DRESDEN

Faculty of Civil Engineering

Institute of Construction Informatics

TU Dresden, Germany

MASTER THESIS

Applying graphical programming methods for parametric bridge modelling and generation of model variations

Anwenden von grafischen Programmiermethoden für die parametrische Brücken Modellierung und Generierung von Modellvarianten

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Dresden

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Declaration of originality

I confirm that this assignment is my own work and that I have not sought or used inadmissible help of third parties to produce this work. I have fully referenced and used inverted commas for all text directly quoted from a source. Any indirect quotations have been duly marked as such.

The 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

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Definition of the Master's Thesis

For Mohammad Saiful Abedin, Master's study program ACCESS, matriculation no.4023371

Topic:

Applying graphical programming methods for parametric bridge modelling and generation of model variations

(German: Anwenden von grafischen Programmiermethoden für die parametrische Brücken Modellierung und Generierung von Modellvarianten)

Traditional design process for Bridge models needs a large number of repetitive design processes which affects the overall project implementation time and becomes a technical challenge for the engineers. The application of graphical programming methods can be used for automated repetitive design process and generation of model variations for bridge models especially in the primary design phase. The main objective of this thesis is the developing of a method and tools for parameterized bridges modelling through graphical programming approach and parametric components of bridge.

Objective:

1. Development of a methodology for generating parametric bridge models based on the graphical programming.
2. Semantic enrichment of bridge models based on IFC standards, multimodel method

Specific tasks:

1. Analysis the state of art in applying BIM methods and available tools for bridge design
2. Prototype implementation using Dynamo, Revit and Excel for parameter inputs
3. Applying the method on a demonstration bridge model
4. Semantic enrichment of the demonstration bridge model (automatically in Dynamo and manually through BIM-Annotator)
5. Evaluation and demonstration of the methodology
6. Analysis and discussion of the results.

Deliverables:

- Master thesis
- Software (Dynamo scripts, Revit models, Excel files, etc.)
- Presentation after delivery
-

Day of issue: 15.05.16 Day of delivery: 15.9.16

Tutors:

TU Dresden: Dipl.-Ing. Ali Ismail MSc. Industry (hkc GmbH): Dipl.-Ing. Carsten Eichberg

Supervisor:

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Die besonderen Hinweise für die Anfertigung der Diplomarbeit des Instituts sind zu beachten.

Abstract

The design of infrastructure projects like complex bridges is challenging task for planners and engineers. The traditional design and modelling process for bridge needs a large number of repetitive design processes and a lot of manual work for each model variation or design modification. The integration of visual programming language (VPL) methods and Building Information Modelling (BIM) software enables automated repetitive design process and simplify the generation of model variations especially in the primary design phase, for example to check the design effectiveness for wind analysis.

At first literature review about the state of the art in applying BIM methods and available tools for bridge design has been described. This research focuses on the possibilities of the visual programming methods in the field of infrastructure and applying the method on demonstration of bridge models. This presents in details a workflow for geometry parameterized bridges modelling with help of VPL tools and study cases to generate bridge model variations. It gives also a brief overview about the semantic enrichment of generated models based on the IFC standard. At present IFC format is considered as interoperability solution in different software applications. And semantic data enrichment refers to the classification of model elements, assigning attributes and defining relationships between model elements.

Furthermore, the application of VPL offers a new design approach for parametric modelling and the semantic enrichment helps to make generated models interoperable in different software platform.

Keywords: Visual programming VP; Parametric bridge modelling; BIM Annotation; Semantic enrichment; Dynamo.

Kurzfassung

Infrastrukturprojekte wie z.B. Brücken stellen Planer und Ingenieure immer wieder vor besondere Herausforderungen.

Beim Klassischen Entwurf und die Modellierung treten immer wieder gleichartige Arbeitsschritte auf, die in mühevoller Handarbeit für jede Plannungsvariante untersucht werden müssen. Durch Ausnutzung die Möglichkeiten von grafishen Programmiersprachen (VPL) und Building Information Modelling (BIM) können viele dieser Entwurfsschnitte automatisiert werden. Dies vereinfacht die Varianten untersuchung speziell in frühen Entwurfsstudien zum Beispiel für Windströmungsanalysen.

Zunächst wird der Stand der Technik für die Nutzung von BIM-Methodik und vorhandene Software in diesem Bereich dargelegt. Diese Arbeit befasst sich mit den Möglichkeiten zur Nutzung grafischer Programmierungen im Bereich des Infrastrukturbaus und nutzt BIM zur Erzeugung von Muster-brückenmodellen. Im Speziellen wird der Arbeitsablauf für parametrisierte Geometrieerfassung von Brücken mit Hilfe von VPL-Programmen beschrieben und Fallstudien an Brückenvariationen durchgeführt. Weiterhin gibt die Arbeit einen kurzen Überblick über die semantischen Verbesserungen der erzeugten Modelle auf Grundlage des IFC Standards. Die semantischen Daten beziehen sich dabei auf die Klassifizierung, verbindende Elemente und definierte Beziehungen zwischen den Modellelementen.

Abschließend lässt sich sagen, dass die Nutzung von VPL einen neuen Ansatz zur Parameter gestützten Modellierung bietet und damit die Nutzung verschiedener Softwareplattformen erlaubt.

Contents

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Notation

Abbreviation	Description
AEC	Architecture, Engineering and Construction
BIM	Building Information Modelling
API	Application Programming Interface
CAD	Computer Aided Design
CFD	Computational Fluid Dynamics
CSV	Comma Separated Files
DWG	Drawing Data format in AutoCAD
GIS	Geographic Information System
GUID	Globally Unique Identifier
IFC	Industry Foundation Classes
MMC	Multimodel Container
NURBS	Non-Uniform Rational B-Spline
VPL	Visual Programming Language
RVT	Revit data format
XML	Extensible Markup Language
2D	Two-Dimensional
3D	Three-Dimensional

1. Introduction

1.1 Motivation and problem description

Bridges and Roadway are important aspect of infrastructure. In today's infrastructure construction field, the design process includes a large number of repetitive processes during the complex design procedure. Now-a-day roads and bridge models are usually generated with numerous software. VPL is used not only to avoid the repetitive design process, but also as a new and innovative method for full geometry parametric design workflow.

The application of visual programming methods can be considered as a great potential for large number of similar task in bridge design process and generation of parametric model variations of the bridge, to optimize the bridge alignment and orientation to fit in the surrounding environment. Here, the term of "parametric" refers to the relationships among all elements of the model that enable co-ordination, variation and change management. The visual design method enables users to design a process rather just objects, it allows the designer to find new solutions and step beyond the limitations of traditional CAD/BIM software and 3D modelers. In fact, the distinction between parametric and non-parametric model is basically in the geometry and rules. Revit as a BIM tool and integration of Dynamo visual programming with Revit, the repetitive process of bridge modelling can be automated especially in the early design phases of bridge planning.

Engineers use CAD systems for creating 2D drawing and – to some extent – 3D models of civils engineering structures such as tunnels and bridges [1]. Now-a-days bridges in Germany won't be designed due to economic aspects but due to alignment. The complex geometry at curved alignment, at longitudinal inclination, skewed substructures, variable bottom edges etc. are the key challenges [2].

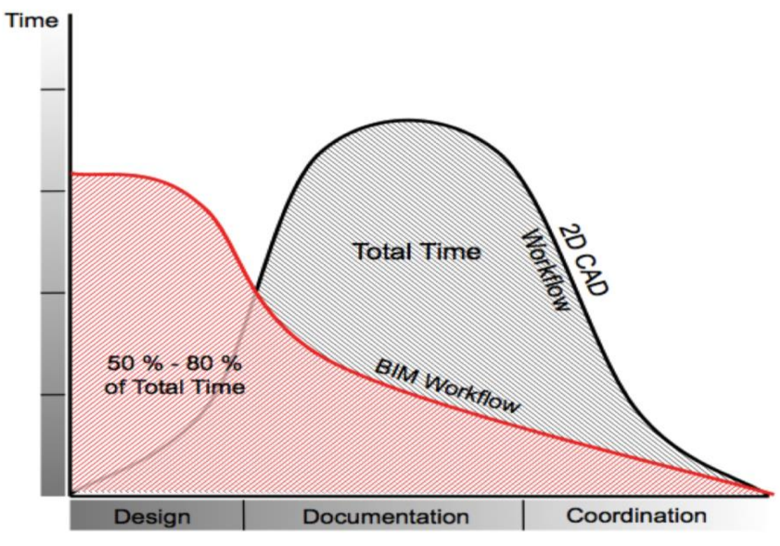


Figure 1 CAD vs BIM workflow [source:Graphisoft 2015]

The graph (Figure 1) shows the BIM reduced tremendously project implementation time compared to tradition CAD based design. It appears that with traditional CAD design is 20% innovation/creativity and 80% is routine work (Singer et. al. 2014). This percentage can be significantly decreased by integrating BIM with design process. Moreover, applying graphical programming for bridge modelling can be interpreted by engineers much more quickly and easily in BIM workflow. The visual languages are often called flow based, as there complex structures as information flow [3].

In Germany, interest is growing among private and public planners in using BIM for executing building projects. Interest in the public sector focuses primarily on infrastructure buildings. Speaking in April 2014, Alexander Dobrindt (Federal Minister for Transport and Digital Infrastructure in Germany) remarked that “the digitization of building processes offers opportunities for large building projects to be realized on time and on budget.” According to Dobrindt, an improved data basis increases transparency and networking among the participants in a building project. With regard to the recent changes in planning regulations politics regarding infrastructure, it is extremely important to further promote the use of BIM. The State authorities have been established that from 2020, all infrastructure works of public to implement with BIM excessively (Federal Ministry of Transport and Digital Infrastructure, 15.12.2015). Most of the designed bridges in Germany are in 2D format. According to the ministerial guidelines introduced the challenge, how BIM for Bridge is feasible transition from tradition design to 3D modelling[2] .

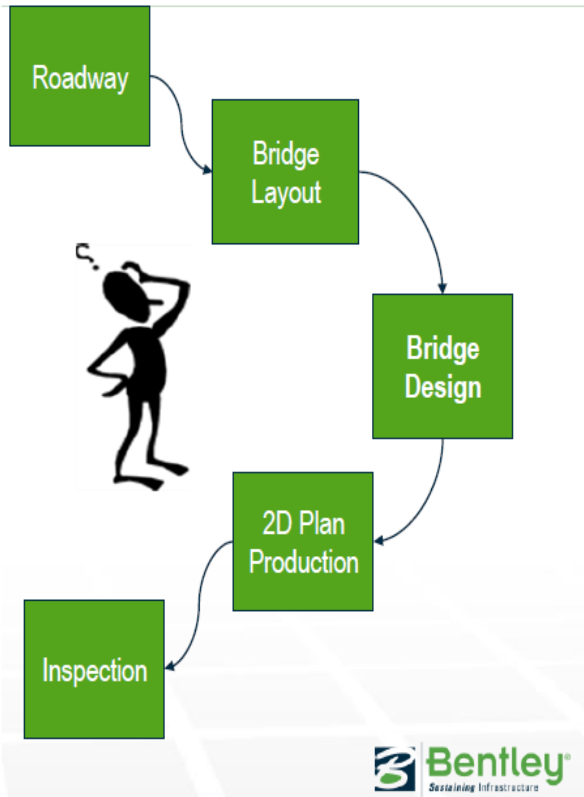


Figure 2 Traditional steps of bridge design

Bentley software solution addresses disadvantages of traditional bridge design in following points-

- Manual data transfer with roadway and repetitive data entry
- Plans production – lack of automation
- Communication issues
- Physical to analytical model transfer issues

In terms of being effective utilize BIM, the skill levels and working method of the user has significant influence. In the construction industry it's now challenging to implement project in time, even before and maintaining high quality. Bridges are rarely modelled in BIM by civil, environment and transportation engineers due to lack of common modelling software at the beginning. This represents an opportunity for further expansion of BIM for Bridges.

1.2 Aim of the work

The aim of this work is to show the possibility of applying graphical programming method in the field of Building Information Modelling for bridge design. The focus is on the generation of bridge model and variation of parameters. The prototype implementation is based on the open source code tool "Dynamo" and the BIM authoring software "Autodesk Revit 2016". To demonstrate bridge through visual programming Dynamo in Revit customized templates for bridge is created, Excel used for parametric data inputs. Furthermore, it also evaluates the bridge model and semantic enrichment of the model through BIM-Annotator for the data interoperability.

Not only in the bridge design but overall in AEC industry, the design process is a controversial issue because they require both a lot of time and financial resources. For example, the German railway has indicated as early as 2008 in an article published on the importance of design studies:

"Just the fact that the proportion of design planning, in the course of whole project life, including a bridge made by authority costs of total planning costs 5% or in comparison to the construction cost accounts 0.8%, shows that it is absurd to save here. "(DB Netz 2008, p.11). With these very strong words it is clear that a variation study is indispensable, especially in the bridge design. The aim is repetitive planning processes, which rely on the experience and expertise of the planers to automate using intelligent support tools partially or even completely.

On the basis of VPL, it is possible with a few input parameters to create most of the construction works. The visual language can be interpreted much more quickly (Knight et al. 2015). Al-ready modelled by an expert member is still understandable, as step by step can be understood exactly at what time and at what point does data. Thus, it is easier to keep track and to understand how the parameters affect the output. Changes to the model can be tracked in real time. Optimization processes also can be carried out in the same manner. (Singer et al. 2016).

1.3 Related work

Although, visual programming (VP) paradigm is relatively new in AEC industry, it is a very promising tool to solve variation problems in this domain (Tedeschi, 2014). This paradigm is used successfully for simplification of building models query like the BIMcarft filter tool for personal at construction site (Wülfing et al. 2014). Also Ritter et al (2015) investigated the fundamental of visual programming and evaluated its possible application in AEC industry. Several CAD and 3D software vendors have developed visual tools which are based on node diagrams to make scripting more accessible to user with limited programming skills.

For bridge modelling, VP design tools have been represented and demonstrated in several articles and tutorials videos. The very first approach of a pedestrian bridge from scratch in Dynamo shown by Kron Z. (2014) proves the potential tool for bridge design and to the ultimate rebar modelling and structural analysis. A feasible study is proposed by Langwich O. (2016) demonstrates an example for bridge modelling according to German bridge standards and requirements with Revit and the visual design tool Dynamo. Singer D. (2015) presented the application of knowledge-based engineering and VP methods in early stages of bridge design. Other applications demonstrate how to extract bridge alignment data to Revit from Autodesk Civil3D and use Dynamo for bridge detailed modelling and comparing alternative of bridge model (Stark 2015, Younghwi 2016). Furthermore, successful rebar modelling for complex shape of bridge with Dynamo in Revit presented by Vermeulen D. (2015) proves the power of computational design through visual script.

1.3 Thesis structure

This thesis is structured as follows-

Chapter 1 states the motivations and current design criteria in the field of infrastructure. Following a review of related work, the concept of applying graphical programming methods for parametric bridge modelling and capability of model variation is introduced.

Chapter 2 presents the state of the art about applying BIM methods in bridge modelling. In this part available tools for bridge design in construction process are presented. Additionally, the term parametric modelling, IFC and IFC-Bridge for neutral data exchange format that captured parametric geometry has been described. It also includes introduction to the software system used for bridge design.

Chapter 3 illustrates about the visual programming, how it can be used as generative design application and integration with Revit. The implementation of parameterized bridge modelling through graphical program and idea of leveraging Excel for parametric data input in Dynamo has been mentioned. Moreover, examples and figures have been demonstrated to provide clear vision of graphical method for bridge modelling.

Chapter 4 demonstrates the idea of semantic enrichment of the bridge model through BIM-Annotator based on the IFC standards. Besides, the chapter also gives an idea of the difference between semantic enriched model and IFC based geometry.

Chapter 5 summarizes this study and evaluates the methodology. It proposes workflow and parametric visual templates for typical bridge types that is more intuitive and efficient for generation of model variation. Next, the semantic quality of the generated models can be enriched using web based BIM-Annotator which contains database of IFC standards and the under development extension IFC-BRIDGE. Besides Users have the opportunities to add, modify the properties.

Chapter 6 finally, it includes the findings and possibility of visual programming for further investigation of the created bridge model. It also addresses the limitations of this research work.

2. Literature review

This chapter presents an overview of Building Information Modelling (BIM) and role of BIM in bridge design are focused. For the success of a construction project, continuous and an intensive exchange of information is required. The term BIM is defined by Autodesk as three dimensional, object oriented, AEC specific computer aided design process. According to Borrmann et al. (2015), BIM includes not only the three dimensional geometry of the component, also additional information such as type information, technical properties or costs. The chapter also covers the aspect of interoperability of BIM with IFC neutral data format in different software vendors.

2.1 Building Information Modelling (BIM)

BIM is an innovative new approach to building design, planning, and construction of infrastructure facilities. BIM supports the continuous and immediate availability of project design scope, schedule and cost information that is high quality, reliable, integrated, and fully coordinated[4]. BIM is an approach, not a technology. To be implemented effectively requires suitable technologies like CAD (Computer Aided Design), parametric building modelling. It is a digital prototype of a construction to understand its behaviour before its building.

According to National BIM Standards-United States-
"BIM is a digital representation of physical and functional characteristics of a facility. As such, it serves as a shared knowledge resources for information about a facility, forming a reliable basis for decision during its life cycle from inception onward."

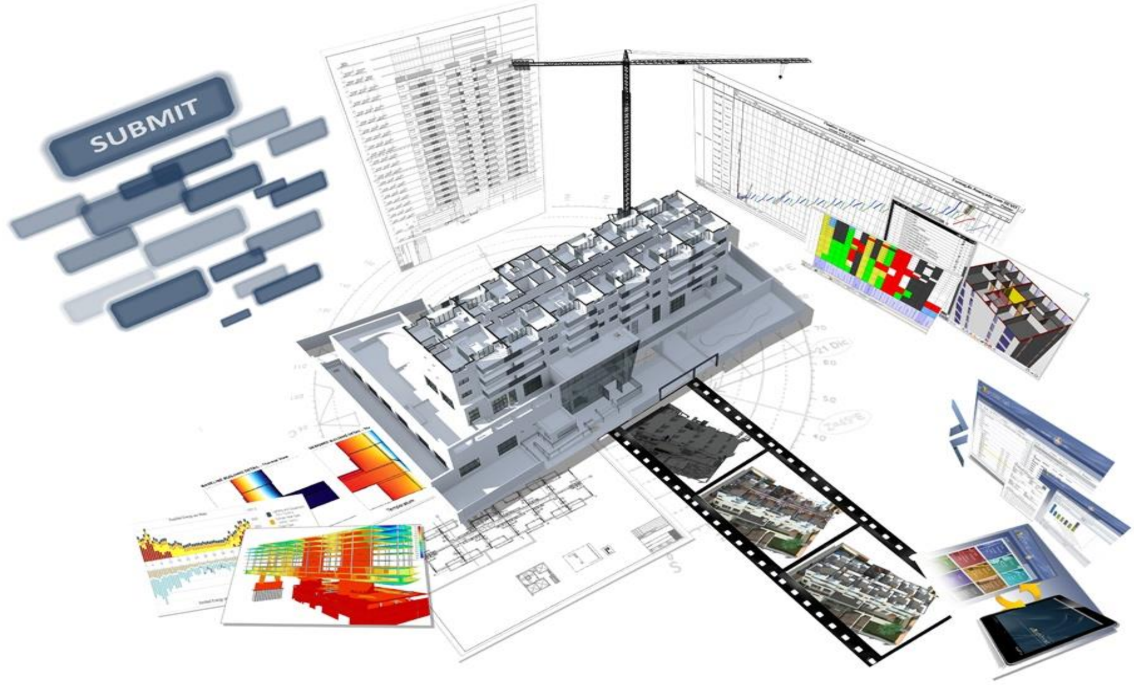


Figure 3 BIM application in project [source: ndBIM]

Traditional building designs contain two-dimensional technical drawings (plans, elevations, sections, etc.). BIM extends this beyond 3D with time as the fourth dimension (4D) and cost as the fifth (5D). Creating real-time, consistent relationships between digital design data- with innovative parametric building modelling technology can save time and money and increase project productivity and quality.

The result of McGraw-Hill Construction research on BIM found the level of BIM adaptation in North America grew by 45% between 2007 and 2012. It is possible for the professional planners throughout the life cycle of a building to visualize the desired task in computerized system and make it transparent for all the project participants. BIM model can be represented in IFC (Industry Foundation Classes) neutral data exchange file format, which is interoperable in different BIM software application.

Currently, a fundamental change in the Architecture, Engineering and Construction (AEC) industry by the introduction of the BIM technology (Eastman et al. 2011) takes place. It aims to represent the complete building facility in a digital product model, which is used throughout the whole life-cycle. Furthermore, parametric modelling is more and more incorporated for the design of infrastructure facilities [5].

2.2 The role of BIM in bridge design

Bridges are complex structures. BIM technology faces challenges especially modelling for non-standard geometry. The role of BIM in bridge design in infrastructure projects can be evaluated through the present working tools and assessing the potential of new tools. The infrastructure sector demands for implementing BIM for bridges, tunnels. Benefits of utilizing BIM have been proved by using parametric model based software like Revit. It is possible to create variable geometry in Revit with the help of graphical programming tool Dynamo. Figure 4 shows a building information model of reinforced concrete road bridge in a low to mid level of detail.

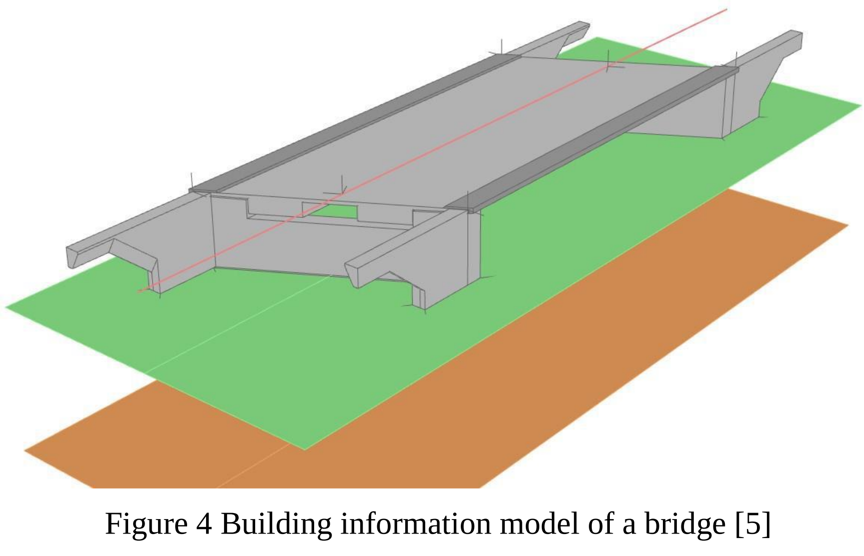


Figure 4 Building information model of a bridge [5]

Designing of a bridge is an iterative process, where changes in the basic data and data received from other disciplines results in a need to update the bridge design. The design of bridge structures is heavily dependent on external conditions, such as the location and the intended function of the structure. The better modelling of bridge helps better understanding among people involved with project. BIM store the information of objects in the model and can be extracted later. BIM provides a possibility to represent the different things in the same platform. The challenge is how it should be presented that the information available in the model.

Euringer (2011) summarized the benefits of BIM for bridge construction for the planning and execution phase in following points:

- Processing and visualization of complex curved structures
- Constructing any structure through various modelling methods (example: parametric modelling method)
- Structural simulation and technical structural analysis
- Fast modifications on parameterized model
- create complex shapes by using traditional construction processes (Extrusion / rotation of the two-dimensional cross-sections)
- Ensuring uni/bidirectional associative or update the model or the drawing creation
- increase the reusability and accurate analysis, through the use of parametric and associative constrains
- Easy management of the model due to the object-oriented modelling
- Virtual prototypes replace costly real models
- Early error analysis during the design phase
- Integration of additional semantic information (such as Materials. Date, location, etc.)
- Analysis of possible geometric collisions
- Basis for the construction process simulations to increase productivity in construction
- Illustration of the time course with the help of special bridge model
- Review of construction progress.

Despite the many advantages that BIM brings for bridge, is still the decisive disadvantage that there is at present time no freely available software that a simple, parameterized implementation of bridge model.

2.3 Parametric modelling

Parametric design refers to the use of geometric parameters and the mathematical formulation of interdependencies between them. It also includes the option of defining geometrical and topological constraints [6]. Using parametric design features, bridges can be coupled with the axis of the roadway, which enables an automatic update of the bridge’s geometry and saves a laborious manual adaptation whenever modifications of the road axis become necessary.

It provides the ability for real time iteration – rather than rebuilding an entire model, a simple integer can be changed with the software then updating automatically, for example, the diameter of an arc that then drives the entire geometry of a bridge deck and everything that follows downstream; the spacing of cables along an arch, or panelisation of a complex surface.

For an efficient use of the structural model, only the drawing of a simple 3D model is not enough. It requires a parametric modelling, through the components act together logically. Linked and assigned them properties, building the structure that is displayed in the virtual space. The geometry is considered parametric model that objects produced not only assigned with a permanent geometry, but also described variable input parameter values. It is thus achieved that objects at individual change update parameters according to their stored dependencies.

“Feature-based parametric CAD is currently the industry standard technology to create geometric models and assemblies, and is widely used across many engineering fields. In a parametric model, the geometry is mainly controlled by non-geometric features called parameters, which can be defined by dimensional, geometric, or algebraic constraints " [7].

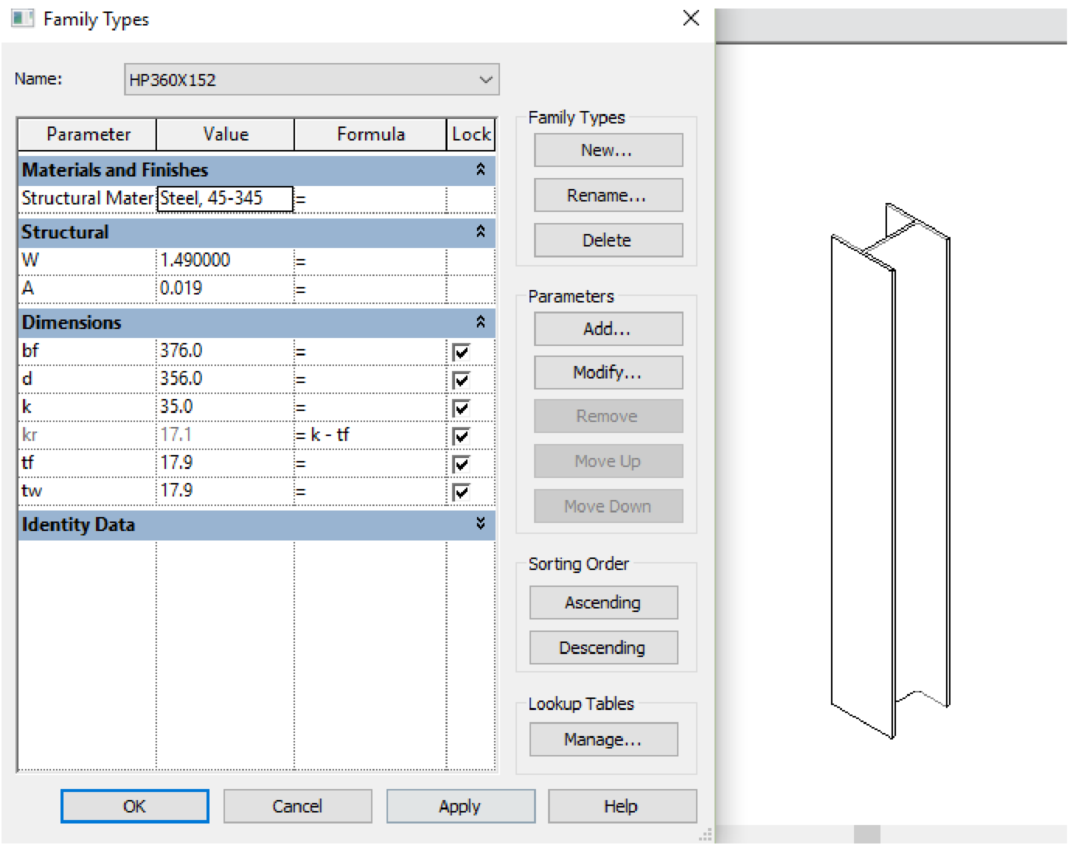


Figure 5 Parameters defined for a structural framing in Revit

A detailed parameterized structural framing in Revit is illustrated in Figure 5. Here perform predefined rules updates means that the model is automatically adjusted. In parametric modelling instead of designing an instance of a building element, defines an element class or family which describes parametric geometry.

The parametric design approach is good for producing fast design variations and thus enables the extensive re-use of existing models. The dimensional and geometric constrains are used for parametric modelling.

2.3.1 Requirements of parametric modelling

For the implementation of BIM in project 3D digital model is core element. Since the 3D modelling of bridges hardly standardized, all the components need to be created as a free-form body and individually with parameters be provided into CAD applications.

Modelling the bridge considered a composite component, otherwise there is no guarantee, that changes in the bridge, the individual components make the changes. Bearings, foundations, wing walls and abutments walls form the abutment, which together with pillars give the substructure. The superstructure is formed from the deck, have the transition structures and caps, on which in turn railings, curbs and parapets may be attached. In contrast to the components of the bridge, the terrain can be re-modelled for each project [8].

Thus, the flexibility and modifiability of the 3D model can be ensured. A wise model is parameterization, linking necessary and allows to a high number of degrees of freedom. Geometric constraints are by formulas in the parameters or using constraints, as concurrency, collinearity etc. ensured. Starting with the axes of the bridge and the road, width, length and height of the bridge to the important boundaries of the separate components, thicknesses of the wing and abutment walls or heights of the superstructure etc. need to be considered while modelling. Parameters that are important for the part that still have a type or instance parameters are classified. Type parameters are applied to every elements of a family and can not later in a parent file individually be changed. Instance parameters however allow an individual change [8].

2.4 IFC- Standard as neutral data exchange format

In order to achieve interoperability between different software applications used in the design and construction process, it is necessary to use a standardized data model. The most mature data model standards in the AEC domain is IFC (Industry Foundation Classes) and it is recognized as ISO 16739 standards. Software interoperability in the AEC industry has been developed and promoted by the International Alliance for Interoperability (IAI) since 1995. The Industry Foundation Classes (IFC) format developed for achieving interoperability [34].

An important aspect for the success of BIM is the availability of open standards for the lossless exchange of high-quality building information models between software applications from different manufacturers. The Industry Foundation Classes (IFC), drawn up by the international organization buildingSMART, represents a standardized data model that meets these requirements and is now supported by many BIM applications[9]

IFC defines an EXPRESS based entity–relationship model consisting of several hundred entities organised into an object-based inheritance hierarchy. Examples of entities include building element such as IfcWall, geometry such as IfcExtrudedAreaSolid and so on. The difference between ‘intelligent objects’ in IFC and blocks or objects in 2D CAD software is that the IFCs are by definition 3D and reside in an integrated model that composes the virtual building. Instead of working with 2D entities such as line, arc, and text, the user works with the objects directly, using their familiar names, such as wall, slab, roof, and building [34].

At the most abstract level, IFC divides all entities into rooted and non-rooted entities. Rooted entities derive from IfcRoot and have a concept of identity (GUID) along with attributes for name, description and revision control. Non-rooted entities do not have identity [Wikipedia]. Figure 6 shows a portion of the inheritance hierarchy. The inheritance hierarchy of IfcRoot and the importance of an Object is the basis for the modelling of the inheritance relationships.

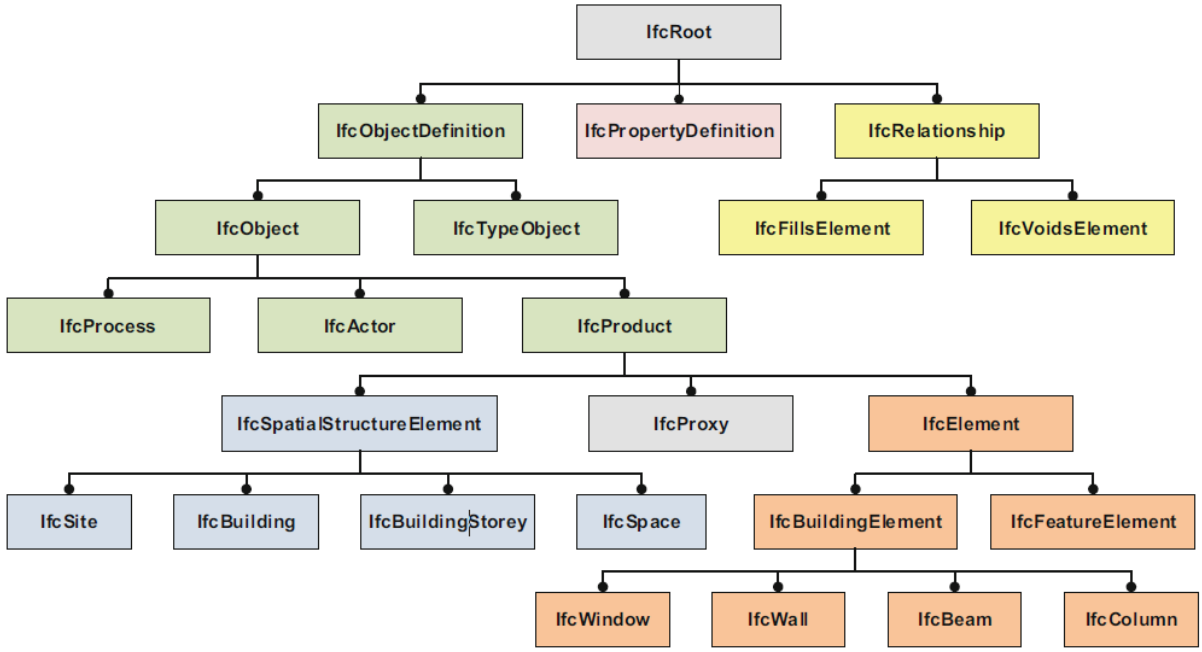


Figure 6 Detail of the IFC data model with the main entities [35]

Currently IFC is in the fourth version (IFC4), most software applications still support only version IFC2X3. Due to the rapidly increasing importance of “BIM for Infrastructure” around the world, the next big release, IFC 5, is scheduled to include a comprehensive civil engineering building extension that will make it possible to describe elements such as roads, railways, bridges, and tunnels.

Though IFC supports numerous engineering and management disciplines such as structural, mechanical and electrical engineering as well as the cost, schedule and facility management.

However, some of which are not yet recognized as standards and not included in IFC database. Particularly in bridged design is noticeable because the complex structure of the bridge geometry depends on the alignment [8]. In December 2015, the German ministry of Traffic and Digital Infrastructure published a graduated scheme for digital design and construction which demands digital data models of all new constructions in a neutral data format from the year of 2020. For this neutral data format IFC is proposed.

2.5 IFC-Bridge extension

Due to the strong fragmentation of the AEC industry, the data exchange between the different participants in a construction project is of crucial importance. The data exchange in the bridge design and engineering domain is still poorly supported by open formats. As a result, data is transferred using conventional, non-digital methods such as plotted plans, or PDF documents. However, currently existing neutral data formats do not allow for an exchange of parametric geometry. To overcome these technical limitations, an extension to the IFC-Bridge format, thus providing a means of interchanging parametric bridge models. With the expansion of IFC-Bridge there is a promising scheme for bridge models is adapted. It is based on the IFC and is also hierarchical and object-oriented structured. Consequently, it is able to represent a wider range of bridge geometry. It's developed independently both by French and Japanese research team in 2006. The current version is Version 2 Release 8(V2R8), dating back to November 2007 [11].

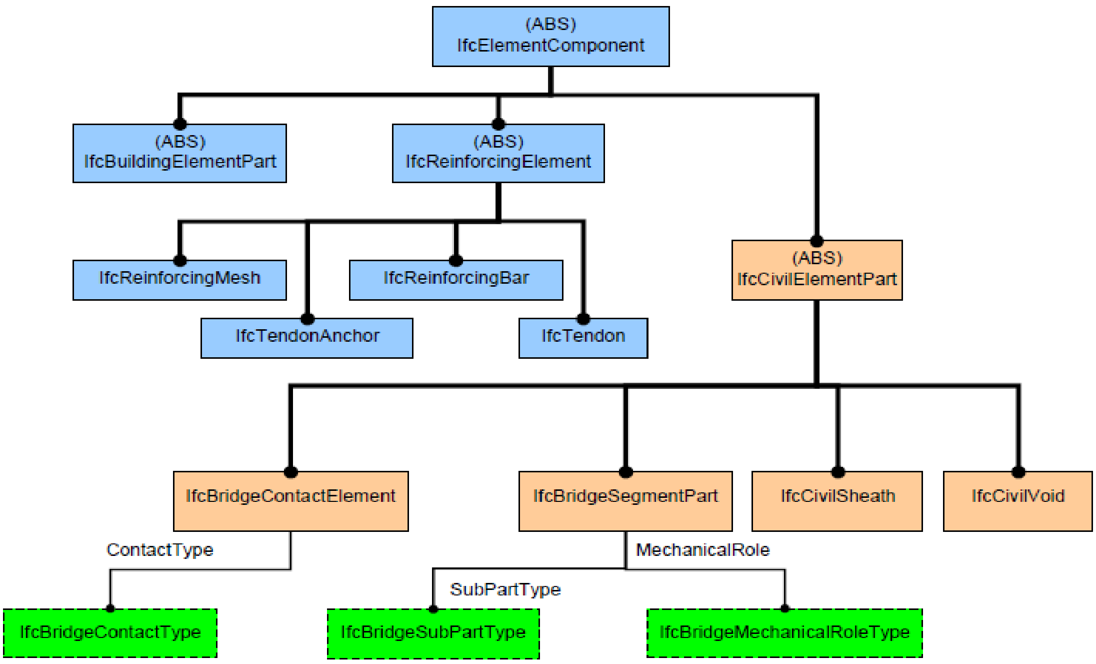


Figure 7 IFC-Bridge element parts [buildingSMART]

IFC-Bridge can be used as a mean for exchanging fully semantic and structured bridges design data. A central component of the model IFC-Bridge 2.0 is the class-

IfcReferenceSectio nedSpine. This describes a 3-dimensional body using a reference curve (IfcReferenceCurve) and several cross sections (IfcProfileDef). These cross-sections obtained by defining the class IfcReferencePlacement, a position on the axis [13].

IFC-Bridge development currently focuses on standardizing definitions of bridge components and their hierarchical relationships which is shown in Figure 8. It provides the core of semantic description of bridge components and relationship between them. The proposed data structures of IFC-Bridge describe 40 entities of bridge profile definition. It introduces a new entity named IfcParametricSketch alongside the conventional IFC profile definition IfcProfileDef. This entity describes parametric sketches with geometry and dimensional constrains [11]

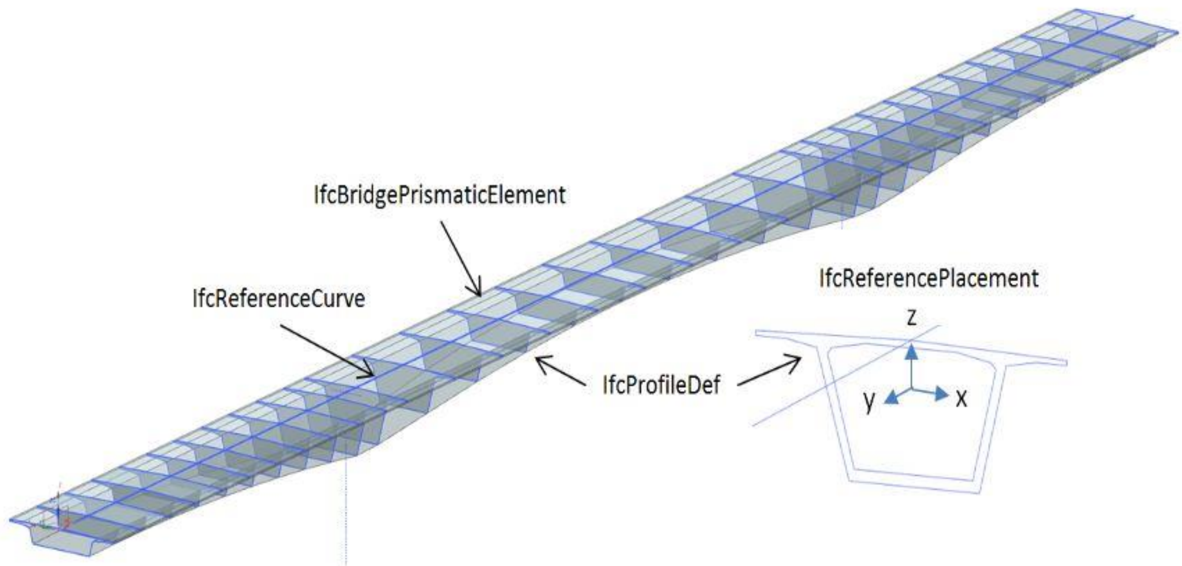


Figure 8 Example of geometry representation in IFC-Bridge [11]

The IFC-Bridge extension has not yet integrated in the official release of the IFC schema because of missing of basic data structure of horizontal and infrastructure projects like the horizontal and alignment definitions and required of acceptance. The recent development and the release of "IFC alignment" extension as a buildingSMART final standard will support the further development of IFC-Bridge and other extensions [12].

2.6 Multimodel data exchange method

In AEC community IFC is gaining increasingly practical importance. However, IFC does not store and carry all relevant data for multi-faceted construction processes [36]. Multimodel approach represents a promising approach to the collaborative editing and analyse project information across the boundaries of disciplines and organizations to support a universal and flexible interoperability to reach. The basic idea of the multimodel is, selected specialist models from the planning and management of the project in a single information resource to combine and map their dependencies through complementary explicit link models [14].

Advantages of multimodel data collaboration in project has been proposed by Fuchs, Katranuschkov & Scherer (2010) are as follows-

- Existing and accepted data models like IFC or the German GAEB specifications model can be used further without modification;
- According to a given task or process, information can be assembled in straight-forward way by composing relevant model data;
- IT coverage of building process information can be extended by alternative data models.

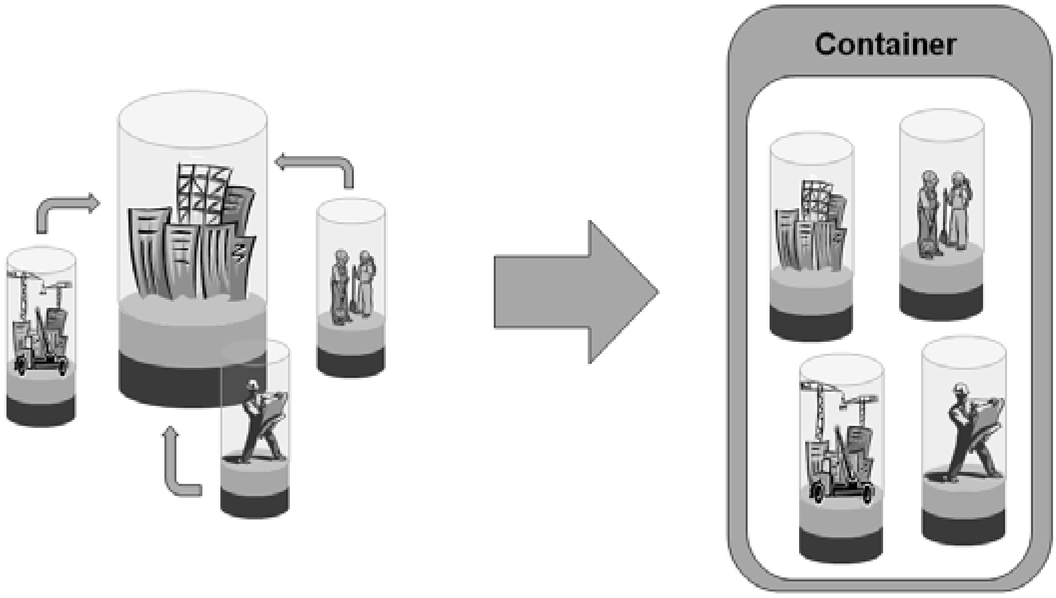


Figure 9 Multimodel concept for BIM approach [36]

Figure 9 shows the paradigm from BIM-centred information management to a federal coloqual multimodels. The class Multimodel is the entry point into the data structure. It consists of elementary models and link models. For information transfer of multimodels, the exchange format of the multimodel container comes (MMC) in used (Figure 10). The multimodel container consists of an open data model. General basis of all multimodels are first the XML schema, then data model for the multimodel container description, mmcXML, link model and LinkXML. Both the multimodel approach and the multimodel containers are generic and do not make any specifications for the technical contents of the specialists and link models[14]. Link model class is a class of models which play the role of the connector between elementary models. Link-models explicitly specify the interdependencies among the models.

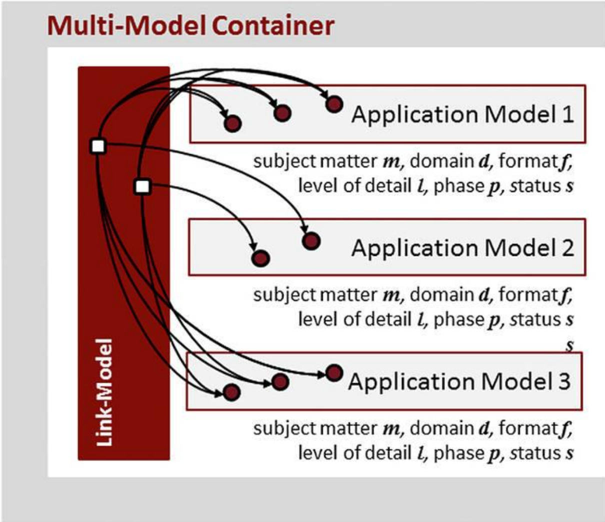


Figure 10 Principle structure of a Multimodel Container [14]

Accordingly, the multimodel container specialized models treated as independent information resources with its own data schema and its own data format [14]. This makes possible:

- The use of established and standardized data formats from different applications and countries
- The flexibility of new application domains and integrating appropriate professional models and software applications
- The re-use of existing building software applications to create individual application models
- The file-based storage, exchange and manage project information. The dependencies among the professional models of multimodel can separate link models. These usually include a plurality of link elements, which matching the elements of two or more specialized models.

The idea of a monolithic building information model, in which the information by integrated product data and building information models are merged, so far could be difficult to enforce. Here, the various application domains are unified with respect to the structure of the building in a format. With the generic multi model a data schema, associated conditions, metadata for neutral exchange and access to multimodels described [8].

Using bridge design software (e.g. Bentley LEAP Bridge, CSI Bridge Modeler, Autodesk Revit with bridge extension, Midas Civil, Allplan etc.) 3D bridge model generated by bridge design software quickly through bridge templates, geometric parameter wizards, component libraries. These good looking bridge models have a very bad semantic information quality and lose most of the design parameters when they are exported as IFC models and are not exchangeable among different tools. Multimodel data exchange method aims to fill this gap. Besides BIM Annotator is used to improve the semantic quality of bridge models[12].

2.7 Tools for implementing BIM in bridge design

To create 3D bridge model several design software are available. Autodesk Revit with bridge extension, Civil3D, Infra-work 360, Bentley LEAP Bridge, CSI Bridge Modeler, Midas Civil are well known software for bridge modelling. Besides, Tekla Structure and Allplan are also used for bridge modelling now-a- days. Below describe some bridge modelling tools.

2.7.1 Autodesk Revit 2016

Revit 2016 is a BIM tool which focuses on 3D object oriented modelling. Autodesk Revit provides a powerful toolbox for parametric modelling. With the help of Revit family editor and mass modeler geometries can be defined and parameterized. Revit can export and import from the file format IFC which is the standard format for BIM interoperability. For data exchange the supported file formats are in. RVT, DWG, DXF, DWF, gbXML and pdf.

Using the Revit Bridge Modelling extension "Civil Structures 2015" bridge models are generated based on user criteria. The user can define simple parameters of the bridge geometry, as plan and elevation profile (for example, from LandXML), superstructure, piers, abutments and railings. Based on user-defined families, which are supplied with the extensions, the bridge model is generated. The available version is Civil Structure 2015 which can be used as extension in Revit 2015, but not compatible with latest Revit version.

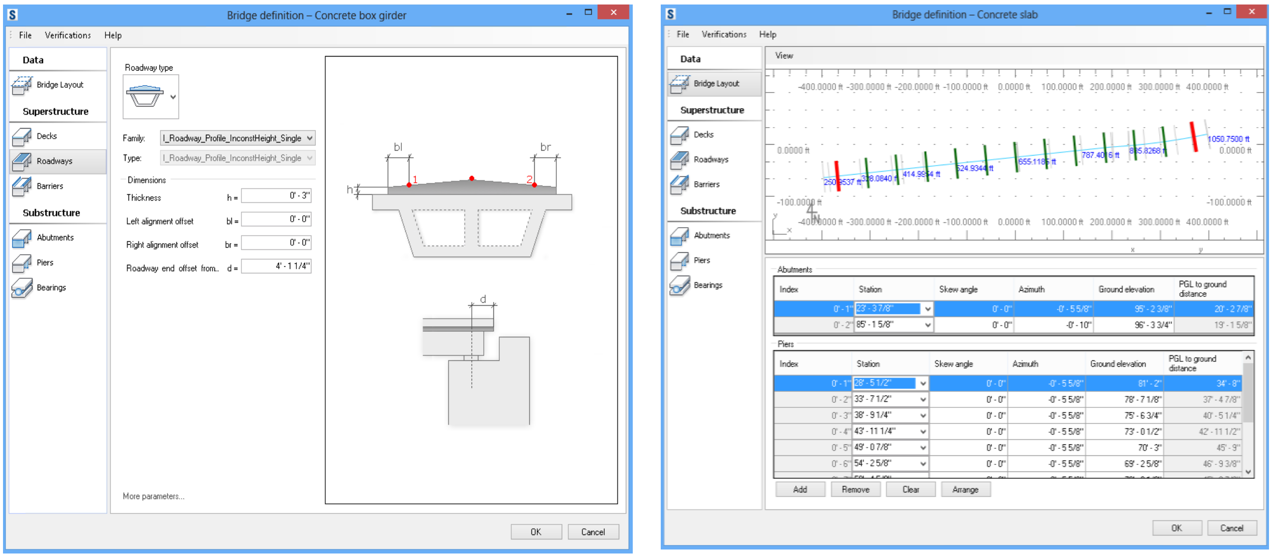


Figure 11 Civil Structures interface for Autodesk Revit 2015

Bridge Modelling Revit extensions are composed of the following modules [source; Autodesk]

- Roads and terrain definition
- Integration with Autodesk AutoCAD Civil3D

- Bridge definition- concrete box girder
- Bridge definition- concrete slab with girders
- Customization of bridges families
- Document generation of bridges

Figure 12 shows two screenshots of the user interface of the plug-ins. On the left, the window to select and definition of the superstructure can be seen. On the right side the window to control the routes and the terrain model is visible.

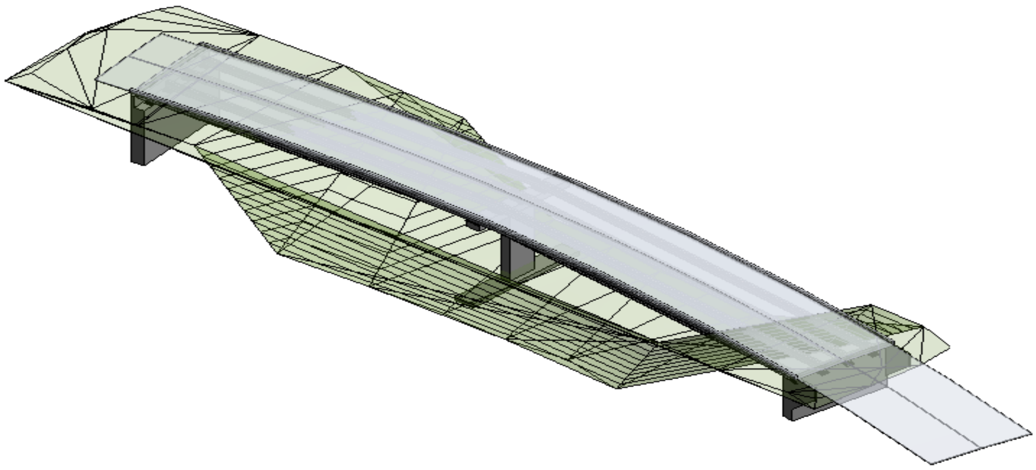


Figure 12 Bridge modelled in Civil Structure 2015, Revit extension

2.7.2 Infrawork 360 Bridge Design module

Infraworks 360 (Autodesk 2016) is Autodesk software to design planning, infrastructure and contains a bridge module for the design of bridges. It creates more realistic bridge structures in the context of the proposed roadway and explore options more quickly. Linking road and bridge is always preserved, so that changes to the location, height or type of the road directly affect the bridge model. The Bank and terrain modelling is performed automatically by Infra Works. The software could work with large amount of data in a variety of native formats [source: Autodesk].

Infra Works 360 has a variety of possible import file formats such as IFC, DWG, SHP, LandXML, CityGML or RVT and ensures support with AutoCAD Civil 3D DWG- File format. Figure 13 shows a screenshot of Infraworks360 while working on a bridge model [8].

Figure 13 Infrawork 360 modelled bridge [source: Autodesk]

2.7.3 AutoCAD Civil 3D 2016

AutoCAD Civil 3D software is a civil engineering design and documentation solution that supports BIM workflows. Using AutoCAD Civil 3D, one can better understand project performance, maintain more consistent data and processes, and respond faster to change. It is suitable for the planning; design for example, roads, bridges, sewers, terrain analysis etc.

AutoCAD Civil 3D includes the complete scope of AutoCAD. Although for usually no CAD primitives, but smart objects for infrastructure planning, as digital terrain model, excavation, road alignments, transverse profiles etc. can be constructed. The subscription Bridge module for Civil 3D enables modelling of bridges and bridge components based on roadway geometry and surfaces. Data formats DWG, DXF, DGN, IFC and LandXML etc. are supported [8].

In AutoCAD Civil 3D, it is not possible to create free modelling according to the designer wishes. The 2D design approach used, it is only possible create along the bridge axis cross-sections, which in conjunction with the profile view represent a 3D model. A great advantage has AutoCAD Civil 3D in the combination of route and bridge, as well as the standard-compliant layout output.

Advantages:

- specializes in the planning of infrastructure projects
- standardized drawing output
- creation of customized cross-section catalogs
- output via IFC

Disadvantages:

- problems cross sections that are not perpendicular to the bridge axis
- not creating freeform geometries
- no geometric plausibility checks or collision control
- visualization

Three-dimensional visualization can be processed in Civil 3D, so that the model for presentations at Infra Works 360 can be passed. Despite the good adaptation of the bridge on terrain and route, the sole use of AutoCAD Civil 3D 2015 is currently not recommended for continuous BIM implementation. It lacks the ways individual freeform body by extrusion, rotation and Boolean generating operators.

2.7.4 CSiBridge Modeller 2016

Using CSI Bridge, engineers can easily define complex bridge geometries, boundary conditions and load cases. The bridge models are defined parametrically, using terms that are familiar to bridge engineers such as layout lines, spans, bearings, abutments, bents, hinges and post-tensioning. The software creates spine, shell or solid object models that update automatically as the bridge definition parameters are changed. Modelling, analysis and design of bridge structures have been integrated into CSiBridge to create the ultimate in computerized engineering tools [15].

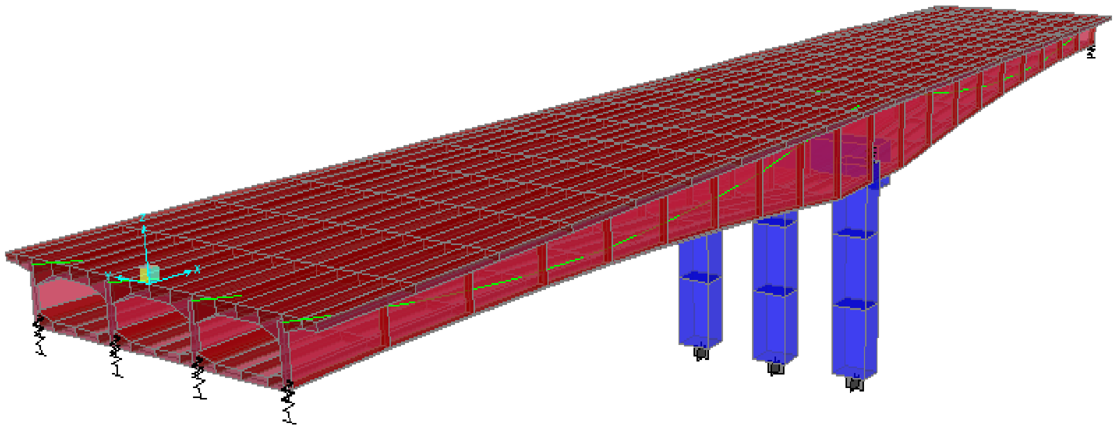


Figure 14 3D view of concrete box girder bridge model[15]

The parametric modeler allows the user to build simple or complex bridge models and to make changes efficiently while maintaining total control over the design process. Lanes and vehicles can be defined quickly and include width effects. CSI Bridge includes an easy to follow wizard that outlines the steps necessary to create a bridge model. In addition, AASHTO LRFD design is included with automated load combinations, superstructure design and the latest seismic design [15].

2.7.5 Other bridge modelling Software

Midas Civil - Midas is state of the art engineering software for the design or bridges and civil structures. It features modelling and analysis functions enable engineers to overcome common challenges and inefficiencies of finite element analysis. It provides design check and load rating features and also structural analysis capabilities. Its highly developed modelling and analysis functions enables engineers to overcome common challenges and inefficiencies of finite element analysis. With Midas Civil high quality designs with unprecedented levels of efficiency and accuracy can be created [37].

Allplan 2016

Allplan is a CAD program of the company Allplan GmbH for architects, engineers and building contractors. It supports 2D design, 3D modelling through to component-oriented building model with cost determination and quantity (4D BIM). It is a powerful BIM solution advertised that and the entire planning process in engineering support planning offices and construction companies. Allplan 2016 contain bridge and civil engineering module to create bridge based on route, section of bridge and creating tendon etc. [37].

Bentley's Leap Bridge

Widely used concrete bridge design and analysis software in the United States. LEAP is used for analysis and design of small to medium-sized concrete bridges with low skews and mild curvatures. Analysis and design of the superstructure, /substructure, and geometry is carried out in a single interface, using different modules that share a common interface [37].

Bentley RM Bridge

Bridge Design, Analysis, and Construction Software Perform bridge design, analysis, and construction simulation to determine resiliency during seismic and natural events and analyse rolling stock. The designer can streamline massive analytical tasks and save time on complex engineering issues by taking a more integrated approach in the design and construction of bridge systems [37].

Bentley RM Bridge –Advanced Plugin

RM Bridge Advanced Wind covers 3 major topics relevant to bridge design for assessment of wind impacts [37]:

(1) CFD calculations simulating wind tunnel tests by calculating aerodynamic coefficients and their derivatives using the mathematical approach of computational fluid dynamics. A CFD calculation is mainly based on input of cross section, wind velocity, and wind direction.

The CFD module is equipped with a mechanism to suggest meaningful calculation parameters, which can be tuned manually. The calculated time histories of drag, lift and moment can be exported either as plots or Excel worksheets, and the whole calculation can be stored as video. Once a set of parameters is fixed, it can be stored and loaded from the RM database. The parameters for the AERO schedule action can now be set directly from the CFD calculation panel. Next to static cross sections, moving cross sections can be calculated now, and a direct calculation of flutter derivatives is possible. To speed up calculation, the CFD module now offers a multi-threading option.

(2) Performing sophisticated wind buffeting analyses taking into account dynamic wind effects (turbulence), interaction between wind and vibration modes of the structure and structural and aerodynamic damping. Wind buffeting analysis must take into account the random properties of wind events, which are described by wind power spectrum and coherence. Detailed information of the considered structure must be provided, which is done in form of eigenvalues and frequencies. This information is combined in a statistical analysis method to provide information about the structure peak response due to a given wind profile.

(3) Performing relevant wind design code checks (vortex shedding, across wind galloping, torsional divergence, classical and torsional flutter).

3 Visual programming for bridge modelling

3.1 Visual programming basics

Generally, a visual language is defined as a formal language with a visual syntax and semantics. This type of representation, the visual language can be interpreted much more quickly and easily by humans. Often the visual languages are also called flow-based, as they are complex structures as information flow [3].

"The use of parametric scripting in combination with analytical results from digital simulation tools broadens the designer's power considerably. Thus it is possible to test many variations to find an optimized and efficient solution. By creating a script that controls and manipulates the characteristics of the design" (Kensek and Noble, 2014)

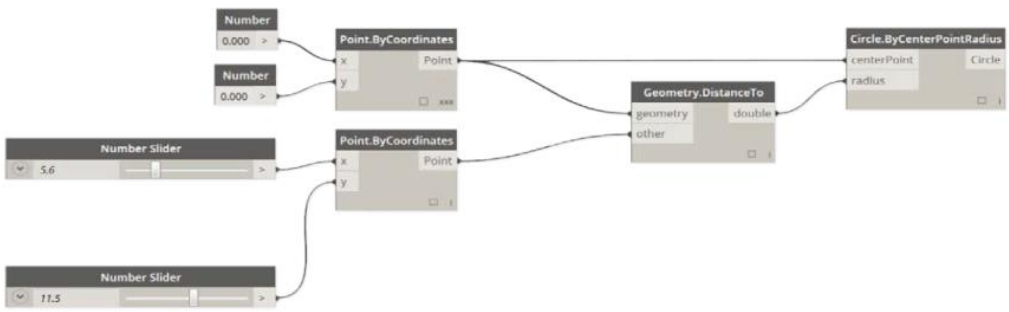
"Visual Programming Language (VPL)" is a concept that provides designers with the means for constructing programmatic relationships using a graphical user interfaces. Rather than writing 'code' from scratch, the user is able to assemble custom relationships by connecting pre-packaged nodes together to make a custom algorithm. This means that a designer can implement computational concepts, without the need to write code.

The difficulty for designers is the abstract way of writing the textual code and to know and understand the language specific syntax. According to Aish et al., (2012) textual program require considerable insight on the parts of the user and not practical for the use by non-experts[16].

Maloney et al. (2010) described it as, because the complexity of text based programming languages make the access for programming beginners difficult, visual (programming) languages like Scratch are used in the surrounding of teaching basic concepts of computer programming. So the user can concentrate on problem solving and must not think about language syntax [23].

The process is essentially the same for both text based programming and visual programming. They utilize the same framework of formalization; however, define the instructions and relationships of the program through a graphical (or "Visual") user interface. Instead of typing text bound by syntax, we connect pre-packaged nodes together[17].

Visual Program:



Textual Program:

```
myPoint = Point.ByCoordinates(0.0,0.0,0.0);
x = 5.6;
y = 11.5;
attractorPoint = Point.ByCoordinates(x,y,0.0);
dist = myPoint.DistanceTo(attractorPoint);
myCircle = Circle.ByCenterPointRadius(myPoint,dist);
```

Figure 15 Difference between visual and text based program representation [17]

The benefits of visual programming language are controversial. The disadvantage is generally argued that the programs created with a VPL usually do not meet the high requirements of a programming environment. In addition, more complex issues, such as recursion, often not be implemented. This contrasts with the ease of a VPL. It is because of their abstract representation for people with basic programming skills easier to understand and also used faster. This is justified by the fact that images can communicate things easier and represent scarce, understanding and remembering support, so there is no language barriers and thus understood by people of every language [3].

3.2 What is Dynamo

In the context of BIM, VPL is becoming increasingly important for steering the geometric modelling process. Thus, for all major BIM tools visual scripting components exist: for Autodesk Revit it is Dynamo, for Rhinoceros it is Grasshoper and for the Bentley platform there is Generative Components. For Vectorworks, Marionette is in development. The geometry may be modified accordingly by adjustment of the input parameter values [1].

Figure 16 Dynamo Logo

Dynamo is an open source Add-in for Autodesk Revit and Vasari. Dynamo allows designers to design custom computational design and automation processes through a node-based visual programming interface. The Add-in provides the user with basic functions such as mathematical operations, lists, scripting, geometry processing, Excel data import and export

[5]. Users are given capabilities for sophisticated data manipulation, relational structures, and geometric control that is not possible using a conventional modelling interface. Dynamo can creates its own geometry with parametric relationships, reads and writes to and from external databases [18].

In addition, Dynamo gives the designer the added advantage of being able to leverage computational design workflows within the context of a BIM environment. The designer is able to construct custom systems to control Revit Families and parameters.

The current stable version is Dynamo 1.2. By linking a Revit document, both project and family members within the Revit project via Dynamo can be selected, filtered, changed or new elements are added. Behind the Revit nodes are the functionalities of Revit Application Programming Interface (API). This enables the Revit API for tasks such as placing families, create and edit a family, changing the parameters of the elements to use, even for users without programming knowledge. It has also its own rendering component to visualize the geometry generated. Projects Dynamo can be saved as a file in **.dyn** format.

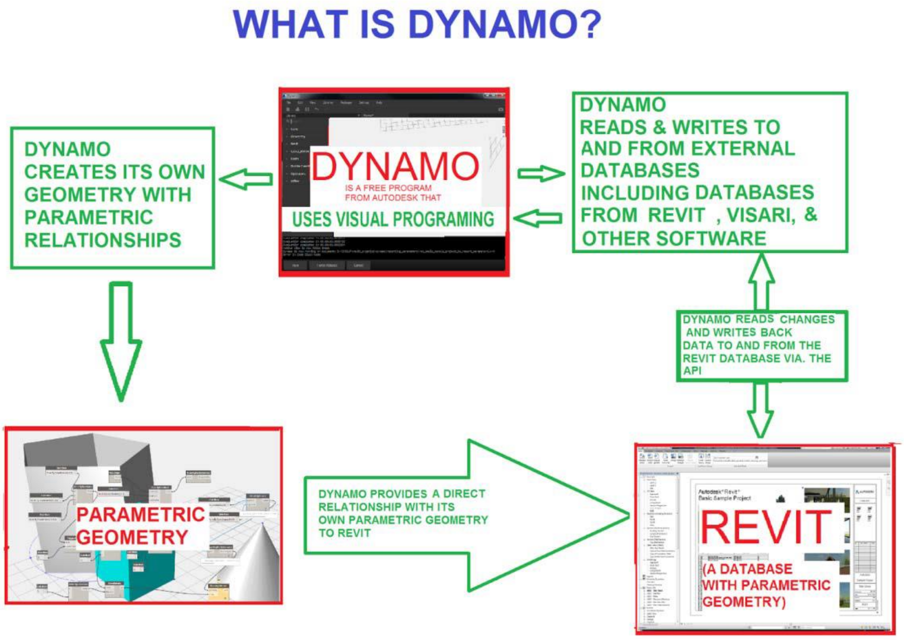


Figure 17 Dynamo conceptual workflow[18]

3.2 Dynamo basics and user interface

Dynamo enables us to work within a visual programming process. Figure 18 shows the user interface of Dynamo. On the left is the library containing all loaded and thus usable node to see. On the right side is Workspace graphical code editor in which the nodes can be placed. About the ports placed nodes can be connected. Using the ports, the expected input and output data types are defined at the same time.

The workspace is the main environment for creation of Dynamo visual programs by placing **Nodes** and connecting with **Wires**. **Nodes** are the objects you place and connect together with **Wires** to form a visual program. **Ports** are the light rectangular areas on Nodes; they are the receptors for **Wires**. Information flows through the **Ports** from left to right. Inputs **Ports** are on the left side of the Node. Outputs **Ports** are on the right side of the Node [16].

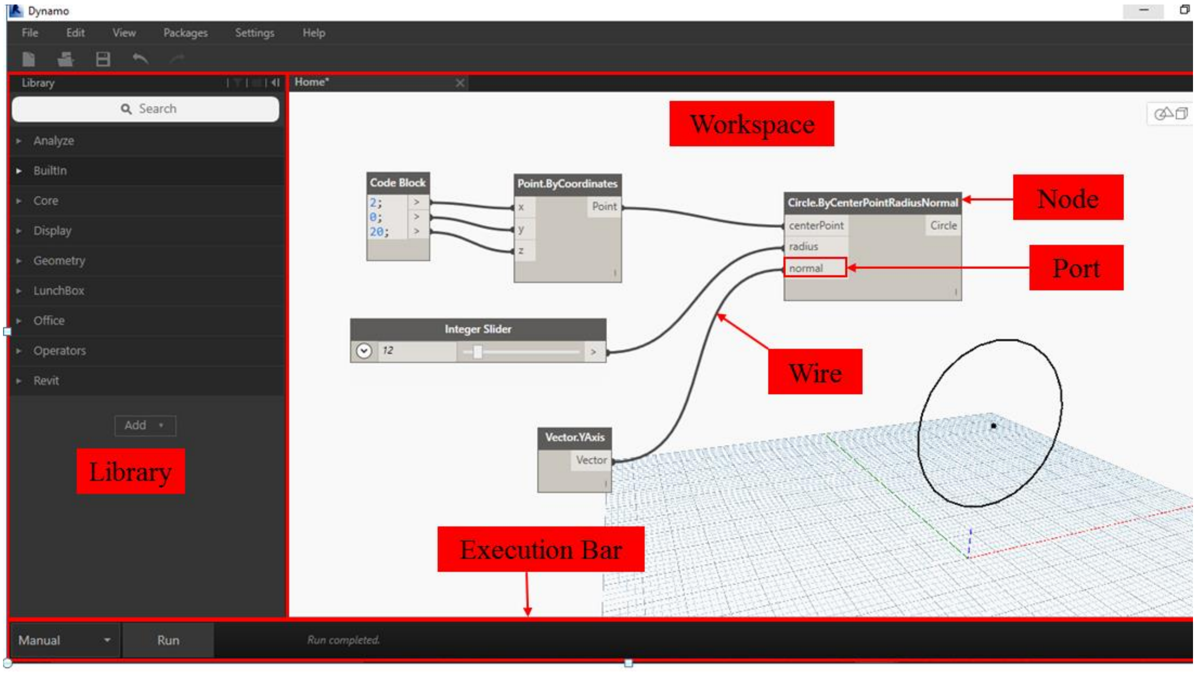


Figure 18 Dynamo user interface

Execution Bar allows the user to run or execute the current workspace. “Run" checkbox will cause the workspace to run if the user changes the workspace or any of the watched Revit elements in Revit or Vasari. The “Manual" checkbox will invoke a more detailed method of execution.

Dynamo can be operated independently from Revit and can be also run as standalone application through Dynamo “Sandbox” If these functions is not sufficient, it can be extended by own node if needed. For several paths to choose form

It offers after installed a number of prefabricated nodes library containing usable functions. Dynamo gives the opportunity to do large part of script in a one single node called “Custom node” Since Dynamo is an open-source project, the menu item nodes "Packages" can be added to the library which is developed by the Dynamo users [31].

In addition, user can use directly in Dynamo in the so-called "code block" design script commands and program their own nodes in Python. Upon visual programming finished code-blocks are linked together so that they form a logical unit and perform tasks.

3.3 Dynamo for Revit

The most famous and oldest VPL language in the field of geometric modelling is available since September 2007 Grasshopper for Rhinoceros 3D. Using this language, user can create free-form geometries and modify. The long-term use Grasshopper has currently the largest community in this area and therefore most extensions, including computation, networking and optimization algorithms.

Inspired by the success of Grasshopper currently developing other software manufacturers own VPL. The most promising product Dynamo for Revit from Autodesk. It stands out from Grasshopper characterized that it allows a direct modification of geometry in Revit components and understands semantics. In addition, Dynamo open-source can be attached to other applications.

Dynamo perfectly fits to interact with Revit because Revit is database with parametric geometry. Upon visual programming finished code-blocks are linked together so that they form a logical unit and perform tasks. It can create its own geometry with parametric relationship.

Possible applications of Dynamo for Revit are:

- Creation of complex parametric geometry

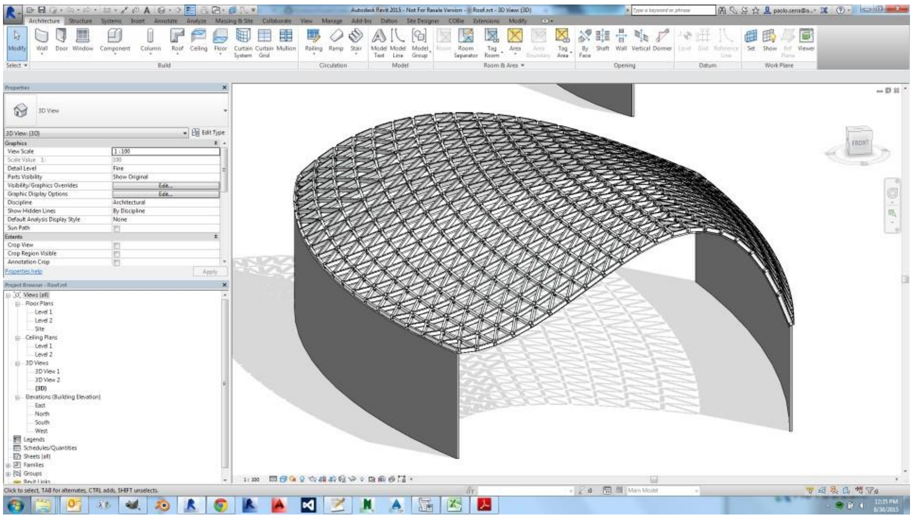


Figure 19 Parametric roof creation using Dynamo (http://dynamobim.org/gallery/)

- Geometry analysis (depending on the sun, distance to certain points, size / shape of individual fields in divided areas)
  Example: Solar Analysis in Dynamo

- Use of analysis data for the parameterization of the geometry (for example, general form finding, alignment of solar panels, facade openings / shading depending on the sunlight, standardization of facade panels)

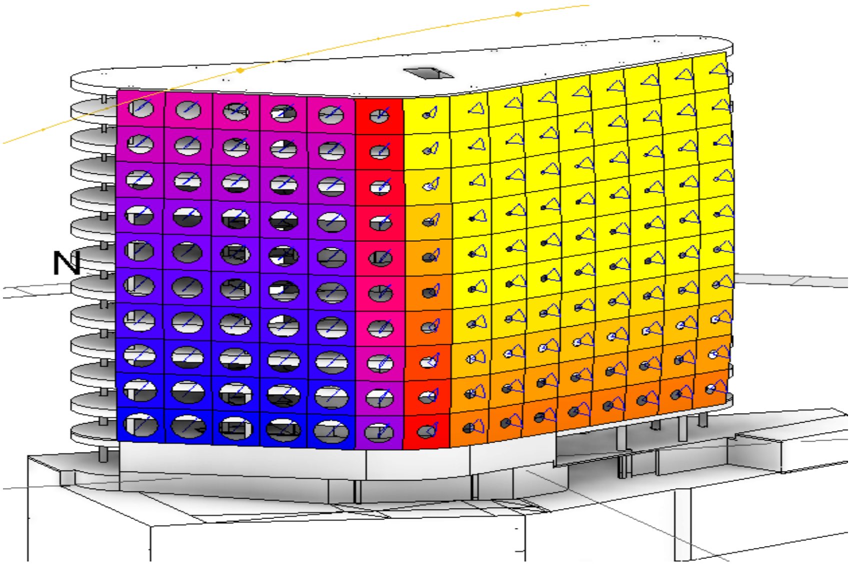


Figure 20 Regulation of aperture size in the façade panels to sunlight (Autodesk)

- Direct import / export of external data, such as CSV or SAT

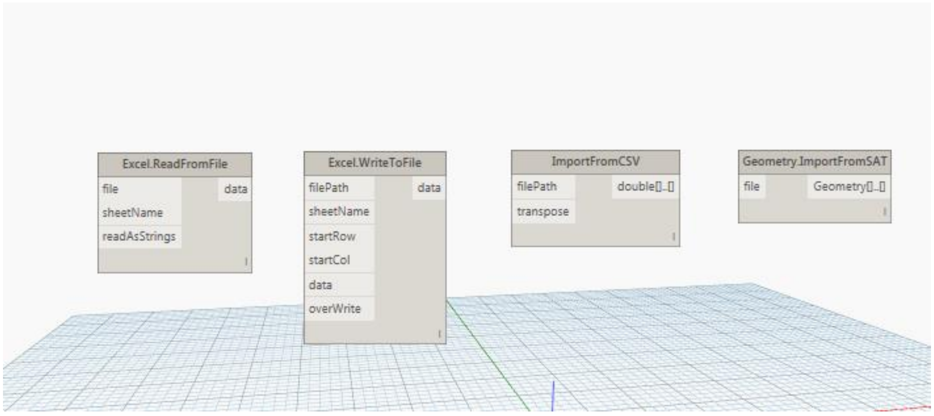


Figure 21 Dynamo nodes for different data format

- Direct access to the Revit programming interface (API), the generation and analysis of Revit geometry, placement of native Revit families, manipulation of parameters etc. allows.

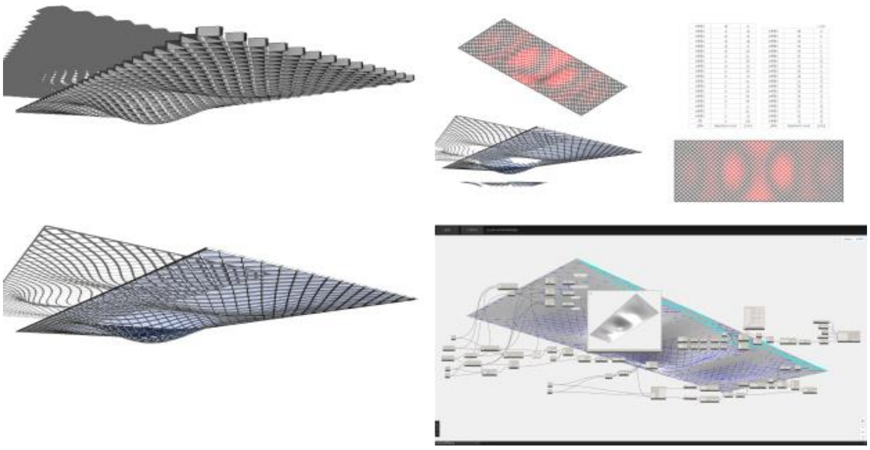


Figure 22 Parametric structure and analysis in Dynamo (http:// vasshaug.net)

- Data mining and analysis (for example, for quantity takeoff, construction books, etc.)

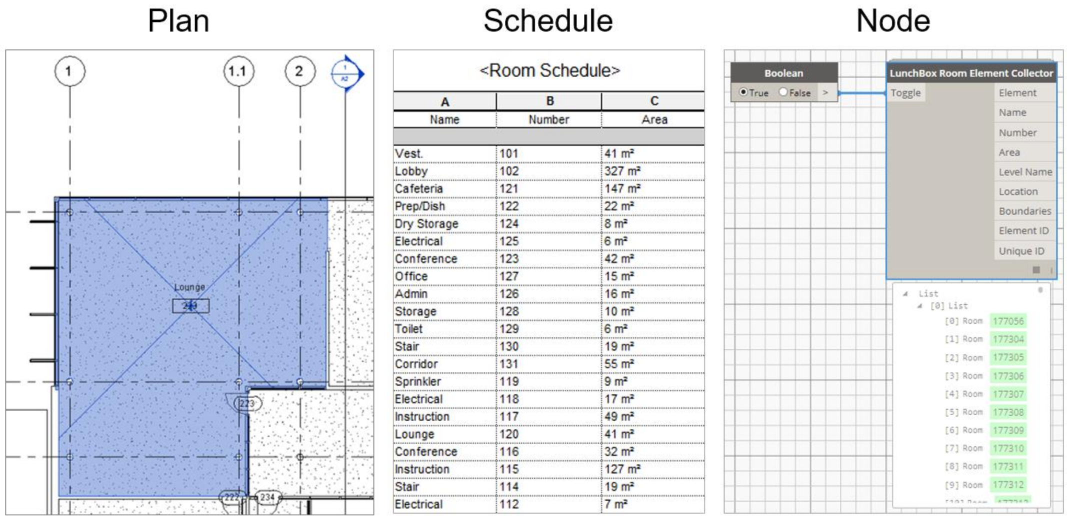


Figure 23 Mining data from Revit with Dynamo [19]

3.4 Dynamo for parametric bridge modelling

Dynamo is a graphical algorithm editor integrated with Revit modelling tools for designers who are exploring new shapes using generative algorithms. In other words, it is a tool for making Revit models parametric. A parametric model allows working on the final 3D model earlier in the process, before the final shape is found, because the parametric properties of the model allows for easy manipulation and reshaping of geometry within the designed system. By representing evaluation criteria parametrically in the design tool, it is possible to make an infinite number of iterations [20].

The application of visual programming methods can be used for iterative tasks and generation of model variations for bridge especially in the primary design phase, for example to check the design effectiveness for wind analysis or to optimize the bridge alignment and orientation to fit in the surrounding environment. The use of visual programming getting popular because of repetitive work or systems with strong dependencies to easily model, without assuming greater programming knowledge.

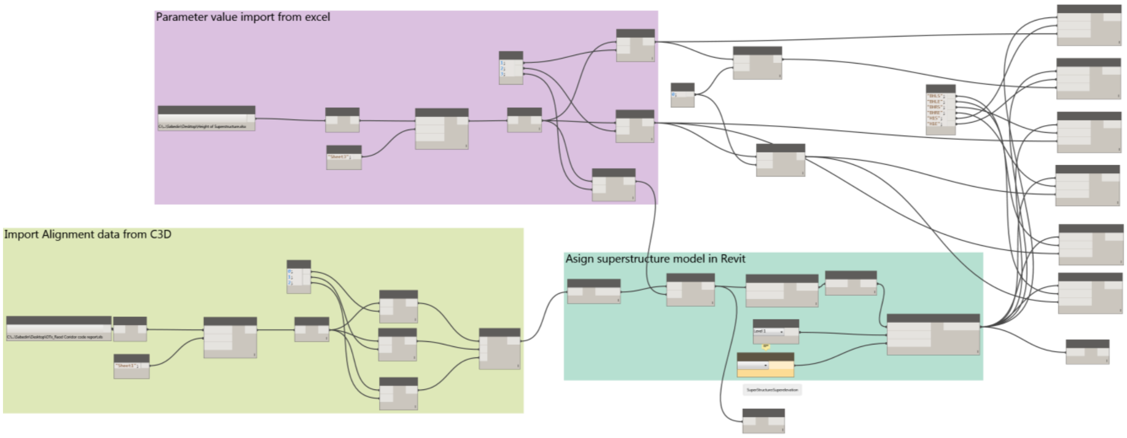


Figure 24 Workflow for bridge modelling in Dynamo

The enumerated deficiencies in modelling with Revit Structure can be eradicated with graphical programming software Dynamo The implementation of fully geometric-semantic modelling of a cable stayed bridge in the VPL environment shows in Figure 24 & 25. The entire modelling process done by Younghwi Kim (Autodesk Korea, 2016). The work inspired how Dynamo can be integrated with Revit for complex geometric modelling and Excel for parametric data manipulation. Kim has successfully created bridge model that the bridge section can be variable along the alignment. The whole process can be controlled through the Dynamo script.

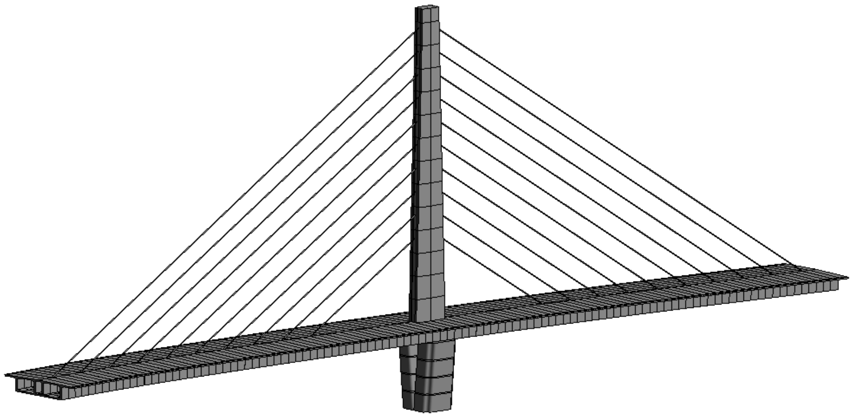


Figure 25 Bridge modelled in Revit through Dynamo (Y.Kim, 2016)

Another example of using Dynamo for bridge design is presented by Oliver Langwich of Contelos GmbH (2015) according to German bridge standards and requirements. As one of the first he has with the combination of Revit Structure and Dynamo a detailed design with a three-dimensional, parametric bridge model developed. The successful example of bridge modelling shows the great potential of Revit in combination with Dynamo.

4 Semantic enrichment of bridge models

4.1 Aim of the semantic data enrichment

This approach aims to enable an open information capture, exchange, sharing, filtering, comparison and storage of BIM models. The data exchange between the different participants in a construction project is of crucial importance. Currently existing IFC based neutral data formats in the domain of bridge construction IFC-Bridge faces challenges of interoperability during data exchange. Semantic enrichment of model refers to the classification of model elements, assigning attributes and defining relationships between model elements. The availability of good quality and rich semantic BIM models is an essential criteria to get the ultimate potential of using these models for different data exchange scenarios. The semantic enrichment improves the interoperability between BIM models for different disciplines and other domains like structural analysis and Computational Fluid Dynamic (CFD) software. However, at the moment the IFC standard, which is the most common natural vendor-independent format to exchange BIM models, doesn't cover special domains like CFD analysis and has a limited support for infrastructures constructions like roads, bridges and tunnels. The basic idea is to introduce an external tool that allows improving semantic enrichment; classification and data exchange for IFC model [12].

Several research works addressed the semantic data enrichment. Lee and KIM (2011) introduced an IFC data schema expansion plan targeting integrated road bridge and tunnel, in which they focused on the enrichment of spatial elements. Ji et al. (2013) proposed an interchanging parametric bridge models as extension to the IFC-Bridge format to deal with its limitation. The project report "Interoperable Information Model for Sustainable Infrastructures" (http://www.minnd.fr/en/) published by the French Ministry of Transport refers to the practical problems of using the current IFC schema for bridge modelling through proxy elements and the lack of standard property sets and semantic definition of bridge elements. Hence it is necessary to have a proper tool to improve the semantics of IFC-Bridge models [12].

For fluid dynamic analysis of wind loads on long span bridges a CFD model should be prepared for each model variation during the primary design phase, however the interoperability between BIM and CFD tools is not solved yet. Extending the IFC standard with special classes and property sets in order to carry most needed information to generate the CFD models based on IFC models is possible. However, this process takes long time and needs huge effort of domain experts. Targeting this problem in a practical way by providing annotation and classification tool for IFC or any 3D models "BIM Annotator", applying a multimodel data exchange method and developing a set of services, which help to semi-automatic generation of CFD models[12].

4.2 BIM Annotator

The semantic enrichment with BIM Annotator is based on a reference database for classification and standard attributes of typical bridge elements. The IFC-Bridge extension provides the core of semantic description of bridge components and the relationships between them. The additional semantic data model is stored separately and linked with the corresponding elements of the original IFC model through a special link model. BIM-Annotator allows exporting the original 3D models, semantic model and the link model based on the multimodel data exchange approach, which has been developed in the German research project Mefisto (www.mefisto-bau.de) and since 2013 by a workgroup of the German chapter of buildingSMART [12].

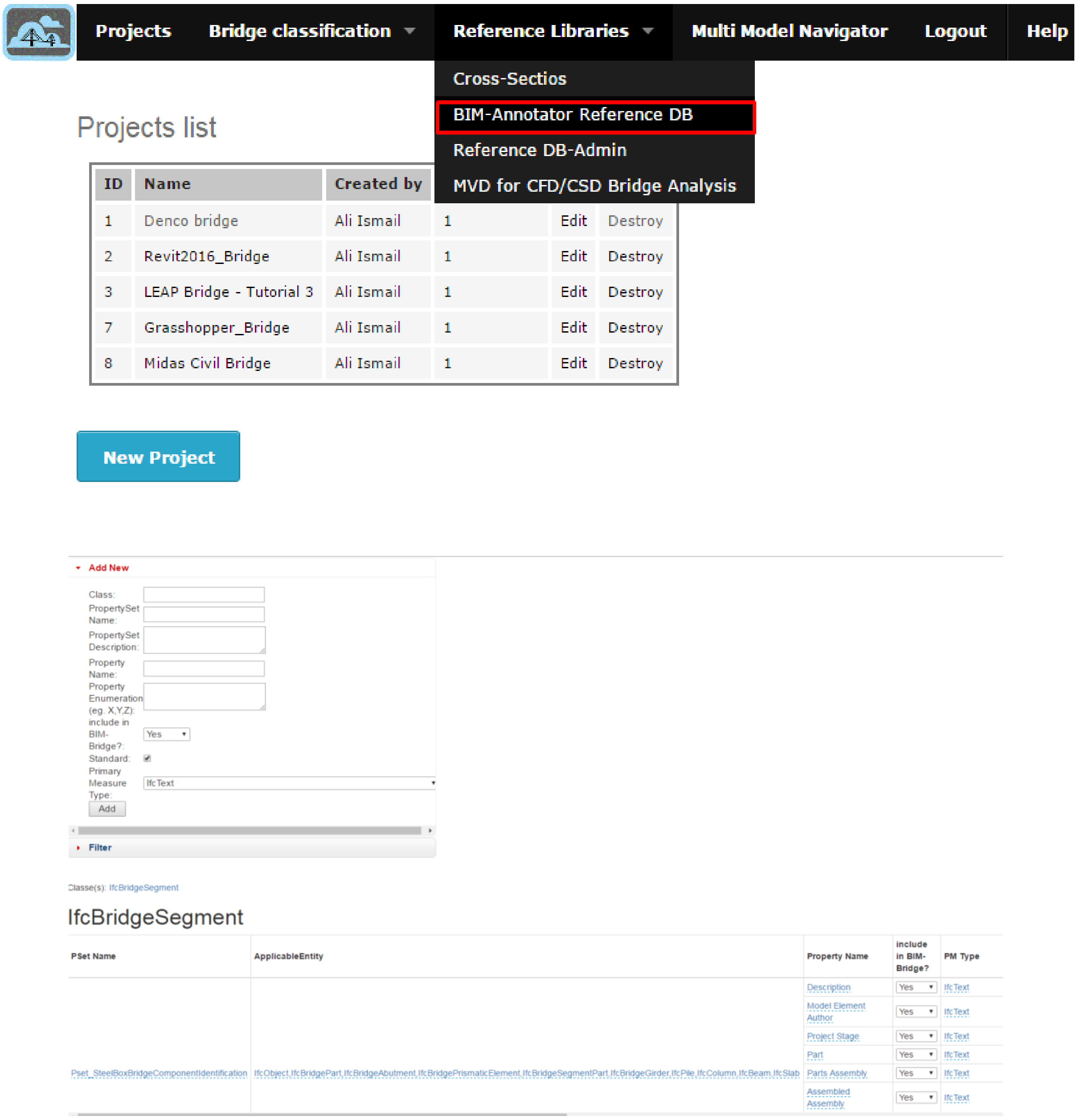


Figure 26 BIM-Annotator reference database

In order to have a 3D model with rich semantic model every object in the model should directly describe a specific component. It should be assigned to a specific class and described with a set of properties and relations with other elements. The result will be a virtual 3D bridge model which consists of components such as piers, beams and abutments and hence views and information can be extracted through filtering and semantic reasoning [12].

BIM-Annotator uses a reference database which includes a list of element classes and templates for property sets. All IFC classes including the special bridge classed of the IFC-Bridge extension and standard property sets of IFC model have been integrated into the reference database. The structure of this database is based on the XSD schema of Property Set Definition (PSD) of buildingSMART to simplify the process of importing standard property sets and exporting user-defined and non-standard domain specific property sets. The reference database can be managed and extended easily through a simple online GUI to include new domain specific property sets and non-standard classes. BIM-Annotator allows the user to assign classes of elements, edit, delete and add new property sets and assign attributes to them.

4.2.1 Annotation process

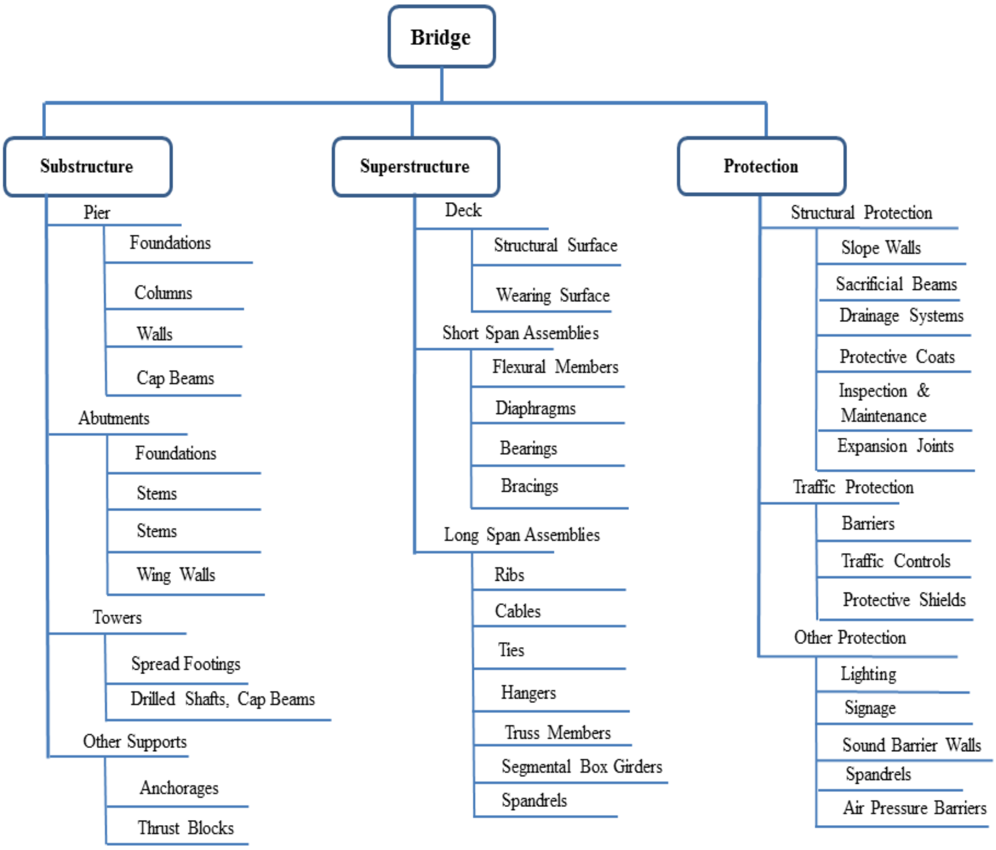


Figure 27 Hierarchical bridge system classification [ASTM standard 2013]

To ensure a consistent annotation process, classification of bridge system is required. This classification facilitates annotation task by equipping bridge components with a correct and compatible description. Also it provides users an accessible and searchable database. The classification method depends on the definition and enumeration available in IFC-Bridge extension and standards like ASTM standard (Figure 27). According to this classification, each element has a specific function and independently can be used among various bridge system types (e.g. highway, railroad, and pedestrian bridges). Furthermore, it helps users to understand the purpose and application of the different elements and allows creating user-defined properties those are not covered yet by IFC [12].

4.3 Difference between semantic and IFC geometric representation

Semantic enrichment engine parses the 3D model and extracts the geometric, topologic and functional characteristics from the model. It then progressively creates, updates or deletes semantically rich model entities (including tangible objects, virtual aggregation containers and objectified relationships of them) following a chain of predefined rules. The rule sets capture the knowledge of bridge engineers concerning the characteristics of the 3D model objects that represent bridge components, including their geometric features (e.g., the parametric cross-sections), their occurrence and the topological and other relationships among them[21]. Figure 28 illustrates difference in semantic and IFC geometric representation.

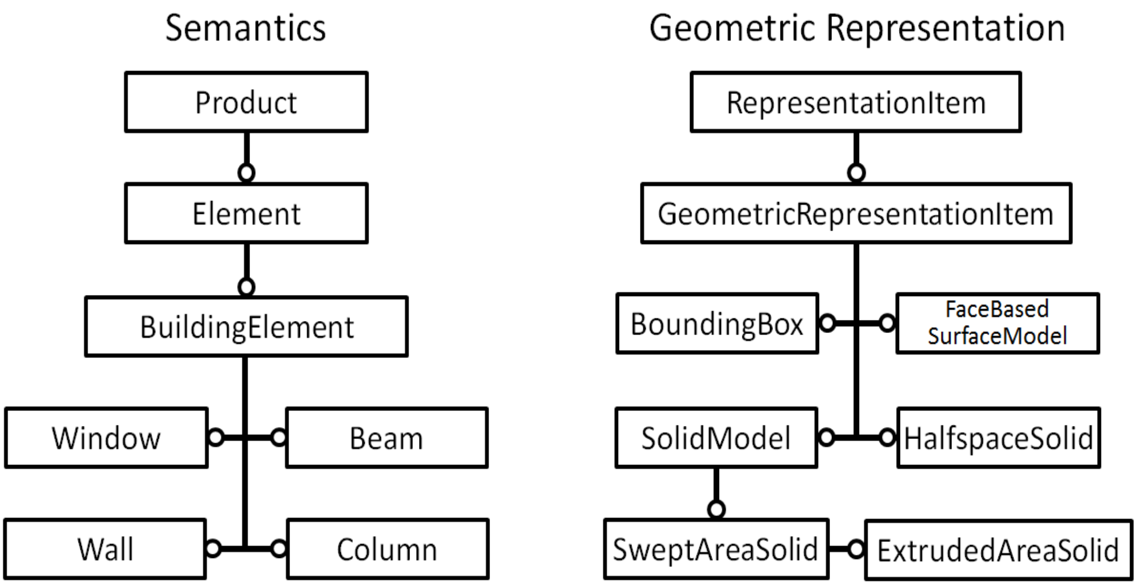


Figure 28 Separation of semantic and IFC in the Geometry (Express- G Diagram)

The IFC Model provides a comprehensive set of entities to describe the semantics and the geometry of a digital building model. It applies the concept of objectified relationships, i.e. there are specific classes which need to be instantiated for representing relationships between entities. The IFC model follows a strict separation of the semantic description and the geometric representation. The semantic part is the leading information structure in the IFC, proving the main access to the model and all associated information. Each semantic object representing a building element or can be associated with one or more geometric representation [22].

5. Methodology of parametric modelling

5.1 Design process

This Chapter presents workflow to generate bridge design model variations using visual programming methods with the help of visual programming tool Dynamo. The most important advantage of this method is the automation of modelling process, the possibility to replace model elements with different level of details and change the geometry parameters in consistent way, using advanced modelling concepts like form-finding algorithms and NURBS curves for complex geometry which satisfy a set of geometric and logical constraints. It saves a lot of manual modelling time and automates as well as the process of linking external data source (AutoCAD Civil 3D, excel etc.) for creating variable profiles and the bridge alignments.

The basic design process and tools for parametric bridge modelling can be described through the workflow diagram (Figure 29)

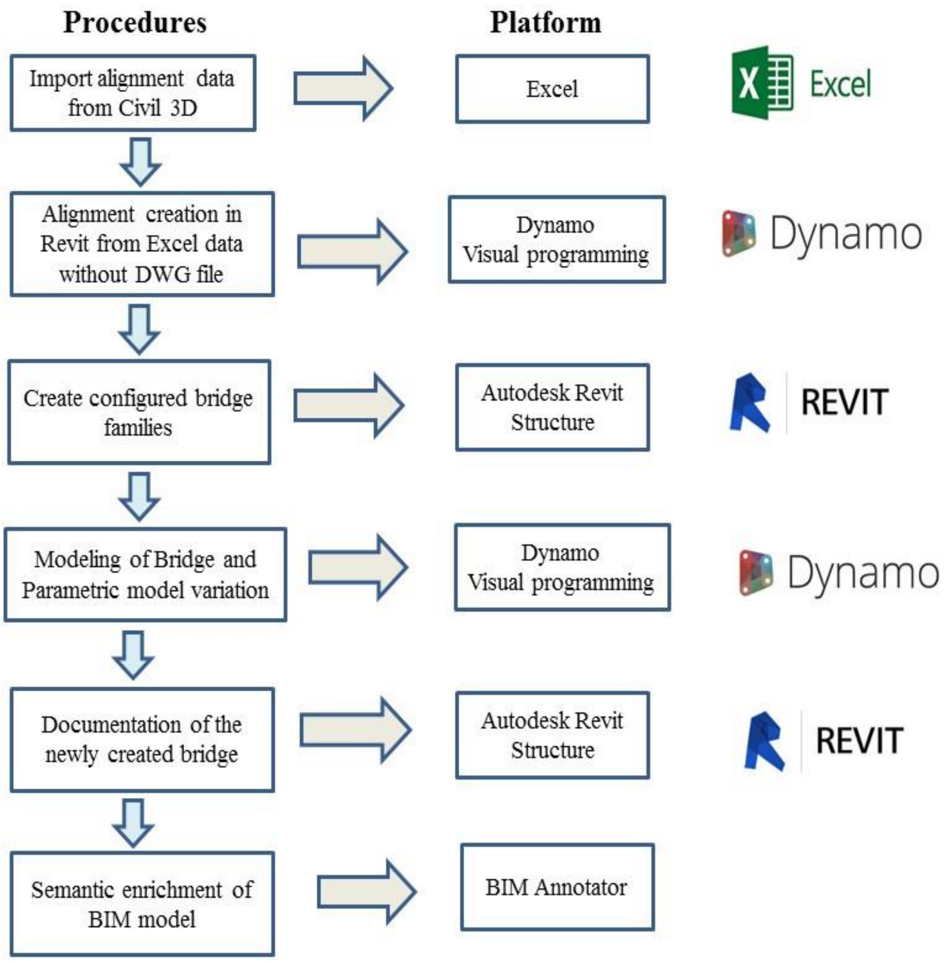


Figure 29 Basic design process and tools

Figure 30 depicts the main steps for creating a parametric and bridge model variations and equipped this models with necessary semantic data based on IFC standard. The result is a BIM enrichment semantic model which can be driven into diverse applications like structural analysis or CFD wind analysis.

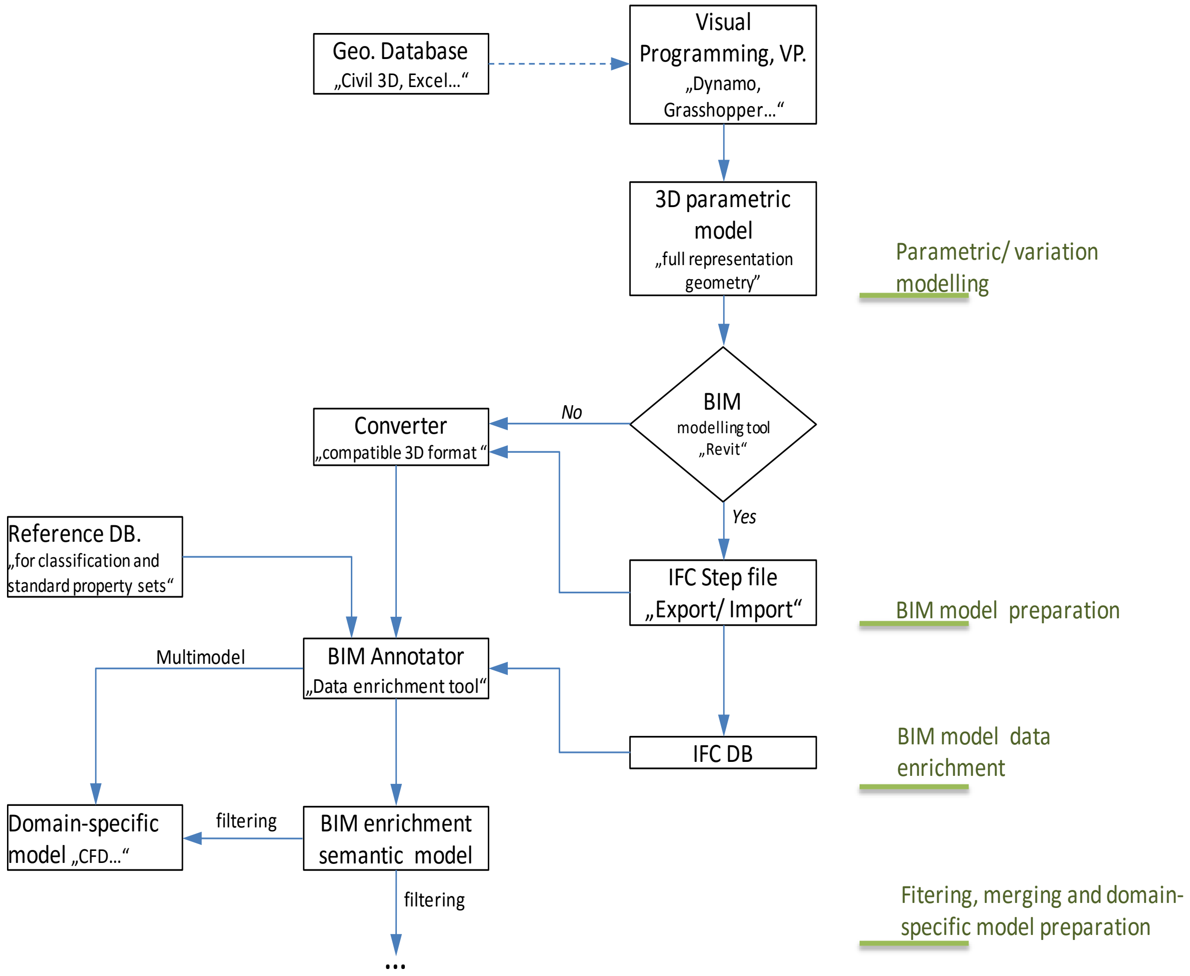


Figure 30 Generic workflow for modelling parametric and semantic enrichment of bridge models [28]

5.2 Bridge modelling in Revit Structure and Dynamo

Bridge modelling in Revit Structure, initially its main components superstructure, pier, and abutments etc. are created each in their own families. Additional components like caps or railings are not initially created; they are imported from the Revit library. By means of extrusion, fusion of two sections, rotation, sweep, sweep merger and their associated subtraction solids components are constructed. The resulting component boundaries be linked in the next step with the respective reference plane. Thus ensures that adapt to the geometry in subsequent parameter changes. With this procedure, it is important to examine means of parameter variation, whether sufficient degrees of freedom are available or if blockages by internal constraints arise.

Subsequently, a classification of the parameters in type and instance parameters. Type parameters have the advantage that the procedure laid down in the family parameters during subsequent insert of the object clearly describes the type of component and the parent component cannot be changed later. However, it can be different in the component itself and hold characteristics of the type.

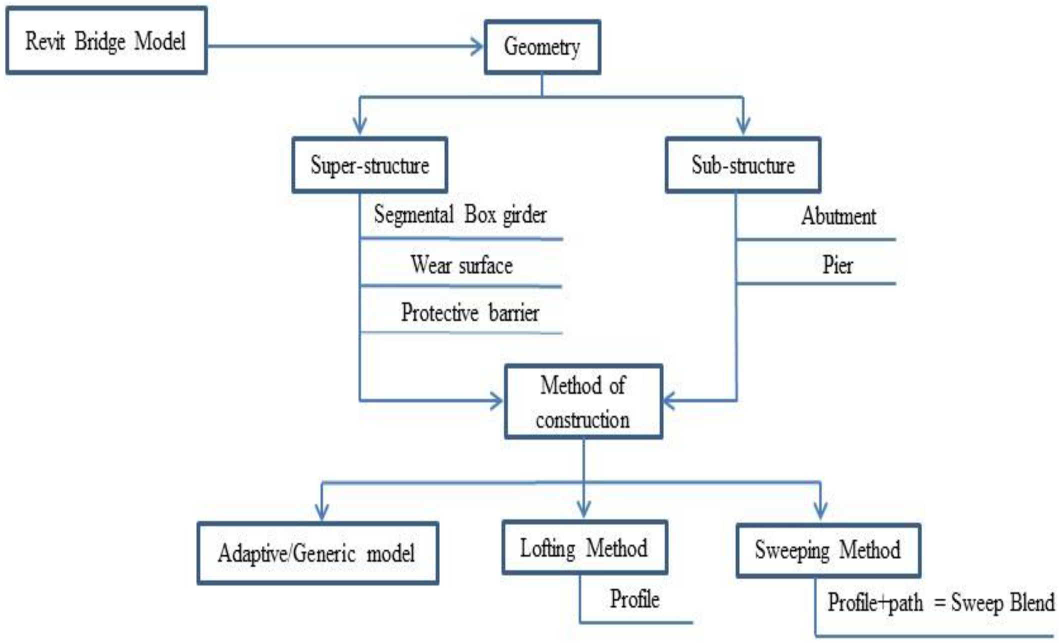


Figure 31 Technique for Revitalize bridge model creation

First the modelling of some Families is necessary for the implementation of the Revit bridge model. All families belong to the structural type family. As a result, these families can be placed along a reference line. In this application, the road and pier axes are the reference line for placement. The selection of the category has been necessary for various reasons. First, it is possible that the road is curved axis, and thus also the superstructure families along this curvature have to be followed. Moreover, the superstructure has a transverse inclination, which must be imaged with the aid of the family. The parameters were as generically defined that each superstructure family have at least the parameters of height, width, cross-slope etc. These parameters are dynamically assigned at runtime node in Dynamo with values.

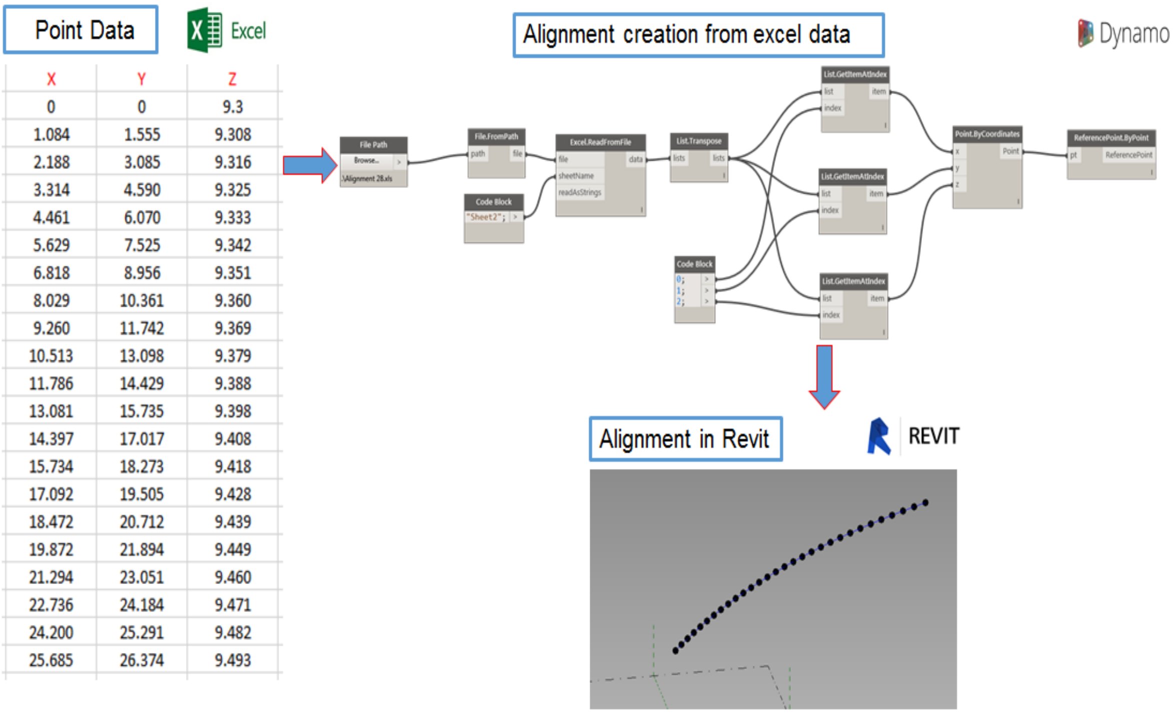
5.3 Study case 1: Parametric bridge modelling in Revit

Dynamo enables designers to apply computational design and automation processes through a node-based visual programming interface without need to write a lot of code. Users can create node-based design definitions for creating, positioning, and visualizing geometry. The visual programming framework lets the user create unique systems and relationships and expand how BIM can be used to drive design ideation (www.dynamobim.org).

While designing a bridge, some issues must be considered. Nowadays the key challenges of the bridge design in Germany are not the economic aspects but due to alignment, the complex geometry at curved alignment, at longitudinal inclination, skewed substructures, variable bottom edges etc. (Stark, 2015).

In this study case, Dynamo is used only to assist creation of bridge route. Easy to understand workflow of visual programming and step results at the same time motivates to know how the visual programming can be integrated with Revit to smooth and automate workflows of bridge design. This approach is carried out based on the adaptive families to create the bridge model in Revit. Bridge cross-section can be correctly placed along the route and sweep volume elements can be created using “Create Form” Revit functionality.
The use of adaptive families carries certain advantages, such as:

- They can be oriented to vertical direction at the placement.
- Start and end can be precisely defined.



X	Y	Z
0	0	9.3
1.084	1.555	9.308
2.188	3.085	9.316
3.314	4.590	9.325
4.461	6.070	9.333
5.629	7.525	9.342
6.818	8.956	9.351
8.029	10.361	9.360
9.260	11.742	9.369
10.513	13.098	9.379
11.786	14.429	9.388
13.081	15.735	9.398
14.397	17.017	9.408
15.734	18.273	9.418
17.092	19.505	9.428
18.472	20.712	9.439
19.872	21.894	9.449
21.294	23.051	9.460
22.736	24.184	9.471
24.200	25.291	9.482
25.685	26.374	9.493

Figure 32 Workflow for alignment creation

The modelling process starts with defining the input parameters of point coordinates from excel to import the alignment data. The superstructure solid is modelled in the following steps:

1. Alignment creation: The modelling process starts with alignment creation of the bridge. The alignment is basically a line of certain points and elevation. Here it has been created arbitrarily in Dynamo creating a curve and extracting points X, Y, Z coordinates along the curve. The coordination of main horizontal alignment can be also imported from other GIS and infrastructure design tools like Autodesk Civil 3D. Later these alignment point co-ordinates can be read as excel data input in Dynamo and imported in metric generic adaptive Revit family template. Above the workflow

shows how excel spreadsheet can be integrated with Dynamo and Revit for parametric data manipulation.

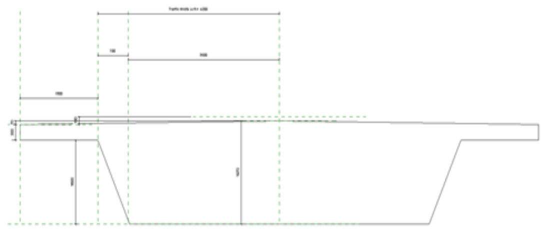
2. Creating bridge cross- section: After creating the alignment the next step is to define the bridge cross-section for superstructure and substructure. The bridge cross section shape has been created as single point adaptive family based. Single point is used to create adaptive family that they can be positioned along the direction of alignment. The orientation parameter of the adaptive point is set to “Global (Z) then Host (XY).

3. Placing bridge cross-section along the alignment: The alignment path in Revit has been divided into certain segments. Adaptive superstructure cross-section is placed on the segment point of the alignment. The bridge superstructure forms then created for whole curve path by “Repeat” and “Create Form” function in Revit.

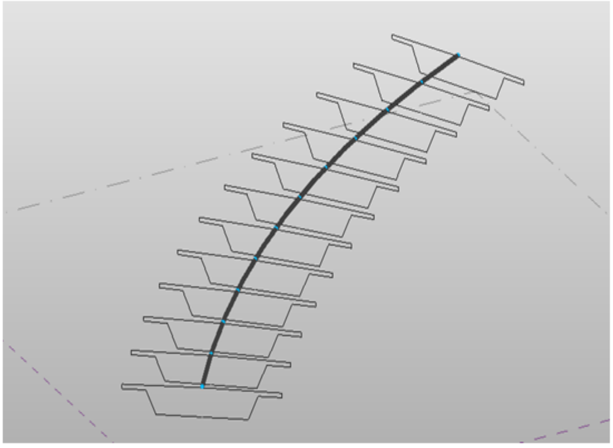
4. Creating bridge superstructure void: The void form has been created similarly placing adaptive cavity family cross-section along the segmental point and using “Create Form” tool in Revit.

5. Abutment creation: The abutment creation is considered as complex than superstructure. Modelling of bridges with non-linear profile such as abutment, simultaneous curvature in the horizontal plane is not possible. A possible alternative would be here creating abutment family with the help of other adaptive families and their placement in the design project. The abutment can be rotated along its axis to enable orientation in space through Dynamo script.

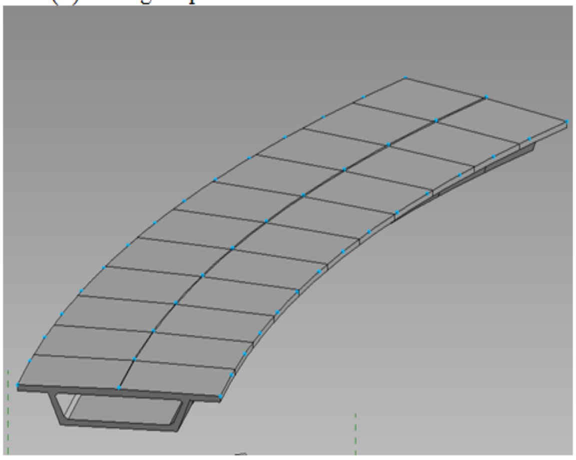
6. Bridge modelling: The creation of complex bridge superstructure from the basic adaptive cross-section shows how the adaptive families can be used for bridge modelling. Similarly, adaptive railing, adaptive abutment has been created and placed with superstructure to complete the bridge modelling in Revit.



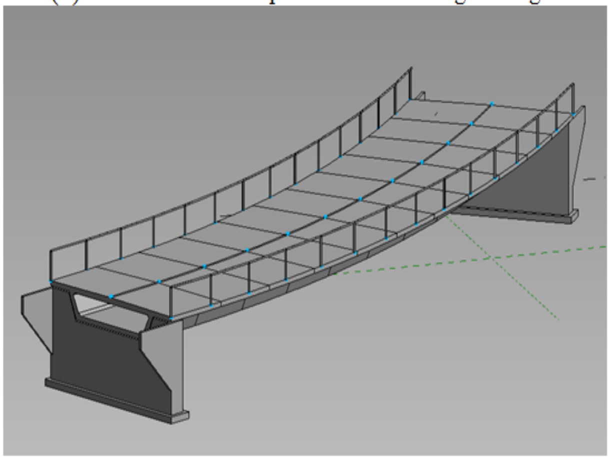
(1) Bridge superstructure cross-section



(2) The cross-section placed vertical along the alignment



(3) Bridge Superstructure created as sweep volume form



(4) Bridge modeled in Revit using adaptive components

Figure 33 Study-case bridge modelling phases

5.4 Study case 2: Arch Bridge modelling in Dynamo

The second study case presents a fully Visual Programming Language (VPL) approach for the geometric modelling of arch bridge. VPL allows creating geometry relationships based on rules and logic. The bridge geometries slab, railing, pier modelled as surface with certain thickness with the help of nodes in Dynamo visual programming. The geometry parameters can be modified accordingly by the adjustment of the input parameter values.

The modelling process of arch bridge is described below in sub-process and the corresponding implementation is shown.

1. **Specifying the start and end station of the bridge**:
   The basic geometric modelling begins with the definition of the bridge arch length and radius. The road length is considered as the tangent to the vertex of the arch (Figure 34). Three independent points representing start, vertex of arch and end of the bridge are defined. These points are manipulated later to succeeding parts to complete the modelling.

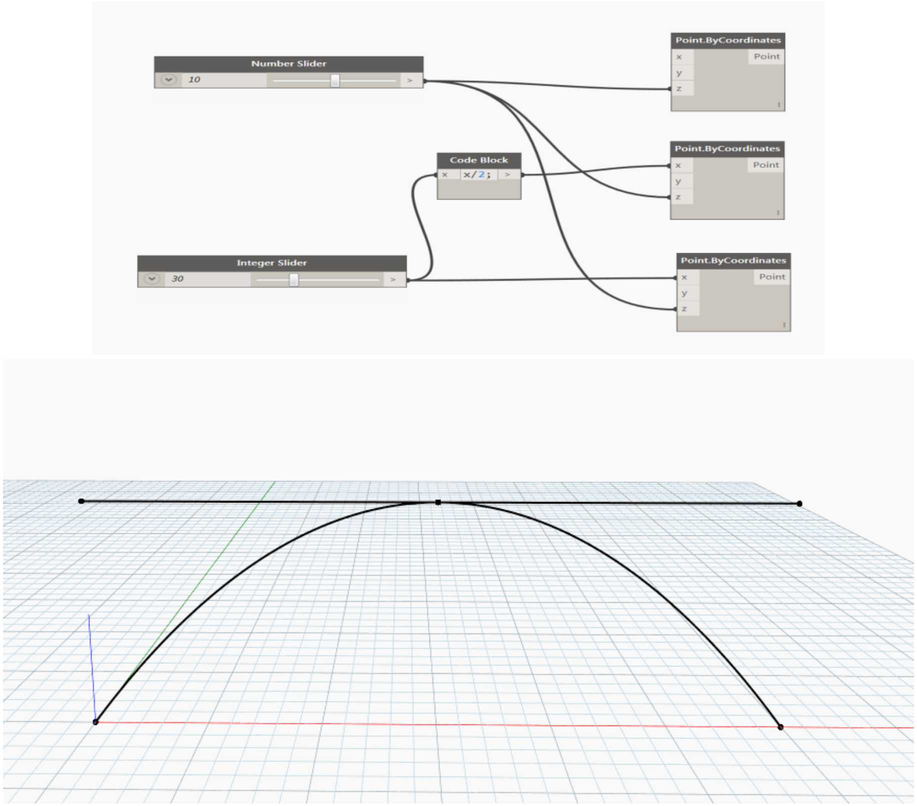
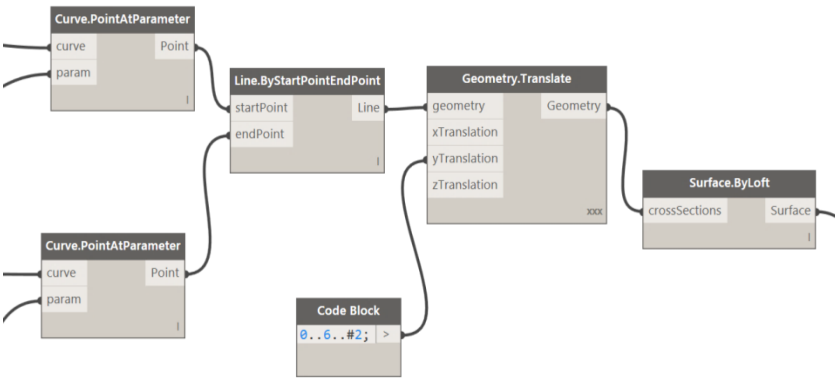


Figure 34 Start and end station of the bridge

2. **Creating arch column support**:
   The vertical arch column has been created at equal distance on the arch. Each column is generated as a function, joining line between the curve points on arch and intersecting points on tangent road length. The column form is modelled by translating the column line in parallel direction and lofting the cross-section between lines to certain thickness. “Line.ByStartPointEndPoint”, “Geometry.Translate” and “Surface.ByLoft” Dynamo nodes used in this operation. The input parameter for the number of columns can be explicitly set by “Integer Slider” node.



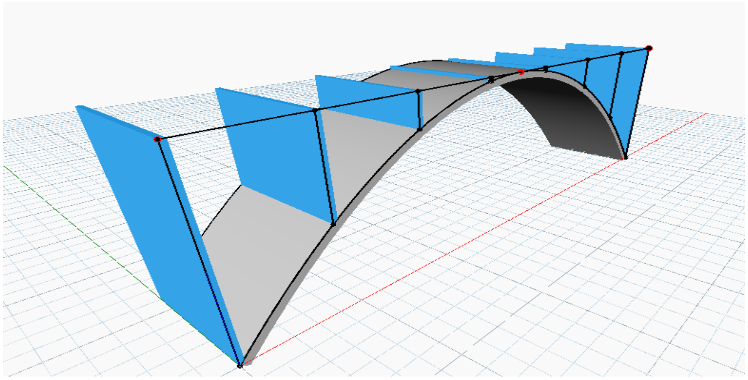


Figure 35 Arch column creation

3. **Creating the road surface:**
The road surface is created as same as arch column geometry by translating the tangent of the arch in the direction of width and lofting inside of the surface. The surface thickness parameter can be controlled by "Number Slider" node.

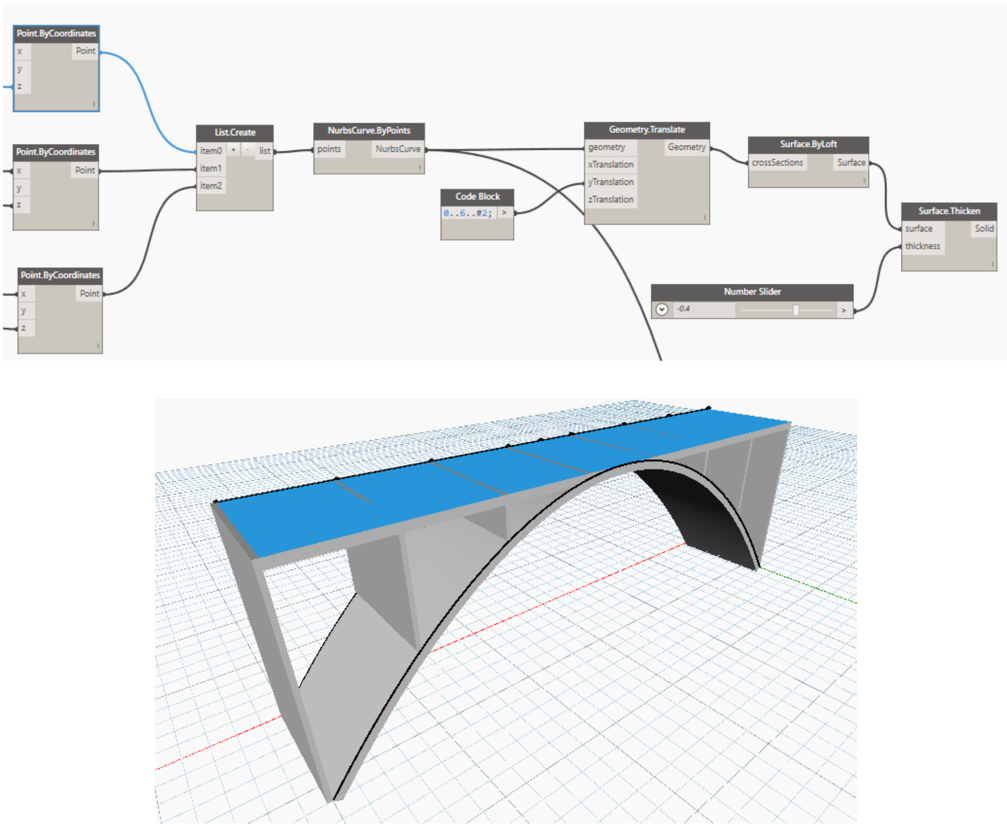


Figure 36 Road surface creation

4. **Creating the railings**:
To complete the geometry of the bridge, we need to create railing on both side of the roadway. To limit the railing start and end point from the bridge length, the tangent curve has been trim by "Curve.TrimByParameter". Translating the trim curve in vertical direction, manipulating both curves into certain segments and after that intersection points are joined through the node "Line.ByStartPointandEndPoint". A series of planes created across the line curve by "Curve.PlaneatParameter" to adjust the geometry according to the curve profile. Generating series of circle on all planes the curve path sweep as solid

circular shape finally, using the node “Geometry.Translate” the created geometry is mirrored on the other side of the road.

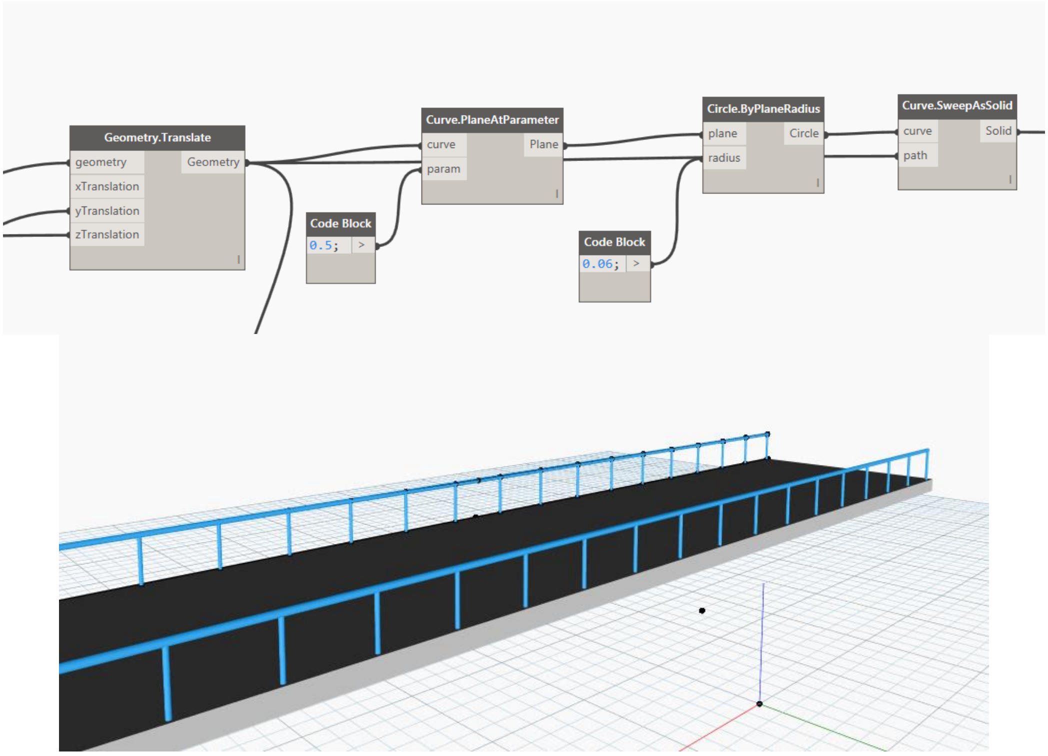


Figure 37 Railing creation

Below shows the arch bridge model generated in Dynamo. Bridge modelled in Dynamo can be imported in Revit as generic model.

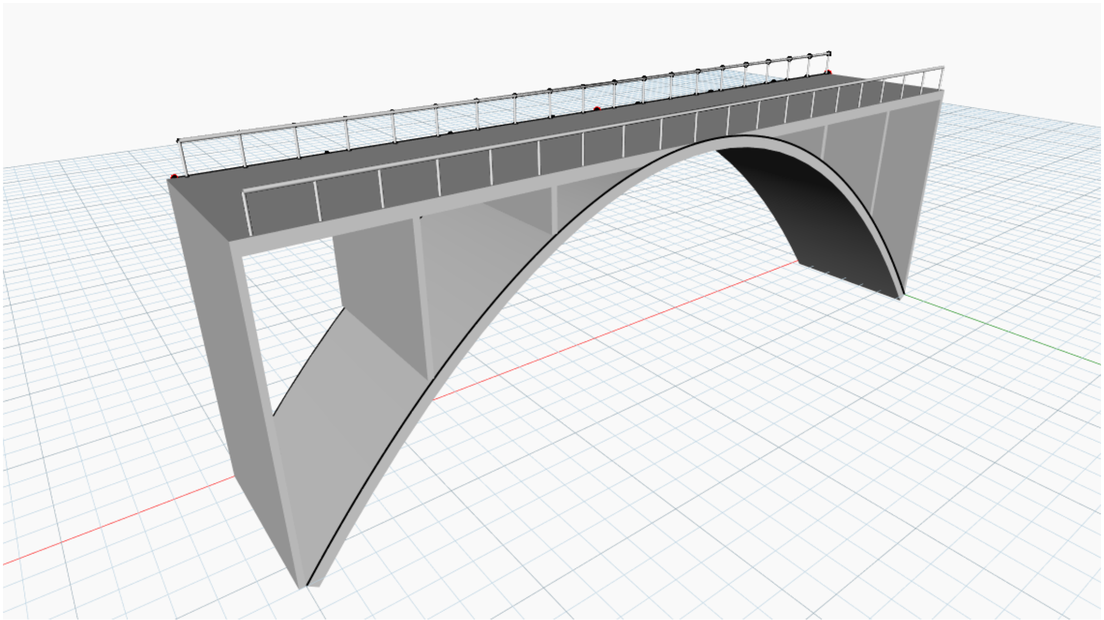


Figure 38 Arch bridge modelled in Dynamo

Further, bridge modelled in Dynamo can be imported in Revit as generic model. Dynamo Plug-in for Robot Structural Analysis/React Structures helps to create parametric and complex structural frames models in Dynamo, then bring it to Autodesk Robot Structural Analysis or Autodesk React Structures for simulation, and review the analysis results.

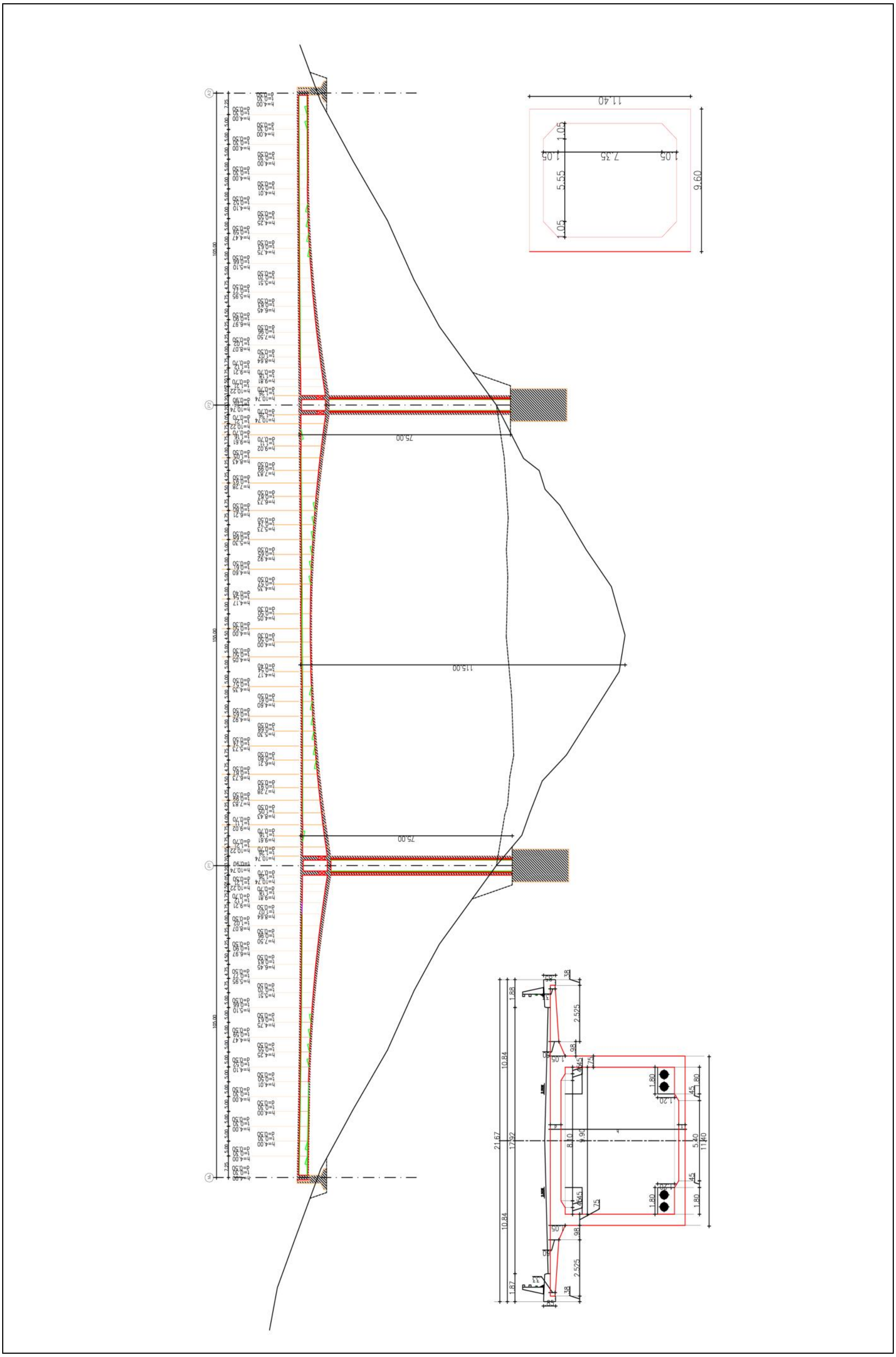
The geometry modelled in dynamo can be transformed into mesh geometry using Dynamo package “Mesh Toolkit”. Meshes are most flexible form of geometry in the computational design. The Mesh geometry can be exported direct as COLLADA format. It can optimize the process of the geometric model first pushed into Revit and converting into IFC. After that an IfcOpenShell converter tool needs to make this IFC model as COLLADA format. To exchange standard information through multimodel method, COLLADA format is needed to link the data model for semantic enrichment. Therefore, study and judgment should be carried out to see the feasibility of the process directly exporting the model from Dynamo to other 3D formats.

5.5 Study case 3: Long span bridge modelling in Revit with Dynamo

For the implementation of parametric bridge modelling in the context of graphical programming interface a bridge model provided as 3D DWG file (AutoCAD format). Provided study case bridge is 365m long and consists of three spans (105m + 155m + 105m). The bridge has been designed with a continuous box-shaped cross section from prestressed concrete. The piers have a maximum height of 75m.

Figure 39 Study case bridge (http://www.denco.gr)

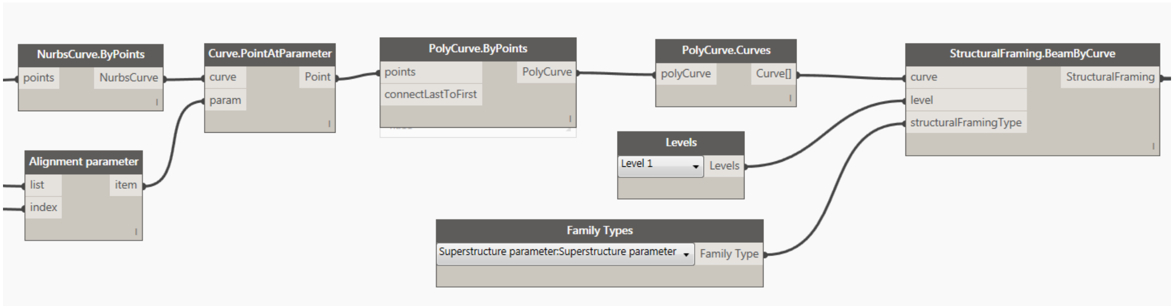
The study case focuses on the implementation of this bridge and parametric variation in graphical programming interface. Later the model is annotated through BIM-Annotator in order to enrich the BIM-model semantically.



The workflow that is applied is based on the creation of lines and curves in Dynamo, which represent the centre lines of the bridge model in Revit. In this modelling approach a Dynamo script is created that enables designer to generate a long span bridge model from Revit family directly in the project environment following the bridge alignment. As excel can be considered as management of building information, in this area Dynamo equipped to parametric data manipulation of the model. To create the bridge model first Revit families for superstructure, substructure, abutment etc. loaded in the Revit project template. The parametric variation of geometry can be easily created and changed through the Dynamo script.

1. Creation of bridge superstructure

The modelling process begins with the bridge alignment creation from excel data point co-ordinates. The workflow for creating the alignment is same as study case 1. Dynamo can create alignment importing X, Y, Z co-ordinates directly from excel.
Later the superstructure form of the bridge created along the alignment curve using Dynamo node "StructuralFraming.BeamByCurve" and with the help of superstructure family. This node will search for loaded Revit family in the project.



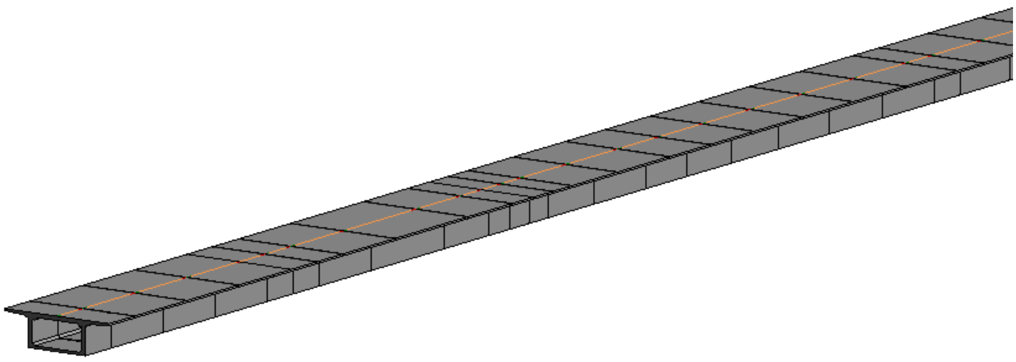
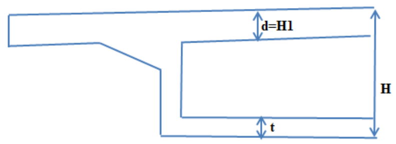


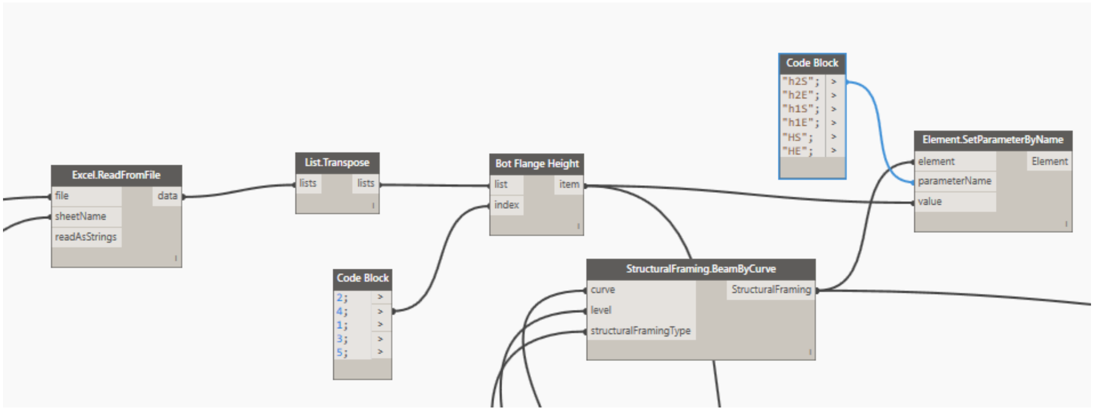
Figure 40 Creation of bridge superstructure

2. Parametric variation of superstructure

Based on the parameters defined on the Revit family, the parameters can be controlled through Dynamo node "Element.SetParameterByname". The variable parameters for the cross-section such as width, thickness, height of the superstructure data can be assigned from excel through this node. Running the Dynamo script can generate variable section of superstructure. Figure 41 shows how excel and Dynamo can be equipped to create free form geometry in Revit.

	Segment Length, (m)	Length parameter	Height of Super-structure, h(m)	Height to Top Flange, h1(m)	Height to Bottom Flange, h2(m)	Bottom Flange Thickness t(m)
	0	0	4	0,5	3,7	0,3
	7,25	0,02	4	0,5	3,7	0,3
	12,25	0,03	4	0,5	3,7	0,3
	17,25	0,05	4	0,5	3,7	0,3
	22,25	0,06	4	0,5	3,7	0,3
	27,25	0,07	4	0,5	3,7	0,3
	32,25	0,09	4,01	0,5	3,51	0,5
Segment (ma)	37,25	0,10	4,1	0,5	3,58	0,52
	42,25	0,12	4,25	0,5	3,7	0,55
	47,25	0,13	4,47	0,5	3,88	0,59
	52,25	0,14	4,75	0,5	4,12	0,63
	57,25	0,16	5,1	0,5	4,44	0,66
	62,25	0,17	5,51	0,5	4,81	0,7
	67,00	0,18	5,95	0,55	5,18	0,77
	71,75	0,20	6,45	0,5	5,62	0,83
	76,25	0,21	6,97	0,5	6,07	0,9
	80,50	0,22	7,5	0,5	6,54	0,96
	84,75	0,23	8,07	0,5	7,05	1,02
	88,75	0,24	8,64	0,5	7,57	1,07





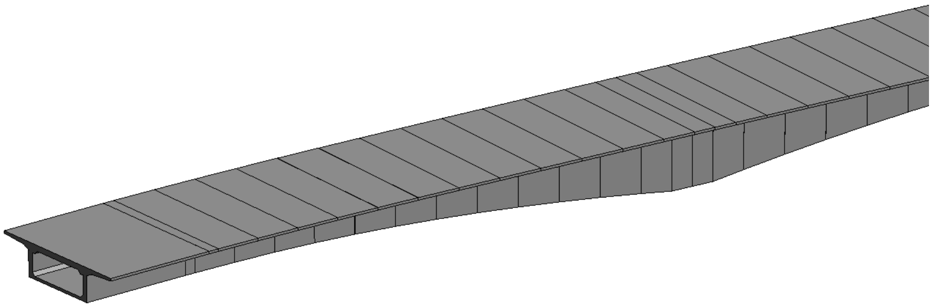


Figure 41 Extract Superstructure parameters from Excel file

3. Pier creation

As the bridge has different span length, first pier locations on the alignment are determined. Using Dynamo node “Point.ByCartesianCoordinates” and connect it to “Line.ByStartPoint DirectionalLength” node two vertical lines are drawn. These 2 lines represent as the curve path for pier and similarly as the superstructure, piers have been created using Dynamo node “StructuralFraming.BeamByCurve”.

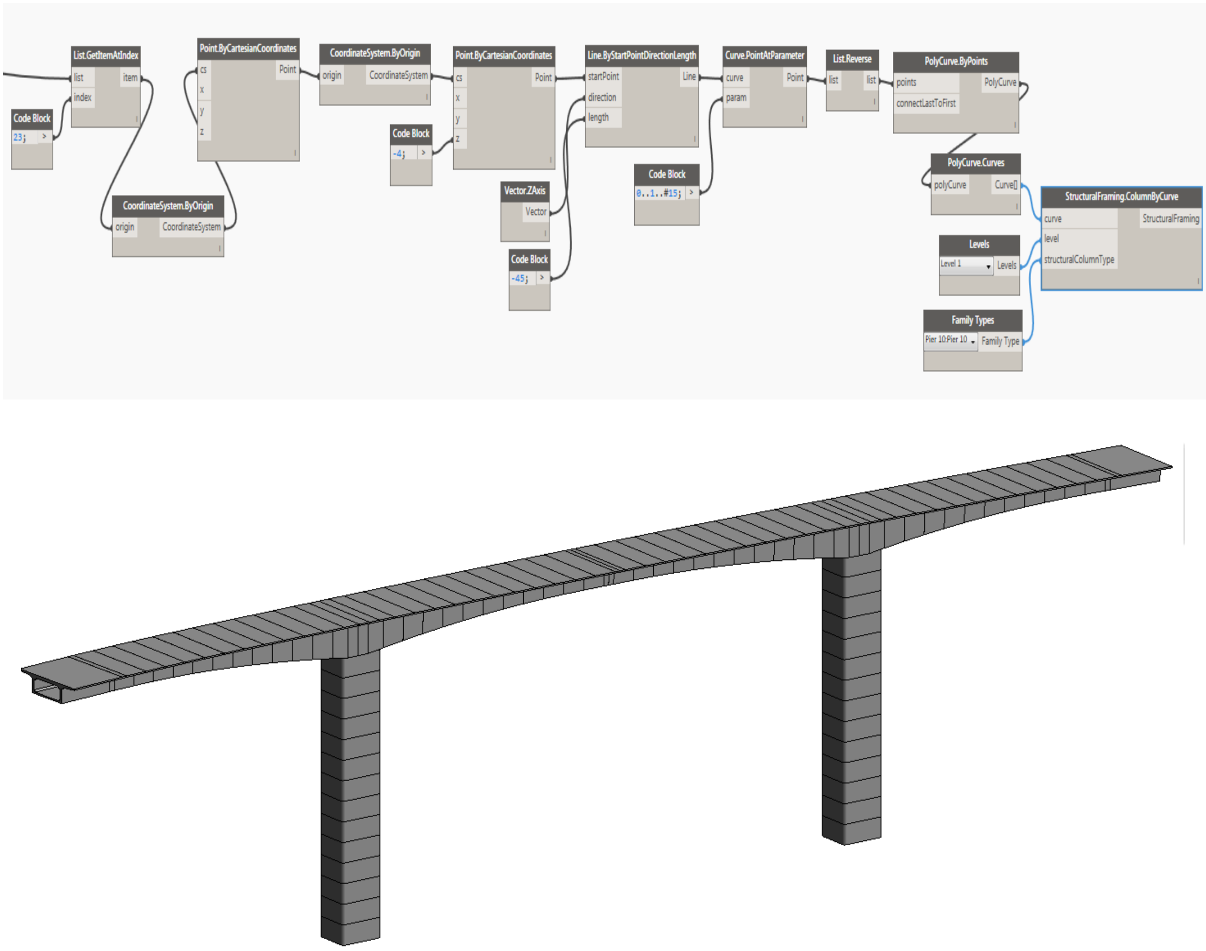


Figure 42 Pier creation

Placing the abutments

At the beginning and end of the bridge alignment abutment are placed. The points for placing the abutment family are determined from the start and end points of the curve. After loading, the abutment family can be placed at the points with the aid of the node "FamilyInstance.ByPoint" (Figure 43). The abutment parameters width, wall thickness, height can be controlled through Dynamo node. The width of the abutment is chosen from the superstructure width to act parametric together with superstructure. Orientation of the abutment can be directed to the bridge alignment by the node "FamilyInstance.Set Rotation".

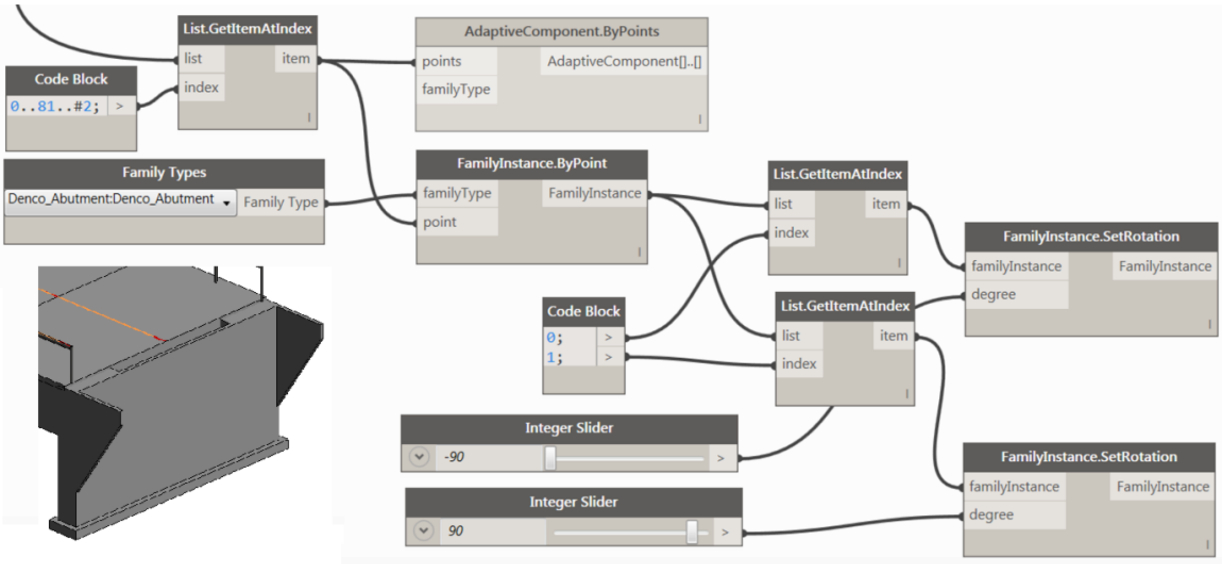


Figure 43 Loading and placing the abutment

After going through all the processes or nodes that the boundary conditions corresponding bridge model (Figure 44) is generated in Revit. Thus the created 3D model can be evaluated with a BIM Evaluation Tool, that the necessary model data is transferred. It must be ensured that both geometric and semantic information are necessary for the respective application.

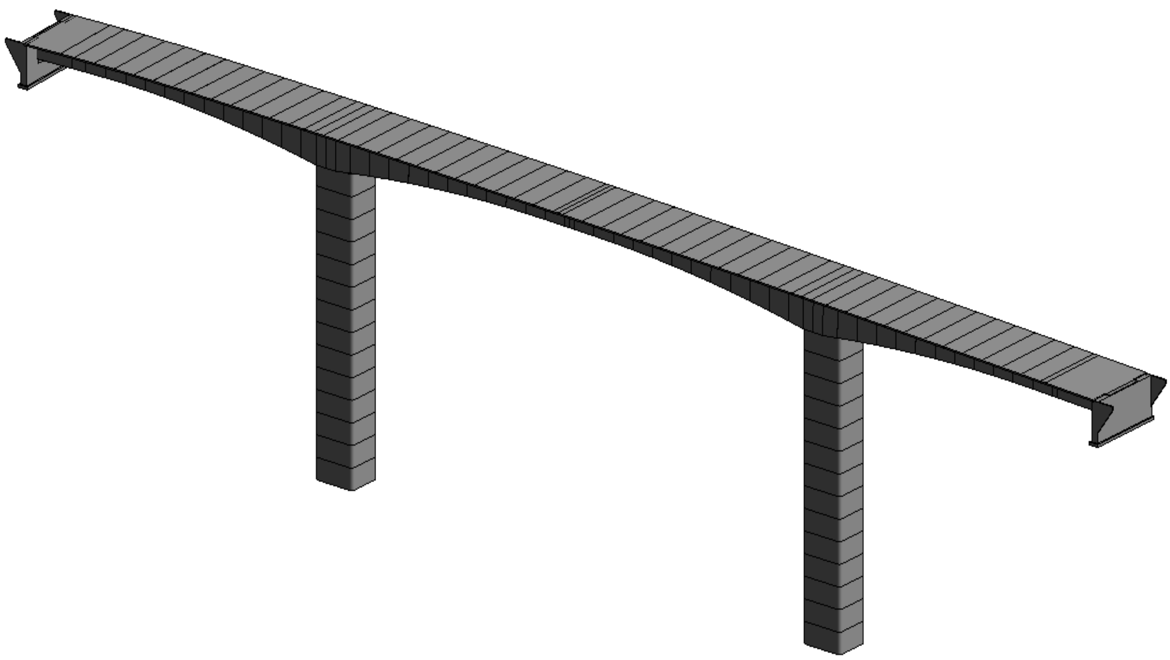


Figure 44 Bridge model generated in Revit

In Revit the bridge model further can be enhanced using terrain surrounding the bridge model (Figure 45).

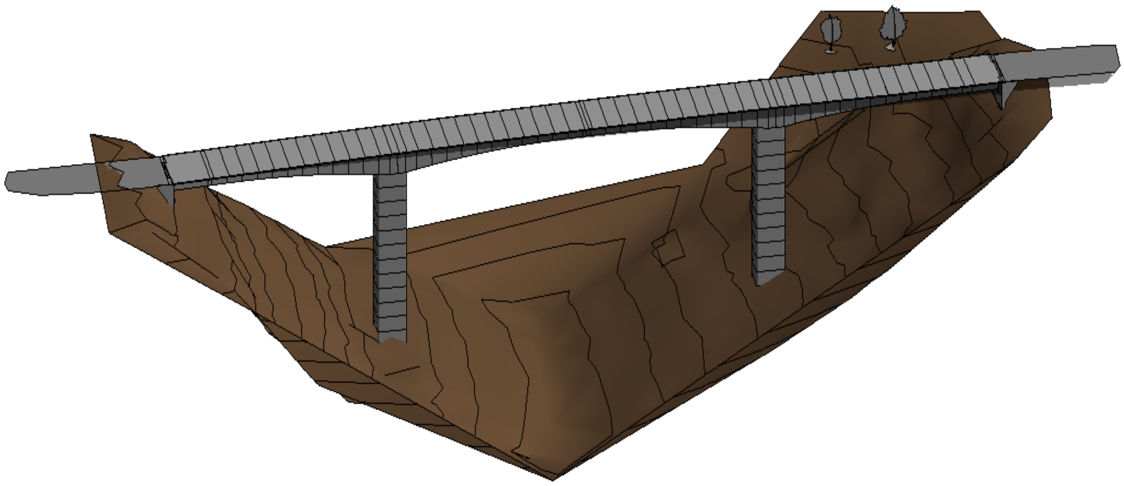


Figure 45 Study case bridge with terrain

5.6 Annotation of bridge model

So far the 3D geometry model of the bridge using VP with Dynamo is generated. The resulting model has a comprehensive geometric representation. However, it has poor semantic information (classification of elements, attributes). To handle this issue and get the ultimate potential of using the BIM models for different data exchange scenarios during the construction life cycle, an annotation tool "BIM-Annotator" with the help of a reference database for classification and standard attributes of typical bridge elements was developed (Ismail et al 2016). Here, BIM-Annotator is used for:

- Collaborative online data enrichment tool by adding, editing and extending information to original model.
- A consistent annotation process by using a reference database (accessible and searchable) for classification and standard attributes of typical bridge element.

In a rich semantic model each element in the model should donate a very specific component. This means, it should be assigned to a specific class and described with a set of predefined properties and relations with other elements. The result will be a virtual 3D bridge model which consists of components such as piers, beams and abutments and hence partial views and specific information can be extracted through filtering and semantic reasoning.

For this purpose, all IFC classes including extra classes of the IFC-Bridge extension and standard property sets of IFC model have been integrated into a reference database. BIM-Annotator allows the user to assign classes of elements, edit, delete and add new property sets, define and organize group of objects hierarchically and assign attributes to them. The semantic data which are entered through the BIM-Annotator can be exported in XML format with an additional XML-Link model, which links the semantic information with 3D objects.

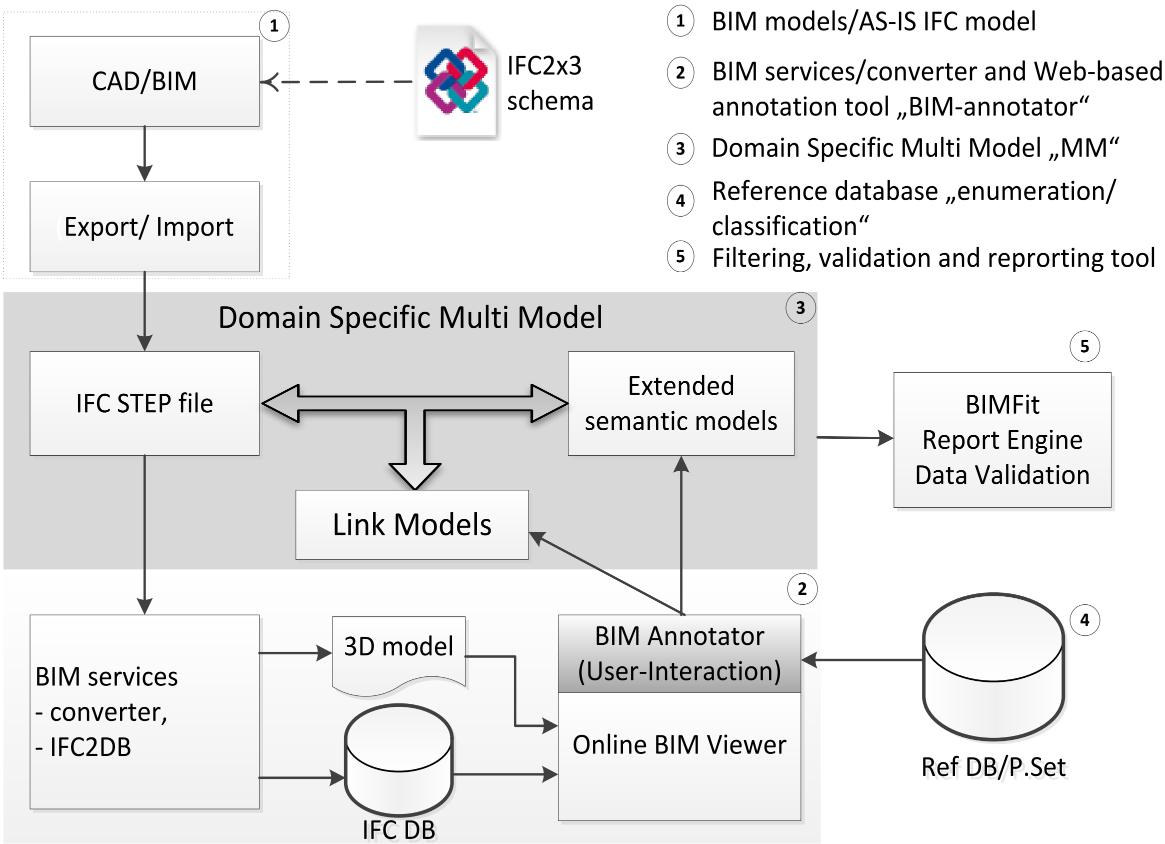


Figure 46 BIM-Annotator data flow and system architecture[12]

In principal, multimodel containers consist of elementary models from different domains and each model can be independently processed by participants. Each participant has the opportunity to create or develop their own elementary models and link it with existing models. This opportunity creates a possibility for participants to recombine the multimodels based on what they need as well as on requirement of the project itself. The container contains an XML-based description of its contents. It provides metadata on the subjects, detailing and data format as well as the creators or contributors for each elementary models.

Figure 47 shows the process of assigning new class and use of the new added property set template (http://150.254.208.60:3000/projects/10/documents/19#) of a bridge segment part element.

For semantic enrichment we need multimodel container as exchange format. Each multimodel container is realized by exchange compressed archive file. The MMC template (Figure 48) is taken from the Bridge cloud project (Ismail et al 2016).

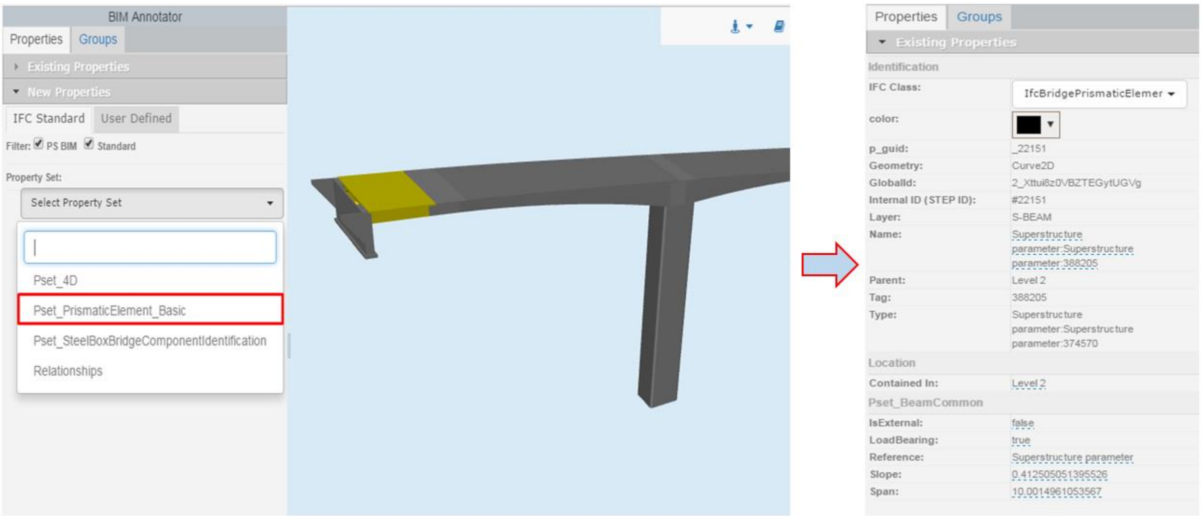


Figure 47 Change the class and add new properties of a bridge segment part element

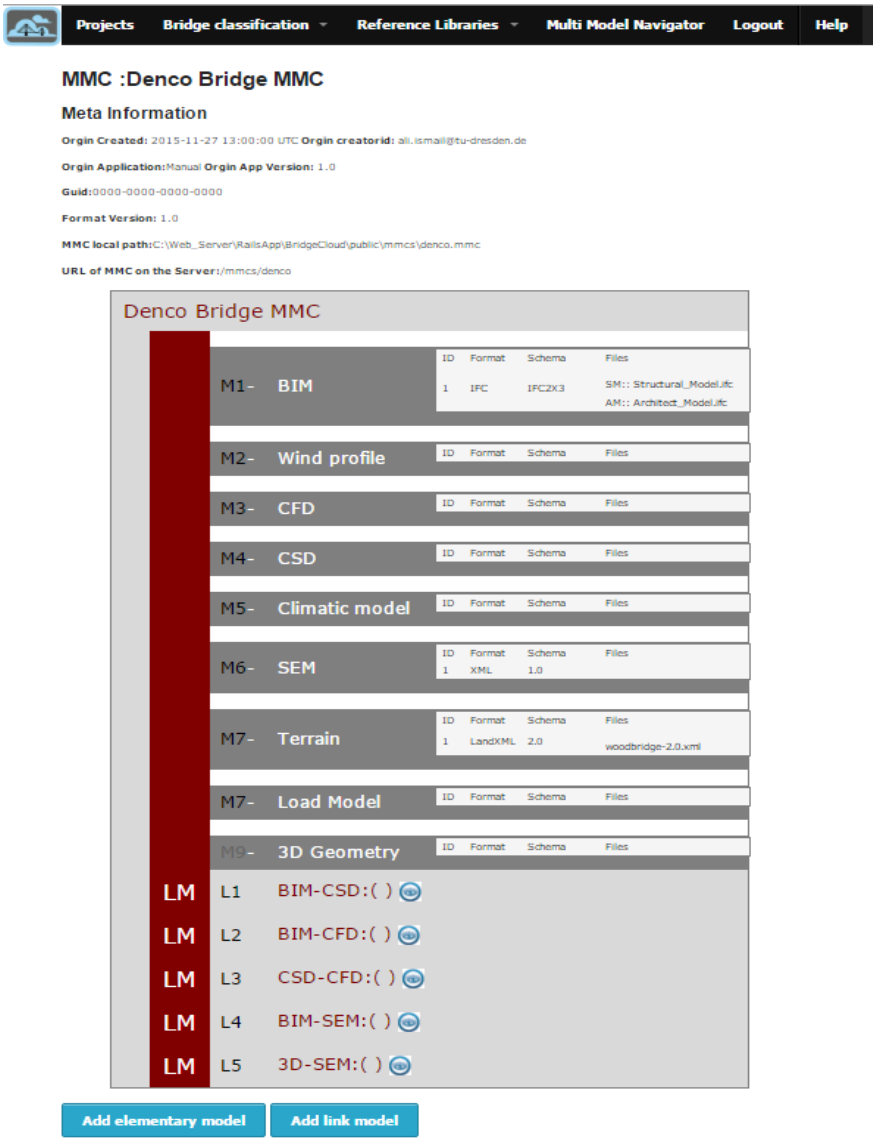


Figure 48 Example of a MMC for a bridge design

```
<?xml version="1.0" encoding="UTF-8"?>
- <linkModel version="1.0" id="L1">
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="4" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="5" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="6" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="7" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="8" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="9" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="10" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_083" m="FM1"/>
      <link id="11" m="FM2"/>
    </linkObject>
  - <linkObject>
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      <link id="13" m="FM2"/>
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      <link id="15" m="FM2"/>
    </linkObject>
  - <linkObject>
      <link id="BRIDGE_CaseStudy_3D_002" m="FM1"/>
      <link id="17" m="FM2"/>
    </linkObject>
```

```
<?xml version="1.0" encoding="UTF-8"?>
<IfcPropertySingleValue id="4">
    <Name>Reference</Name>
    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>ref 001
</IfcDescriptiveMeasure-wrapper>
    </NominalValue>
</IfcPropertySingleValue>
<IfcPropertySingleValue id="5">
    <Name>BuildingHeightLimit</Name>
    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>75
</IfcDescriptiveMeasure-wrapper>
    </NominalValue>
</IfcPropertySingleValue>
<IfcPropertySingleValue id="6">
    <Name>TotalArea</Name>
    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>1500
</IfcDescriptiveMeasure-wrapper>
    </NominalValue>
</IfcPropertySingleValue>
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    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>ASSIGNMENT
</IfcDescriptiveMeasure-wrapper>
    </NominalValue>
</IfcPropertySingleValue>
<IfcPropertySingleValue id="8">
    <Name>Identifier</Name>
    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>Bridge 001
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    </NominalValue>
</IfcPropertySingleValue>
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    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>1.0
</IfcDescriptiveMeasure-wrapper>
    </NominalValue>
</IfcPropertySingleValue>
<IfcPropertySingleValue id="10">
    <Name>VersionDate</Name>
    <NominalValue>
        <IfcDescriptiveMeasure-wrapper>01.01.2010
```


Figure 49 a) Semantic-Link data b) Semantic elementary model data

As mentioned above using BIM-annotator to improve the semantic quality of bridge model. The bridge IFC model is exported as multimodel after annotating user defined properties to the model. The container contains an XML-based description of its contents (Figure 49). It provides metadata on the subjects, detailing, data format as well as the creators or contributors for each elementary models. Every component has identification number defined as “Ifc PropertySingleValue”. As an example “link id= 5” in link model data refers to the “Building Height Limit” in semantic data model which is dimensional constraint a numerical value of 75m (IfcDescriptiveMeasure-wrapper), describes the height of the bridge.

Semantic database contains the classes of IFC and IFC-Bridge with their property sets. The user can also add more property set in database. Furthermore, these new property set with attributes accessible in BIM-annotator workspace. This opportunity is much convenient to assign these properties in new model.

Besides assigning the classes and property sets of model elements, BIM-Annotator act as container of geometric information and project related data too. The designer can store the information for types of structure, quantity of segment, Strength, about reinforcement, project schedule for segmental element constructions (Figure 50) and so on.

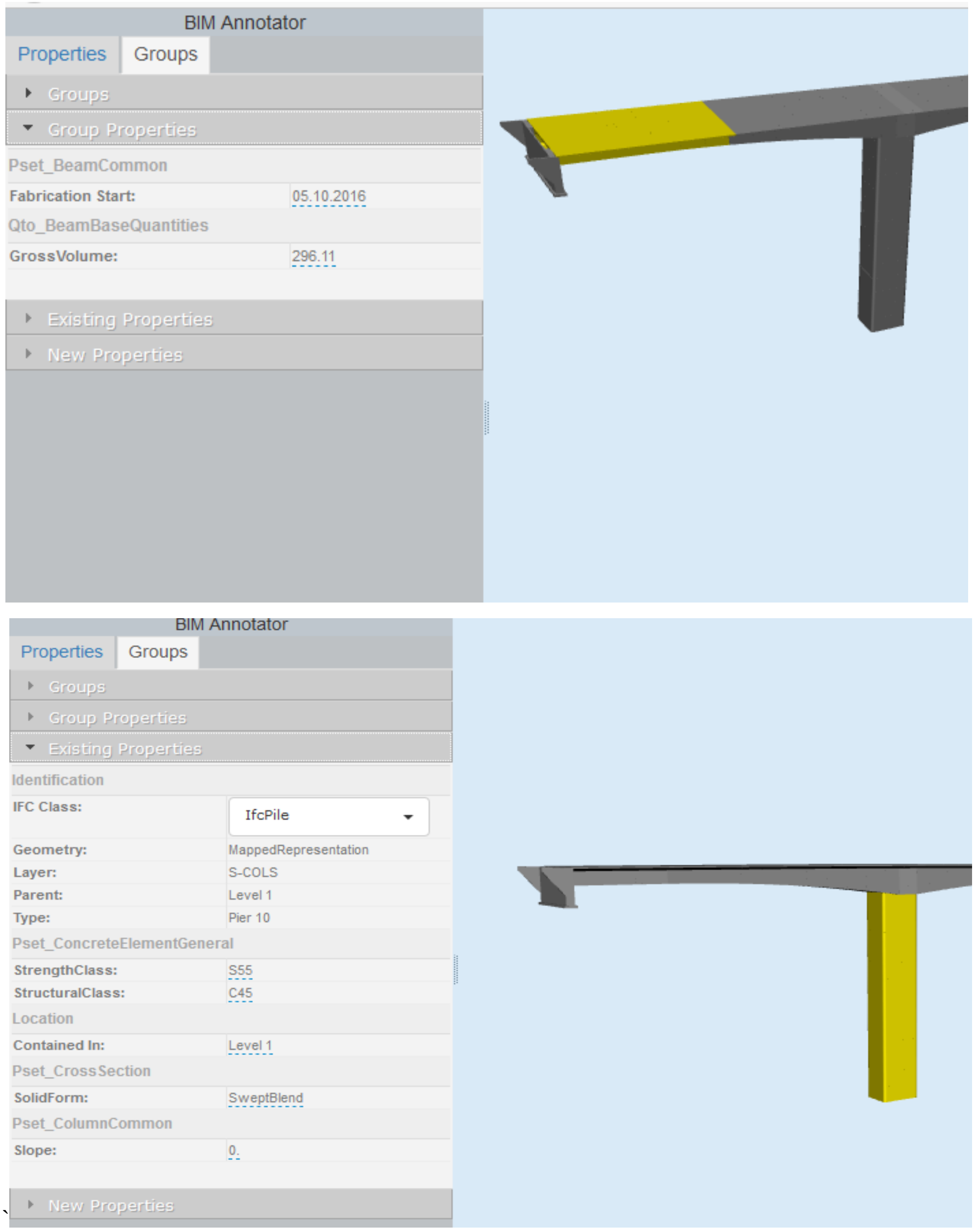

Figure 50 Semantically enriched study case bridge segment

5 Conclusion and Future work

First, the term Building Information Modelling and its current adaptation in the bridge design is clarified. Study cases workflow to generate bridge model variations based on the visual programming approach and the semantic enrichment of these models based on the IFC standard presented. Bridges are modelled using Dynamo standalone and as extension inside Revit. First, Dynamo plugin for Revit has been used to create the alignment and the bridge is fully modelled in Revit from adaptive families. Limitation of Revit with the Civil Structures plugin are bridge definition, substructure (supports, abutments etc.) from the templates are freely modifiable, but not all bridge types can be modelled. Here, the users have less choice to create complex shape of bridge geometry through this plug in.

First study case approach has the disadvantage that the entire bridge regarded only as a composite component in Revit project environment and all sub components lose their attributes. The property as a composite component complicates the further evaluations. Each component must be manually selected first and will subsequently provide with attributes for BIM annotation.

The second study case shows the possibilities for the designer to model the bridge from scratch fully standalone in Dynamo visual programming workspace. The parameters such as adjustment of dimensions, insertion or movement of components can be managed automatically through nodes in Dynamo. The last study case offers parametric bridge modelling and variation in Revit through visual programming script. Finally, the bridge model can be driven into the BIM Annotator tool to improve the semantic quality of bridge models and link specific domain information from various domains with focus on bridge models based on the IFC standards. In Revit Structure, a template file to be created contains all references in the respective family link and used for each component as a base before the modelling.

The study cases presented here are presentation of how geometric modelling can be automated and shows the potential of Revit, Dynamo and Excel together in one platform. New ideas are waiting to make this geometric model for further structural analysis, rebar design, directly export the model as IFC from Dynamo standalone created geometry. Also to make it efficient BIM model for further phases like level of Development (LOD). Current model fulfils only the lower LOD classification LOD 200. The study case bridge (Denco) model is tried to analysed statically importing the model in Robot Structural Analysis (RSA). Its need to explore how the analysis can be done for user defined Revit section in RSA instead of its own geometric section.

Dynamo can be considered as free hand tool for generative design. Thus, the design freedom is given and changes can be accommodated quickly. The great advantage of Dynamo is that it can integrate with several software for computational design and link with Microsoft Excel for data records and read the parameters. A large community of Dynamo user stands behind it and showing the progress and new challenges to expand the Revit for parametric modelling.

In conclusion remains to say that the future work is to extend the visual script for more bridge type that can be easily user controlled such that the script will contain Revit family for several bridge types, cross-sections etc. Furthermore, generation of analytical model for structural analysis, detail plan generation of model etc. perhaps with a deeper understanding of the Dynamo visual programming.

The concept of collaborative semantic enrichment, annotation of BIM model improves the semantic quality of the bridge model. The information can be exchanged in different domain through Multimodel concept. Current BIM-Annotator semantic database does not include IFC definition of quantities properties. It is necessary to have filtering options for objects, improved semantic database for a better annotation process.

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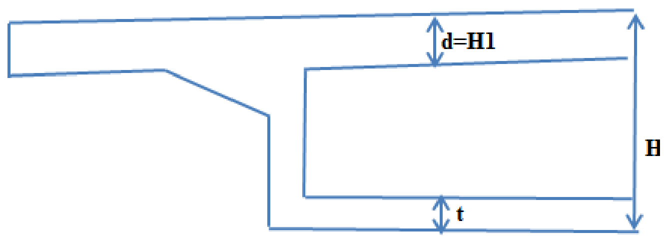
Appendix

A.1 Used Software

AutoCAD 2014
Autodesk Revit 2016
Dynamo version 1.0.0.1180
Microsoft Excel 2013
Solibri Model Viewer v9.6
BIM-Annotator

A.2 Denco bridge super-structure parameter



Height of superstructure H

Height to top flange H1=d

Height to bottom flange H2= H-d

Segment	Length, (m)	Length parameter	Height of Super-structure, H(m)	Height to top flange, H_1(m)	Height to bottom flange, H_2(m)	Bottom flange thickness t(m)
Ma	0	0	4	0,5	3,7	0,3
	7,25	0,02	4	0,5	3,7	0,3
	12,25	0,03	4	0,5	3,7	0,3
	17,25	0,05	4	0,5	3,7	0,3
	22,25	0,06	4	0,5	3,7	0,3
	27,25	0,07	4	0,5	3,7	0,3
	32,25	0,09	4,01	0,5	3,51	0,5
	37,25	0,10	4,1	0,5	3,58	0,52
	42,25	0,12	4,25	0,5	3,7	0,55
	47,25	0,13	4,47	0,5	3,88	0,59
	52,25	0,14	4,75	0,5	4,12	0,63
	57,25	0,16	5,1	0,5	4,44	0,66
	62,25	0,17	5,51	0,5	4,81	0,7
	67,00	0,18	5,95	0,55	5,18	0,77
	71,75	0,20	6,45	0,5	5,62	0,83

	76,25	0,21	6,97	0,5	6,07	0,9
	80,50	0,22	7,5	0,5	6,54	0,96
	84,75	0,23	8,07	0,5	7,05	1,02
	88,75	0,24	8,64	0,5	7,57	1,07
	92,50	0,25	9,21	0,7	8,09	1,12
	96,25	0,26	9,81	0,7	8,63	1,18
	98,75	0,27	10,22	0,5	9,01	1,21
	101,80	0,28	10,74	0,7	9,48	1,26
P1	105,00	0,29	10,74	0,9	9,48	1,26
	108,20	0,30	10,74	0,7	9,48	1,26
	111,25	0,30	10,22	0,7	9,01	1,21
	115,00	0,32	9,61	0,7	8,45	1,16
	118,75	0,33	9,02	0,7	7,91	1,11
	122,75	0,34	8,43	0,5	7,38	1,05
	127,00	0,35	7,83	0,5	6,84	0,99
	131,25	0,36	7,28	0,5	6,35	0,93
	135,75	0,37	6,73	0,5	5,86	0,87
	140,50	0,38	6,21	0,5	5,41	0,8
	145,25	0,40	5,73	0,5	4,99	0,74
	150,25	0,41	5,3	0,5	4,62	0,68
	155,25	0,43	4,92	0,5	4,27	0,65
	160,25	0,44	4,6	0,5	3,99	0,61
	165,25	0,45	4,35	0,5	3,78	0,57
	170,25	0,47	4,17	0,4	3,63	0,54
	175,25	0,48	4,05	0,3	3,55	0,5
	180,25	0,49	4	0,3	3,5	0,5
	184,75	0,51	4	0,3	3,5	0,5
	189,75	0,52	4,05	0,3	3,55	0,5
	194,75	0,53	4,17	0,4	3,63	0,54
	199,75	0,55	4,35	0,5	3,78	0,57
	204,75	0,56	4,6	0,5	3,99	0,61
	209,75	0,57	4,92	0,5	4,27	0,65
	214,75	0,59	5,3	0,5	4,62	0,68
	219,75	0,60	5,73	0,5	4,99	0,74
	224,50	0,62	6,21	0,5	5,41	0,8
	229,25	0,63	6,73	0,5	5,86	0,87
	233,75	0,64	7,28	0,5	6,35	0,93
	238,00	0,65	7,83	0,5	6,84	0,99
	242,25	0,66	8,43	0,5	7,38	1,05
	246,25	0,67	9,02	0,7	7,91	1,11
	250,00	0,68	9,61	0,7	8,45	1,16
	253,75	0,70	10,22	0,7	9,01	1,21

	256,80	0,70	10,74	0,7	9,48	1,26
P2	260,00	0,71	10,74	0,9	9,48	1,26
	263,20	0,72	10,74	0,7	9,48	1,26
	266,25	0,73	10,22	0,7	9,01	1,21
	268,75	0,74	9,81	0,7	8,63	1,18
	272,50	0,75	9,21	0,7	8,09	1,12
	276,25	0,76	8,64	0,5	7,57	1,07
	280,25	0,77	8,07	0,5	7,05	1,02
	284,50	0,78	7,5	0,5	6,54	0,96
	288,75	0,79	6,97	0,5	6,07	0,9
	293,25	0,80	6,45	0,5	5,62	0,83
	298,00	0,82	5,95	0,5	5,18	0,77
	302,75	0,83	5,51	0,5	4,81	0,7
	307,75	0,84	5,1	0,5	4,44	0,66
	312,75	0,86	4,75	0,5	4,12	0,63
	317,75	0,87	4,47	0,5	3,88	0,59
	322,75	0,88	4,25	0,5	3,7	0,55
	327,75	0,90	4,1	0,5	3,58	0,52
	332,75	0,91	4,01	0,5	3,51	0,5
	337,75	0,93	4	0,5	3,7	0,3
	342,75	0,94	4	0,5	3,7	0,3
	347,75	0,95	4	0,5	3,7	0,3
	352,75	0,97	4	0,5	3,7	0,3
	357,75	0,98	4	0,5	3,7	0,3
Mb	365,00	1,00	4	0,5	3,7	0,3

A.3 Bridge alignement data

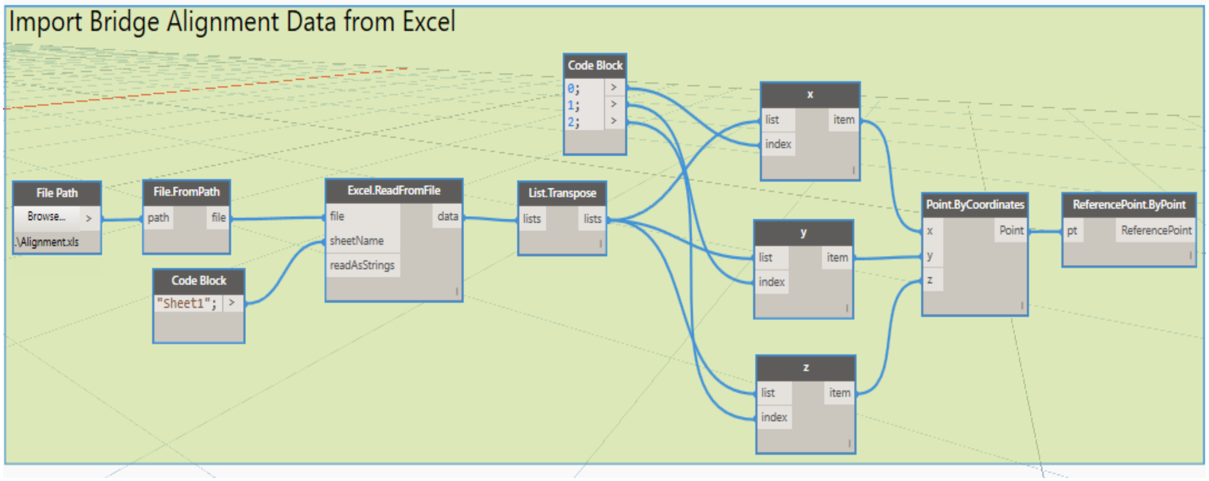
Station	Easting	Northing	Elevation
0+70	4,45123554	0,04100742	15
0+72	8,90247068	0,08205621	15
0+74	13,3537054	0,12314637	15
0+76	17,8049398	0,1642779	15
0+78	22,2561737	0,2054508	15
0+80	26,7074073	0,24666507	15
0+82	31,1586405	0,28792071	15
0+84	35,6098732	0,32921772	15
0+86	40,0611056	0,3705561	15
0+88	44,5123376	0,41193586	15
0+90	48,9635692	0,45335698	15
0+92	53,4148004	0,49481948	15
0+94	57,8660311	0,53632334	15

0+96	62,3172615	0,57786858	15
0+98	66,7684915	0,61945518	15
0+100	71,2197211	0,66108316	15
0+102	75,6709503	0,70275251	15
0+104	80,1221792	0,74446322	15
0+106	84,5734076	0,78621531	15
0+108	89,0246356	0,82800877	15
0+110	93,4758632	0,8698436	15
0+112	97,9270905	0,9117198	15
0+114	102,378317	0,95363737	15
0+116	106,829544	0,99559632	15
0+118	111,28077	1,03759663	15
0+120	115,731995	1,07963831	15
0+122	120,183221	1,12172136	15
0+124	124,634446	1,16384579	15
0+126	129,08567	1,20601158	15
0+128	133,536894	1,24821875	15
0+130	137,988118	1,29046728	15
0+132	142,439341	1,33275719	15
0+134	146,890564	1,37508847	15
0+136	151,341786	1,41746111	15
0+138	155,793008	1,45987513	15
0+140	160,24423	1,50233052	15
0+142	164,695451	1,54482728	15
0+144	169,146672	1,58736541	15
0+146	173,597893	1,62994491	15
0+148	178,049113	1,67256578	15
0+150	182,500333	1,71522802	15
0+152	186,951552	1,75793163	15
0+154	191,402771	1,80067662	15
0+156	195,853989	1,84346297	15
0+158	200,305207	1,88629069	15
0+160	204,756425	1,92915979	15
0+162	209,207643	1,97207025	15
0+164	213,65886	2,01502209	15
0+166	218,110076	2,05801529	15
0+168	222,561292	2,10104987	15
0+170	227,012508	2,14412582	15
0+172	231,463723	2,18724314	15
0+174	235,914938	2,23040183	15
0+176	240,366153	2,27360188	15
0+178	244,817367	2,31684331	15

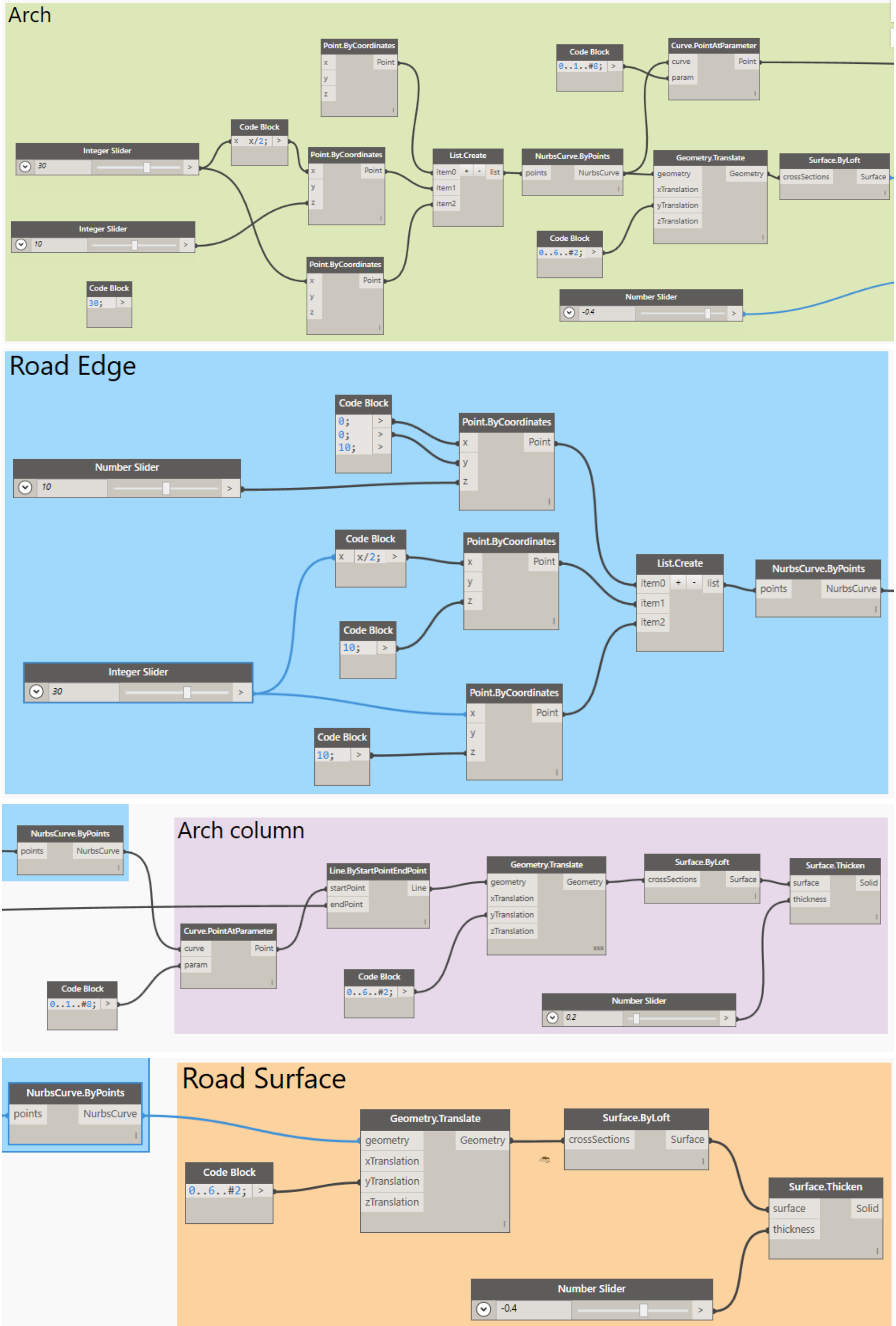
0+180	249,268581	2,36012611	15
0+182	253,719794	2,40345029	15
0+184	258,171007	2,44681583	15
0+186	262,62222	2,49022274	15
0+188	267,073432	2,53367102	15
0+190	271,524644	2,57716068	15
0+192	275,975855	2,6206917	15
0+194	280,427066	2,66426409	15
0+196	284,878277	2,70787786	15
0+198	289,329487	2,75153299	15
0+200	293,780697	2,7952295	15
0+202	298,231906	2,83896738	15
0+204	302,683115	2,88274662	15
0+206	307,134324	2,92656724	15
0+208	311,585532	2,97042923	15
0+210	316,03674	3,01433259	15
0+212	320,487947	3,05827732	15
0+214	324,939154	3,10226342	15
0+216	329,390361	3,14629089	15
0+218	333,841567	3,19035973	15
0+220	338,292773	3,23446995	15
0+222	342,743979	3,27862153	15
0+224	347,195184	3,32281448	15
0+226	351,646388	3,3670488	15
0+228	356,097593	3,4113245	15
0+230	360,548797	3,45564156	15
0+232	365	3,5	15

A.4 Dynamo scripts

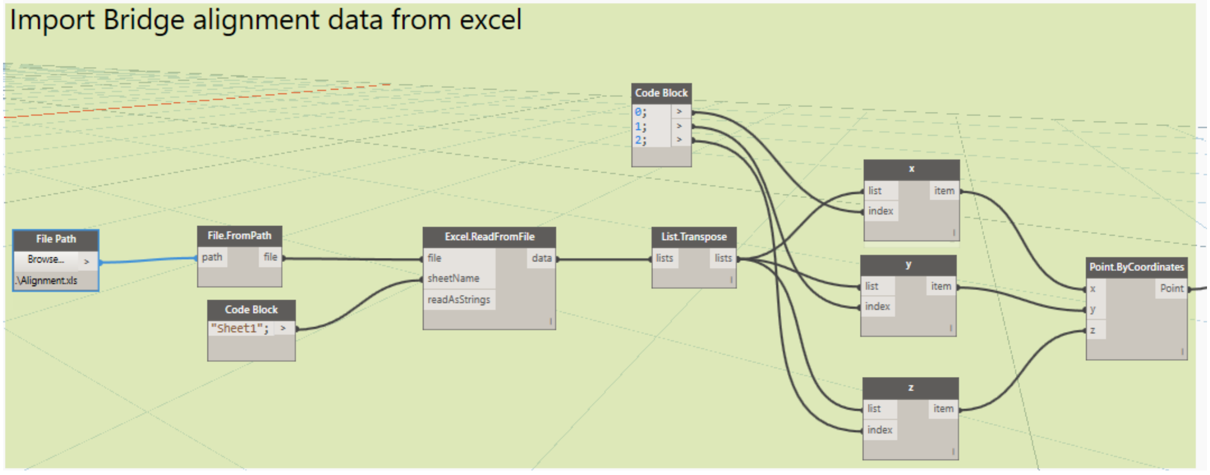
Study case 1

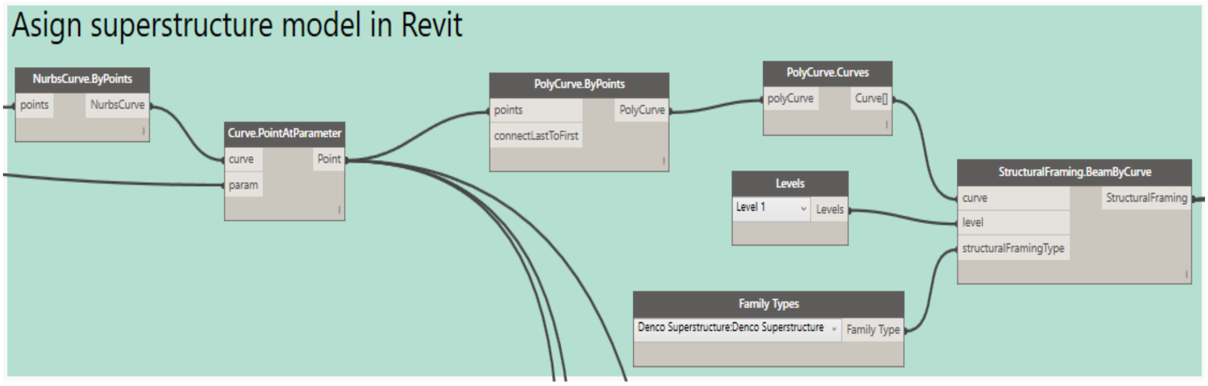


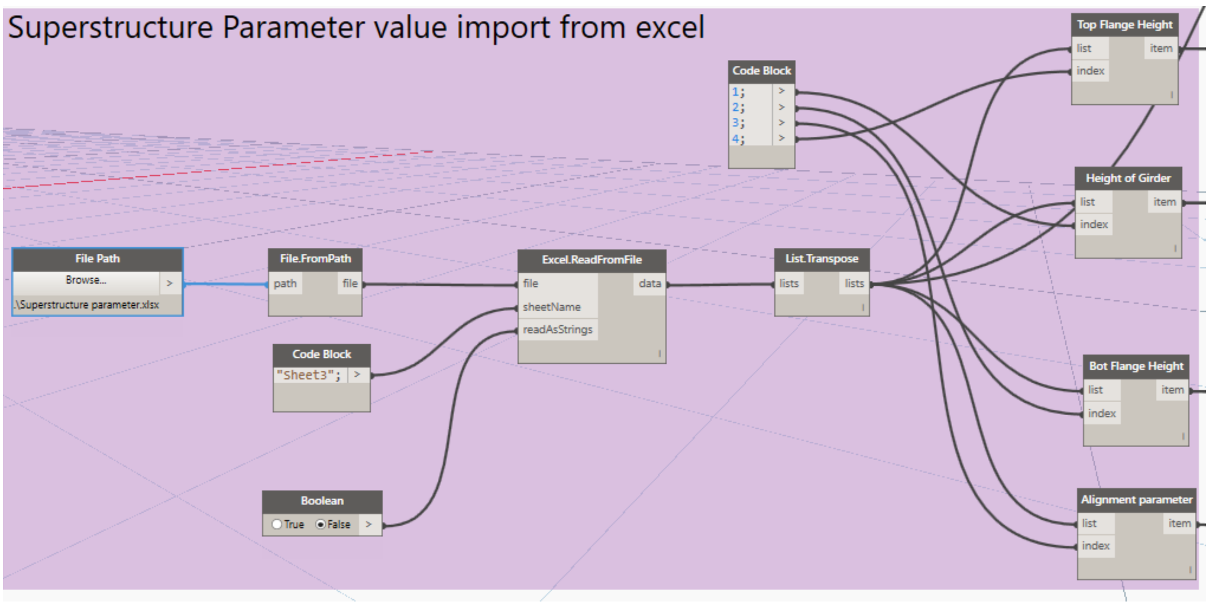
Study case 2

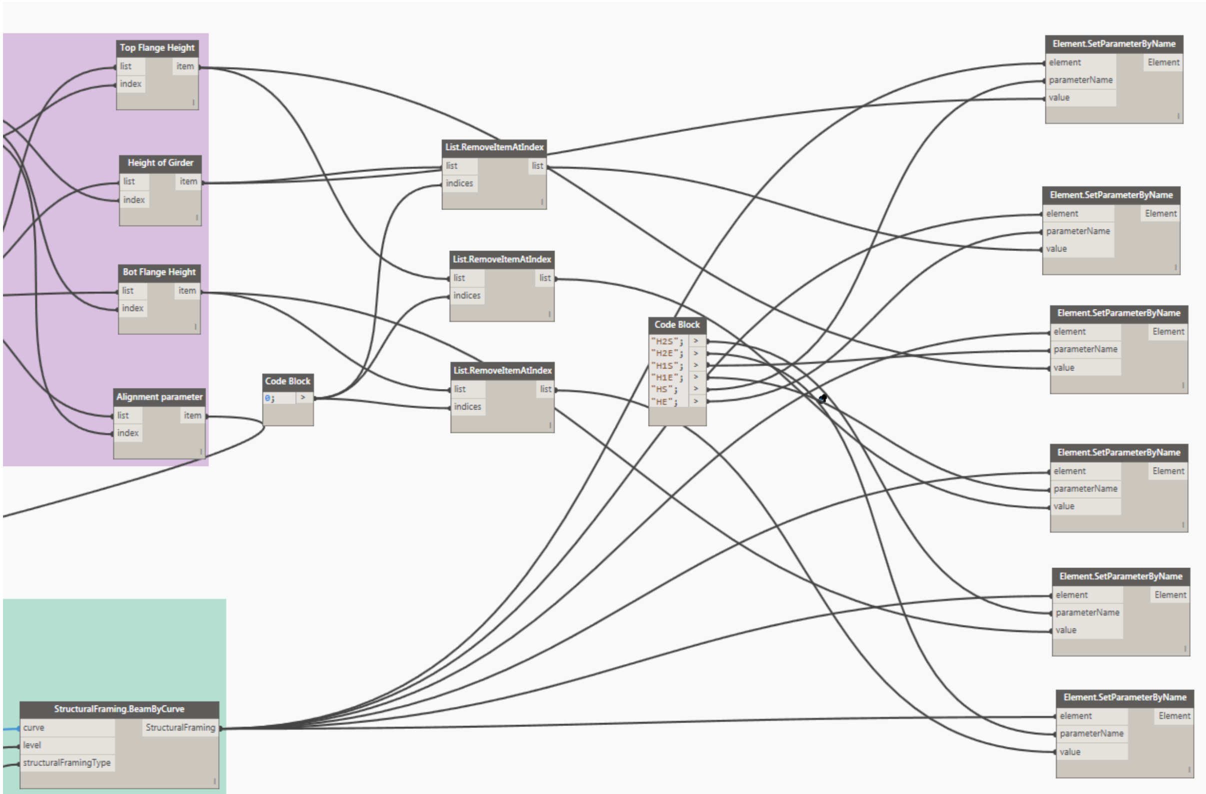

Arch
Point.ByCoordinates
Code Block
0..1..#8;
Curve.PointAtParameter
Integer Slider
30
Code Block
x/2;
Point.ByCoordinates
List.Create
NurbsCurve.ByPoints
Geometry.Translate
Surface.ByLoft
Integer Slider
10
Code Block
0..6..#2;
Code Block
30;
Point.ByCoordinates
Number Slider
-0.4
Road Edge
Code Block
0;
0;
10;
Point.ByCoordinates
Number Slider
10
Code Block
x/2;
Point.ByCoordinates
List.Create
NurbsCurve.ByPoints
Code Block
10;
Integer Slider
30
Point.ByCoordinates
Code Block
10;
NurbsCurve.ByPoints
Arch column
Line.ByStartPointEndPoint
Geometry.Translate
Surface.ByLoft
Surface.Thicken
Curve.PointAtParameter
Code Block
0..1..#8;
Code Block
0..6..#2;
Number Slider
0.2
NurbsCurve.ByPoints
Road Surface
Geometry.Translate
Surface.ByLoft
Code Block
0..6..#2;
Surface.Thicken
Number Slider
-0.4

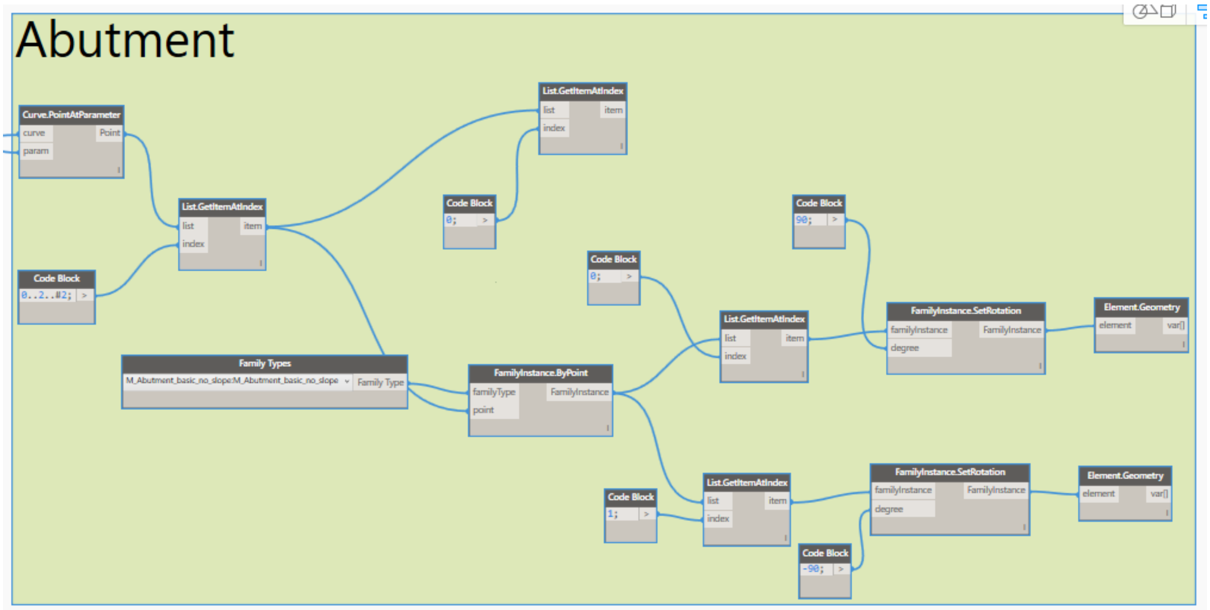
Study case 3

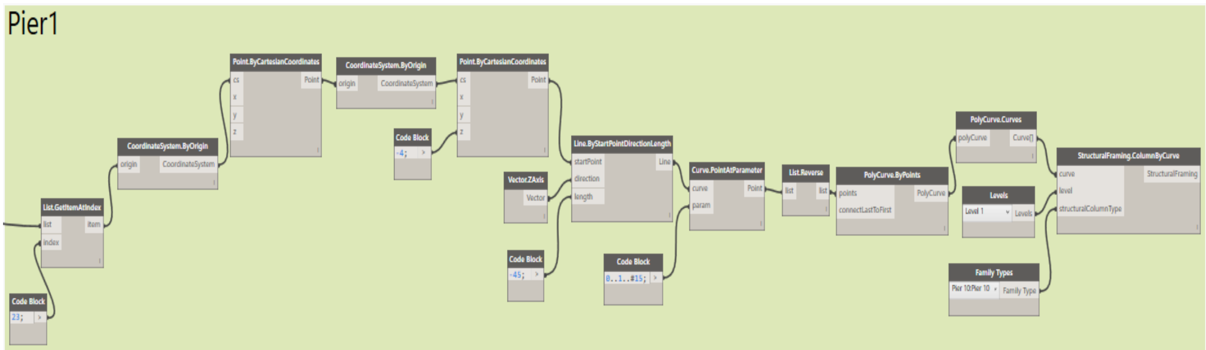

Import Bridge alignment data from excel
Code Block
File Path
Browse...
..\Alignment.xls
File.FromPath
path
file
Excel.ReadFromFile
file
sheetName
readAsStrings
data
List.Transpose
lists
Code Block
"Sheet1";
x
y
z
list
index
item
Point.ByCoordinates
Point


Asign superstructure model in Revit
NurbsCurve.ByPoints
points
NurbsCurve
Curve.PointAtParameter
curve
param
Point
PolyCurve.ByPoints
points
connectLastToFirst
PolyCurve
PolyCurve.Curves
polyCurve
Curve[]
Levels
Level 1
StructuralFraming.BeamByCurve
curve
level
structuralFramingType
StructuralFraming
Family Types
Denco Superstructure:Denco Superstructure
Family Type


Superstructure Parameter value import from excel
Code Block
File Path
Browse...
..\Superstructure parameter.xlsx
File.FromPath
path
file
Excel.ReadFromFile
file
sheetName
readAsStrings
data
List.Transpose
lists
Code Block
"Sheet3";
Boolean
True
False
Top Flange Height
Height of Girder
Bot Flange Height
Alignment parameter
list
index
item


Top Flange Height
Height of Girder
Bot Flange Height
Alignment parameter
List.RemoveItemAtIndex
Code Block
Element.SetParameterByName
StructuralFraming.BeamByCurve


Abutment
Curve.PointAtParameter
List.GetItemAtIndex
Code Block
Family Types
FamilyInstance.ByPoint
FamilyInstance.SetRotation
Element.Geometry


Pier1
Point.ByCartesianCoordinates
CoordinateSystem.ByOrigin
List.GetItemAtIndex
Code Block
Vector.ZAxis
Line.ByStartPointDirectionLength
Curve.PointAtParameter
List.Reverse
PolyCurve.ByPoints
PolyCurve.Curves
Levels
Family Types
StructuralFraming.ColumnByCurve

A.5 CD content

S.1 Project Document	Thesis_4023371_ Saiful Abedin.pdf
S.2 Study Case 1	
S.2.1. Revit File-	Study Bridge.rft
S.2.2. Dynamo Script-	Study Bridge.dyn
S.2.3. Excel Data File-	Alignment
S.3 Study Case 2	
S.3.1. Revit File-	Arch Bridge.rvt
S.2.2. Dynamo Script-	Study Bridge.dyn
S.2.3. Excel Data File-	Alignment
S.4 Study Case 3	
S.4.1 AutoCAD File-	Study Bridge_Denco.dwg
S.4.2 Revit Project File-	Study Bridge_Denco.rvt
S.4.3 Dynamo Script-	Study Bridge_Denco.dyn
S.4.4 IFC File-	Study Bridge_Denco.ifc
S.4.5 COLLADA File-	Study Bridge_Denco.dae
S.4.6 Excel Data-	Study Bridge_Denco