Modélisation des INformations INteropérables pour les INfrastructures Durables

Projet National MINnD

RAPPORT DE RECHERCHE

Livrable UC3 – IFC Bridge

- State of the Art & Missing Concepts
- Data Dictionary
- Lifecycle view IDM (Information Delivery Manual)
- Development Methodology (Application to other Infrastucture Domains)

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RAPPORT DE RECHERCHE / LIVRABLE

IFC-Bridge
State of the Art & Missing Concepts

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1 Abstract

Résumé en français

L'objet de ce livrable est de faire un état des lieux de l'applicabilité des entités IFC (Industry Foundation Classes) à l'établissement d'un modèle d'échange d'information dans le cadre de la réalisation d'un pont. L'étude se base sur la connaissance de la norme ISO 16739 (IFC) et les travaux préparant une extension IFC-Bridge. L'étude se base également sur l'analyse de « Cas d'Usage » ayant conduit à la production de fichiers d'échange IFC fondé sur la norme ISO IFC, donc avec des entités orientés bâtiment. Le livrable conclut en identifiant les concepts non correctement supportés aujourd'hui et en proposant des pistes pour développer les entités manquantes.

Abstract

This deliverable aims at providing a state of the art about the applicability of Industry Foundation Classes (IFC) entities to describe the data exchange model associated to a bridge under construction. The study is based on the knowledge of ISO 16739 standard (IFC) and the preparatory works for the IFC-Bridge extension. The study has also taken into account the results of Use Cases, in particular the analyses of the IFC files exported according to the ISO 16739 standard, with entities developed for buildings. As a conclusion, concepts not appropriately addressed have been listed and proposals have been given for developing the missing IFC entities.

Thanks

Statens vegvesen

The authors have to thank Statens vegvesen, the Norwegian Public Road Administration, for allowing the project to use the Nordenga Bridge (Oslo) as a Proof Of Concept. These documentation and files were relevant materials to demonstrate the wide scope of bridge data, and to emphasize missing concepts in current bridge design using IFC exchange files.

2 Introduction

The deliverable is divided in three parts:

a) **State of the Art**. The key features of IFC are emphasized. The main new concepts proposed by IFC-Bridge are described. Use Cases have been selected to identify and test the needs and finally to exhibit the missing concepts. Then the software editors' members of the MINnD consortium have used their own software packages to model the Use Cases and provide an exported IFC file. These files have been analyzed regarding IFC compliance and comments have been given about what is appropriate and what is missing. In addition analyses of buildingSMART International initiatives that could provide answers to the missing concepts have been carried out. The initiatives that have been audited are IFC-Alignment and IFC-Roads. A first conclusion closes this first part.

b) **Missing Concepts**. Based on the State of the Art, the missing concepts are detailed and explained in order to clarify them. Some proposals for future development have been given.

c) **Conclusion**. A global conclusion is then developed.

At the end of the deliverable, an Annex has been offered to each software editor to allow him to defend its work presented previously and present his future developments to address these new needs.

3 State of the Art

3.1 Industry Foundation Classes

The Industry Foundation Classes (IFC) data model is intended to define an open and neutral data format for building and construction industry data in order to facilitate interoperability in the architecture, engineering and construction (AEC) industry. It is registered by ISO and is an official International Standard ISO 16739:2013. [1]

IFC defines an entity-relationship model consisting of several hundred entities organized into an object-based inheritance hierarchy. IFC divides all entities into rooted and non-rooted entities. |1]

All entities having semantic significance derive from the entity *IfcRoot*, where instances are identifiable within a data set using a compressed globally unique identifier (*IfcGloballyUniqueId*). This identifier must never change during the lifetime of an object, which allows data to be merged, versioned, or referenced from other locations. [2]

Resource-level instances (not derived from *IfcRoot*) do not have any identity. This implies that non-rooted instances may only exist if referenced by at least one rooted instance through either a direct attribute or inverse attribute, or following a chain of attribute references on instances. [2]

There are 3 fundamental entity types in the IFC model, all deriving from *IfcRoot*:

- **Object Definition** is the generalization of any semantically treated thing (or item);
- **Relationship** is the generalization of all relationships among things (or items) that is treated as objectified relationship in the IFC model;
- **Property Definition** defines the generalization of all characteristics (i.e. a grouping of individual properties) that may be assigned to objects. [3]

There are six fundamental entity types in the IFC model, all deriving from *IfcObject*. They are associated to six fundamental concepts: [1, 3]

- **Products** are physical objects (manufactured, supplied or created) for incorporation into a project. They may be physically existing or tangible. Products may be defined by shape representations and have a location in the coordinate space. They represent ***"where"*** as occurrences in space such as physical building elements and spatial locations.
- **Processes** are actions taking place in a project with the intent of acquiring, constructing or maintaining objects. Processes are placed in sequence in time. They represent ***"when"*** as occurrences in time such as tasks, events and procedures.
- **Controls** are concepts that control or constrain other objects. Control can be seen as guide, specification, regulation, constraint or other requirement applied to an object that has to be fulfilled. They represent ***"why"*** as rules controlling time, cost or scope such as work orders.
- **Resources** are concepts that describe the use of an object mainly within a process. They represent ***"how"*** as usage of something with limited availability such as material, labour and equipment.
- **Actors** are human agents that are involved in a project. They represent ***"who"*** as people or organizations, producing deliverables and making decisions according to their role in the project.
- **Group** is an arbitrary collection of objects. It represents ***"what"*** as collections of objects for particular purpose such as electrical circuits.

The *IfcProduct* is an abstract representation of any object that relates to a geometric or spatial context. Subtypes of *IfcProduct* usually hold a shape representation and an object placement within the project structure. This includes manufactured, supplied or created objects (referred to as elements) for incorporation into an AEC project. This also includes objects that are created indirectly by other products, as spaces are defined by bounding elements. Products can be designated for permanent use or temporary use. Products are defined by their representations and properties. In addition to physical products (covered by the subtype *IfcElement*) and spatial items (covered by the subtype *IfcSpatialElement*), the *IfcProduct* also includes non-physical items that relate to geometric or spatial contexts, such as annotation (*IfcAnnotation*), spatial referencing grid (*IfcGrid*), port or connector (*IfcPort*), structural analysis elements[1] (*IfcStructuralActivity, IfcStructuralItem*). [4]

The *IfcElement* is a generalization of all components that make up an AEC product: [5]

- The *IfcBuildingElement* comprises all elements that are primarily part of the construction of a building (structural and space separating system): *IfcBeam*, *IfcColumn*, *IfcCovering*, *IfcFooting*, *IfcMember*, *IfcPile*, *IfcPlate*, *IfcRamp*, *IfcRoof*, *IfcSlab*, *IfcStair*, *IfcWall*…
- The *IfcDistributionElement* is a generalization of all elements that participate in a distribution system (heating, cooling, ventilation, plumbing, electrical, communication.
- The *IfcElementAssembly* represents complex element assemblies aggregated from several elements.
- An *IfcElementComponent* is a representation for minor items included in, added or connecting to or between elements, which usually are not of interest from the overall building structure viewpoint.
- An *IfcFeatureElement* is a generalization of dependent elements which modify the shape and appearance of the associated master element.
- An *IfcGeographicElement* is a generalization of all elements within a geographical site. It includes occurrences of typical geographical element, often referred to as features, such as roads, zones, trees, etc.

[1] Structural analysis elements have a specific status due to structural analysis modelling constraints. Their description is driven by the physical mechanical model. Nevertheless the global consistency of the IFC model is maintained by specific relationships linking the architectural elements with the associated structural analysis elements.

3.1.1 Construction Product Approach

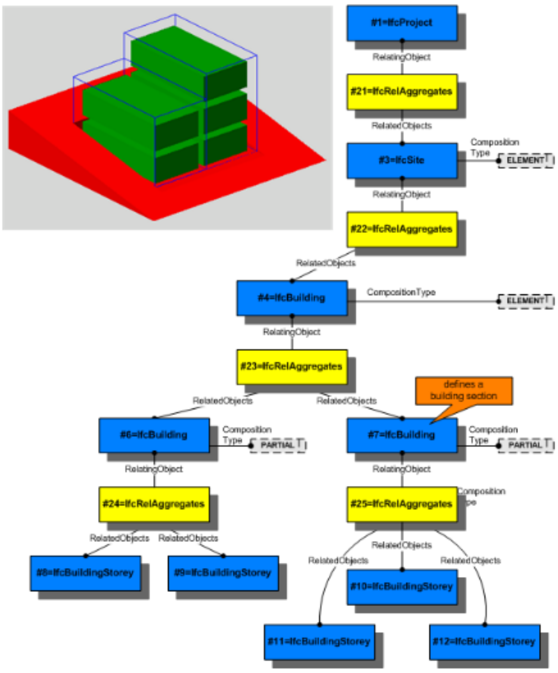


Figure 1: Building Breakdown Structure

The spatial structure can be defined as "*breakdown of the project model into manageable subsets according to spatial arrangements".* It should be noted, that other decomposition structures for a project exist, but that the spatial structure is common to most disciplines and design tasks. It is therefore seen as the primary structure for building projects and required for the data exchange.

Four different concepts derive from the *IfcSpatialStructureElement* entity: *IfcProject* (uppermost container of all information), *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*, *IfcSpace*. These different entities are contained by each other such as they provide a clear hierarchical structure for the building project[2]. [3]

The AEC project is defined as a product-based assembly. Products have placement in space, shape representation, associated materials. Physical building elements include wall, beam, door… as well as distribution elements (HVAC, electrical, plumbing…). Distribution elements have a concept of ports where elements may have specific connections for various services, and connected together using cables, pipes or ducts to form a system (see *IfcRelConnectsPortToElement*). Various connectivity relationships are used for building elements such as a wall having openings filled by doors or windows. [1]

IfcOwnerHistory defines all history and identification related information. In order to provide fast access it is directly attached to all independent objects, relationships and properties. It is used to identify the creating and owning application and user for the associated object, as well as capture the last modifying application and user. [6]

IfcOwnerHistory addresses the problem of *design change management*. Regarding traditional documents, the owning history is attached to the document and managed with a Document Managing System. In the case of an object-based approach, the change management has to be supported at object level. IFC offers a way to tackle this with root-derived entities. [7]

In addition to the architectural product breakdown, others breakdowns are needed to cope with the structural analysis or the work plan point of views.

The *IfcStructuralAnalysisModel* is used to assemble all information needed to represent a structural analysis model. It encompasses certain general properties (such as analysis type), references to all contained structural members, structural supports or connections, as well as loads and the respective load results. Important functionalities for the description of an analysis model are derived from existing IFC entities. [8]

[2] It should be noted that the current IFC model is not complete. The building is like a "spacecraft" flying in outer space. Neither the surrounding ground and utilities nor the required earthworks are described.

The abstract entity *IfcStructuralItem* is the generalization of structural members and structural connections, that is, analysis idealizations of elements in the building model. It defines the relation between structural members and connections with structural activities (actions and reactions). Relationships between elements in the building model and structural items as their idealizations can be expressed by instances of *IfcRelAssignsToProduct.*[3]

An *IfcWorkSchedule* represents a task schedule of a work plan, which in turn can contain a set of schedules for different purposes. [9] An *IfcTask* is an identifiable unit of work to be carried out in a construction project. A task is typically used to describe an activity for the construction or installation of products, but is not limited to these types. For example it might be used to describe design processes, move operations and other design, construction and operation related activities as well. [10] Assigning a product to a process is done by using *IfcRelAssignsToProcess* linking the *IfcProduct* to an *IfcProcess.* An example of this relationship is the assignment of products like wall, slab and column to a construction task for construction planning.

IfcPropertyDefinition defines the generalization of all characteristics (i.e. a grouping of individual properties), that may be assigned to objects.

The last but not the least concept is connectivity. Objects may participate in various connectivity relationships with other objects:

- Spatial structures, such as site, building, storey, or spaces, may contain physical elements, including building elements, distribution elements, and furnishing elements. The containment relationship between the physical elements and the spatial structures is hierarchical, i.e. a physical element shall only be contained within a single spatial structure;
- Spaces may have boundaries defined by building elements such as walls, slabs, doors, and windows. For instance, such information may be used to determine heat transmission through surrounding materials.
- Elements may be connected to other elements, where the *RelatingElement* is of equal or higher priority, is generally constructed first, and/or anchors the *RelatedElement*.
- Elements such as doors and windows may be placed inside openings of walls, slabs, or other elements.

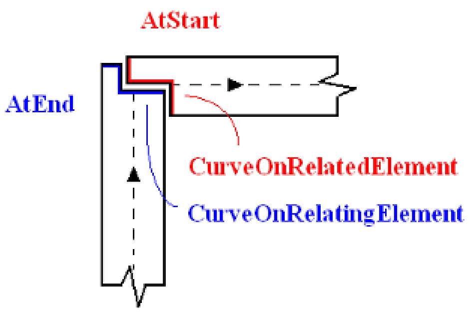


Figure 2 : IfcRelConnectsPathElements

[3] It is clear that two models are developed in parallel: one hand the architectural model and on the other hand the structural analysis model. The relationships linking elements from one model to elements of the other model are mainly here to manage modifications and to inform the end-user that he has to check if there are discrepancies. The two models are so different that the consistency can only be done by a human expert. The structural analysis model remains currently very poor and to our knowledge has never been used in conjunction with an architectural model.

3.1.2 Machine Readable Exchange File

BIM is considered as the integration of a *process* (Building Information Modelling) and also the *digital representation of a shared knowledge resource* (Building Information Model). The limiting factor regarding BIM implementation is the interoperability between the BIM applications. [11]

The Industry Foundation Class (IFC) schema is accepted as the industry standard for ***interoperability***. IFC is coded in EXPRESS, which is a standard data modelling language for product data, and STEP definitions, STEP being a mechanism capable of describing product data throughout the life cycle of a product, independent from any particular system. Data models formally define data objects and relationships among data objects for a domain of interest. Classification, ontology and semantic relationships allow data model exchange to be ***machine readable*** and even ***machine understandable***.

However, model exchanges based on IFC are still error prone and incomplete. The errors are a result of software translators and of the completeness (descriptions complete in terms of entities and objects defined in the most semantically rich format) of the IFC models, even those which are IFC compliant, exporting specific data needed for the targeted exchange in a manner semantically not understood by the importing application and its more or less complete IFC model description. Hence, object schemas such as IFCs are a necessary but not a sufficient condition for achieving robust data exchanges. Based on varying exchange requirements, different research and development groups propose restrictions of the global data model, also called Model Views Definitions (MVD), as a solution for specifying exchange requirements. However, the current model view development methodologies, which are based on use cases, leaves scope for different interpretations based on end-user requirements and lacks a formal framework. Moreover, the granularity and atomicity with which such model views are defined is not consistent across the industry. This hinders IFC based implementations. [11]

The IFC Model has been developed in order to cover the large scope of buildings during all the stages of their life-cycle. This is why almost all the attributes of the entities are optional and even the use of a given entity is driven by the exchange requirements. Therefore an IFC-based exchange is supported by so-called Information Delivery Manuals (IDM) in semantics appropriate to groups of professionals and Model View Definitions (MVD) in IT specific languages.

It is the purpose of an IDM to capture processes and exchange requirements while MVD is aiming at mapping exchange requirements to IFC data schema, and potential constrains to the used data model. [12]

To define an IDM, the following steps have to be clarified:

1) <u>IDM Scope</u>, i.e. defining the lifecycle process to be satisfied;
2) <u>Use Case Narrative</u>: the business use case is a plain language narrative description of the industry process, as subject of the IDM. A use case can be a single exchange of information between two parties (share architecture model with engineer), or one contributing to the greater network of information developed during a project or the building lifecycle. The use case provides the scope, context, rationale, level of detail (LOD), and projected outcome for use;
3) <u>Process Maps</u>: A process map is a visual representation of the logical and sequential flow of activities and information exchanges described in the IDM Use Case. The purpose of a process map is to gain an in-depth understanding of the relationships between the activities (processes) to achieve the outcome, the actors involved, and the information required, consumed and produced;

4) Exchange Requirements: An exchange requirement documents the information needs between two or more parties to be exchanged in support of a particular business requirement at a particular stage of a project. An exchange requirement represents the connection between process and data. It applies the relevant information defined within an information model to fulfil the requirements of an information exchange between two business processes at a particular stage of the project.
5) Exchange Requirements Model: An exchange requirement model is the technical solution of an exchange requirement. It provides a complete schema that can be supported by a software application for the exchange of information for a particular purpose, at a particular point in time on a project, and at a particular location. That is, it satisfies all the conditions for supporting a project workflow according to the rules and methods of working defined for a region, country or framework agreement.

The main goal of MVD is to enable high quality IFC implementations that satisfy a given set of data exchange requirements defined in one or more IDMs. The MVD format should further satisfy the following requirements:

- Enable data exchanges, as defined in the IDM process and formats, in building industry projects. The MVD process does not change these requirements, but may refine and merge data exchange requirements into packages that are meaningful from the viewpoint of soft-ware implementation.
- Provide a way for software developers to implement meaningful IFC support in software without wasting resources. Implementing an MVD should be the easiest way to implement IFC support in software.
- In order for IFC to become a mainstream data exchange solution, implementing IFC sup-port must not require face-to-face meetings or attendance in workshops. This applies only to implementing support for an already agreed data exchange scenario. Face-to-face meetings can still be used in the process of defining data exchange scenarios. [12]

3.2 IFC-Bridge

3.2.1 Content description

IFC-Bridge V3 model is an extension of the IFC4 [13]. Based on IFC4, its aim is to provide a standard exchange and archiving model data related to the whole bridge life cycle.

The scope of IFC-Bridge is to address the following topics:

- Integration of bridges into their environments;
- General structure of bridges;
- Complete geometry definition;
- Technological definitions;
- Materials associations (concrete, steel, wood…);
- Pre-stressing information;
- Process control.

IFC-Bridge stresses out that the main characteristic of a bridge is to be defined relatively to a so-called reference curve.

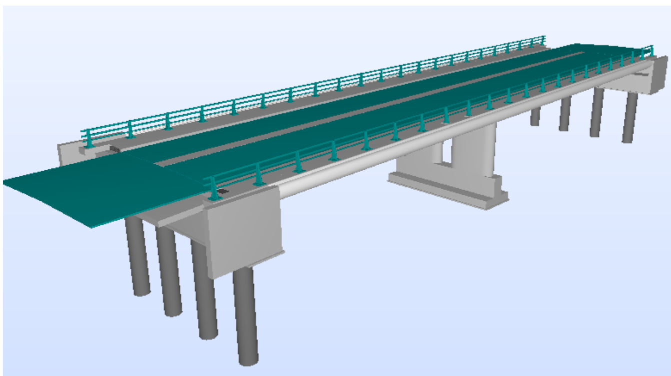
Spatial Structure Elements

Similarly to the spatial structure developed to describe a building project, IFC-Bridge proposes a spatial structure dedicated to bridges. The spatial structure can be defined as "*breakdown of the project model into manageable subsets according to spatial arrangements*". [3].

The following four different concepts are subsumed under the *IfcSpatialStructureElement*:

Building	***Bridge***
Project (uppermost container of all information)	
Site (also site complex and part of site)	
Building (building complex or building section)	Bridge (bridge complex or bridge section)
Building Storey (also partial building storey)	Bridge Part (also partial bridge sub-part)
Space (also partial space)	

An example is not a definition, but gives a tangible overview of a concept: see section 3.3.2.



- ***IfcProject***
  - ***IfcSite***
    - ***IfcRoad*** New Road
    - ***IfcRoad*** Old Road
    - ***IfcBridge*** OverPass
      - ✓ ***IfcBridgePart*** Deck
      - ✓ ***IfcBridgePart*** Abutment C0
      - ✓ ***IfcBridgePart*** Pier P1
      - ✓ ***IfcBridgePart*** Abutment C2

Physical Elements

Similarly to the building elements (such as wall, covering, beam, column, door, window, roof, slab, stair, ramp...), IFC-Bridge proposes specific civil elements:

- *IfcBridgePrismaticElement*, associated to a reference line allowing positioning and directing the element in the global reference frame. It accepts variable cross sections along the reference line. The element representation is defined by *IfcReferenceSectionedSpine* already defined in IFC2x3;

EXPRESS specification:

```
ENTITY IfcBridgePrismaticElement
  SUBTYPE OF (IfcBridgeElement);
    PredefinedType : OPTIONAL IfcBridgePrismaticElementType;
END_ENTITY;
```

EXPRESS specification:

```
TYPE IfcBridgePrismaticElementType = ENUMERATION OF (
  UNICELLULAR MONO BOX-GIRDER,
  MULTICELLULAR MONO BOX-GIRDER,
  UNICELLULAR MULTI BOX-GIRDER,
  MULTICELLULAR MULTI BOX-GIRDER,
  DOUBLE BEAM RIBBED SLAB,
  MULTI BEAM RIBBED SLAB,
  MASSIVE SECTION ELEMENT,
  HOLLOW SECTION ELEMENT,
  SOLID SLAB,
  HOLLOW SLAB,
  SLAB WITH BROAD CANTILEVER,
  MASTER BEAM,
  LONGITUDINAL GIRDER,
  RIGIDITY BEAM,
  BRACING,
  UPPER FLANGE,
  LOWER FLANGE,
  WEB,
  DECKPLATE,
  AUGET,
  LONGITUDINAL WEB STIFFENER,
  RAKER,
  TRANSVERSE GIRDER,
  DEFLECTER,
  TRANSVERSE MEMBER,
  TRANSVERSE,
  DIAGONALE,
  JAMB,
  TENSION MEMBER,
  BONDING BAR,
  TRANSVERSAL STIFFENER,
  STIFFENER FOOTING,
  TENDON);
END_TYPE;
```

- *IfcBridgeSegment* that should be considered as a part of an *IfcBridgePrismaticElement*. For example it could be associated to a construction phase.

EXPRESS specification:

```
ENTITY IfcBridgeSegment
    SUBTYPE OF (IfcBridgeElement);
    SegmentType: IfcBridgeSegmentType;
END_ENTITY;


TYPE IfcBridgeSegmentType = ENUMERATION OF (
      TYPICAL SEGMENT,
      PIER SEGMENT,
      PIECE,
      LIFT,
      ELEMENT,
      JAMB,
      PYLON HEAD,
      SPAN,
      CANTILEVER);
END_TYPE;
```

Elements Parts

IfcBuildingElementPart represents major components as subordinate parts of a building element. Typical usage examples include precast concrete sandwich walls, where the layers may have different geometry representations. In this case the layered material representation does not sufficiently describe the element. Similarly IFC-Bridge proposes specific entities derived from *IfcCivilElementPart* including:

- *IfcBridgeContactElement*, a representation of a physical element used to connect two other bridge elements, typically through the *IfcRelConnectsWithRealizingElements* relationship;
- *IfcBridgeSegmentPart*, an homogenous sub-part of a bridge segment composed with only one material;
- *IfcCivilSheath*, a representation of the physical tube containing a pre-stressing tendon and placed in a concrete element. It is also a kind of connexion that could be described through the *IfcRelConnectsWithRealizingElements* relationship;
- *IfcCivilVoid*, a representation similar to the *IfcOpening*.

In addition to the definition of new entities, specific property sets are also described:

- *Pset_IfcBridgeRelConnectsElements* that is applicable to the relationship *IfcRelConnectsWithRealizingElements* to detail the associated contact element;
- *Pset_IfcBridgeTendon* to describe specific characteristics of tendons used for bridge.

Alignment Elements

These entities allow describing the so-called reference line of a bridge.

Object Placement

This section tackles with the problems raised by placing objects relatively to a reference curve.

Shape Representation

Shape representation defines:

- the *IfcClothoid* entity needed to define the reference curve and
- the *IfcReferenceSectionnedSpine* entity necessary to describe the shape of a three dimensional object composed of a bridge reference curve and a number of planar cross sections.

3.2.2 First comments

The best way to test a data model is to apply it to specific use cases. This will be detailed in sections 3.3 and 3.4. Here the discussion is launched through some "thought experiments".

IFC-Bridge provides the *IfcBridgeStructureType* type describing which kind of bridge is defined, in particular suspension bridge, cable-stayed bridge. Unfortunately there isn't any entity able to describe appropriately a suspension cable, a stay-cable or their associated components. The same applies to bow-string, arch bridge, etc.

There are also no appropriate definitions of groups of entities into sub-mechanical systems of bridges: connections to networks, foundations, embankments, temporary works, abutments, piles and pylons, support systems and joints, suspension systems (that may include specific equipment connecting with viscoelastic responses girder and piles etc.), safety and traffic.

The *IfcSiteElement* should include for instance, in addition to soil, sub-soil, and elements describing the environment and biosphere, traffic calibres or gauges, for the supported traffic of for the crossed traffic.

IfcBridgeTechnologyType type provides a broad enumeration of cross sectional girder profiles. Unfortunately these various profiles have not been proposed as new subtypes of *IfcProfileDef.*

IfcBridgePrismaticElementType type provides a broad enumeration of prismatic elements whose geometrical shape could be far from building ones. Unfortunately there are no new proposals for "complex" geometry. It would be valuable to have a look on the work carried out for ISO/DIS 16757-2 regarding geometry for MEP (Figure 3). Piers have often similar geometrical shapes.

A.13 Oval duct transition

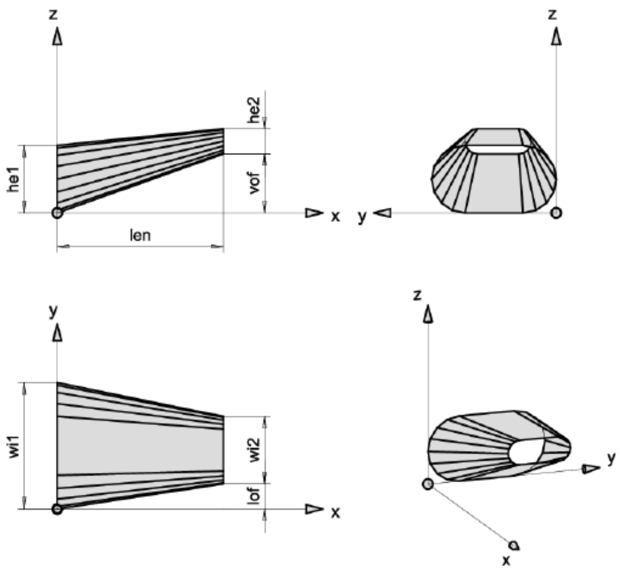


Figure 27 — Oval duct transition

Figure 3: Oval Duct Transition (ISO 16757-2)

Regarding pre-stressed concrete and bridge structures, the existing definition developed for building cannot apply, particularly in the case of a segmental precast bridge. The tendons are passing through sheath located in the concrete segments. Tendon should rather be seen as an electrical distribution system with cables, cable carriers, junctions, ports…

Regarding reinforcements of concrete, the capabilities offered by the existing entities are too poor to address the needs of concrete bridges and should be revisited. Such a work should be included in IFC-Bridge.

A similar system approach should also to be used in order to describe suspension cables, suspenders, stay cables and all the various associated connecting devices.

The design of a bridge is strongly related to a Structural Analysis in order to validate in parallel the design choices. The Structural Analysis Model goes progressively deeper and deeper in detail according to the progress of the associated design study. It is therefore critical to maintain a close link between the Structural Analysis Model and the Architectural Model.

Semantics has also to be emphasized regarding connections between entities using *IfcRelConnects* relationships. Nodes of the Structural Analysis Model are located at element connections in the Architectural Model. It is critical to detail where and how the deck sits on the piers and the abutments, as well as to define where and how the footing or the piles sit on the ground. By the way, ground element should be defined to describe this connection and to be able to associate the according properties and quantities.

In fact two kinds of concept are needed. One hand there is the so-called terrain whose geometric representation is a Digital Terrain Model (DTM), a surface defined triangular faces. It is used to describe the existing environment and to manage its impact on the bridge design and construction and vice versa. It should include the existing roads, rivers, networks, areas authorised for bridge construction activities. It is the link between the surrounding Geographic Information System and the Project. On the other hand there is the ground concerned by the earthworks, including volumes such as cut, fill, embankment, boring hole for pile and so on. These works are full part of the foundations and the abutments.

Last but not least, alignment as described is not enough to describe a deck bridge. The deck supports the “carriage way, the part of the running surface which includes all traffic lines, hard shoulders and marginal strips”. In curves (including torsion and curvature), it includes specific super elevation and over widths. Consequently the specific alignment defining the parapets is needed and cannot be defined with the proposed entities. It is derived from the definition of the carriage way. The parapet has a constant cross-section and its geometric representation must be an extrusion along such an alignment. On a similar way, the axis curve of a tendon located in a deck bridge is derived from the definition of the carriage way.

The associated Model View Definition (MVD) is missing.

3.3 Use Cases description

Regarding bridge modelling, IFC-Bridge introduces new entities to cover the semantic of bridge description and new geometric representations to address the specificities of bridge shapes.

Today to our knowledge, there are no authoring software packages available being able to export IFC-Bridge files. In addition no existing viewer is able to display IFC-Bridge files.

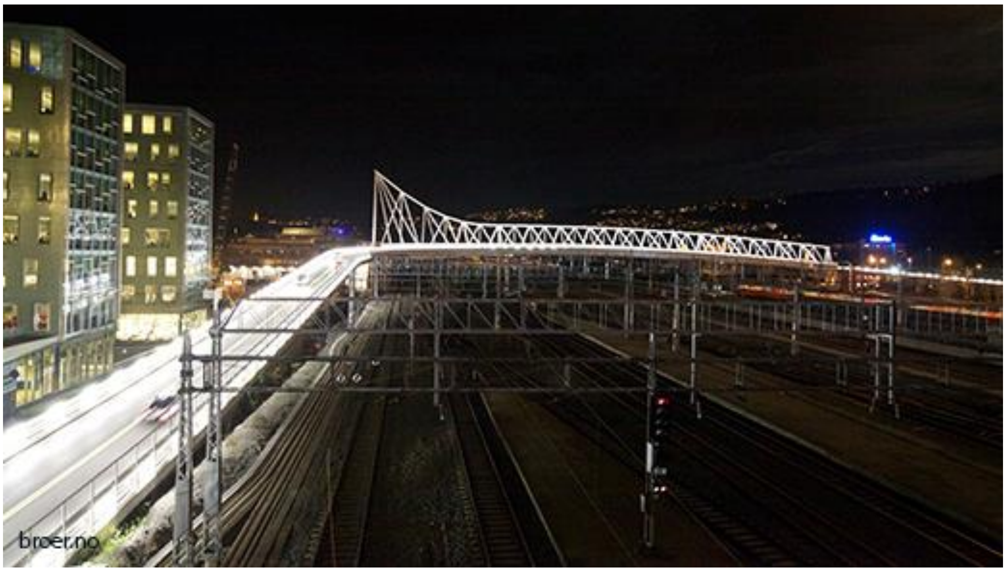
Therefore the MINnD project decided to define bridges with authoring tools currently used for buildings and to analyse the content of the exported IFC file based on building entities. The semantic will be poor, but nevertheless enough data is available to analyse the consistency and the usability of the results, having in mind the missing semantic and the missing capabilities.

3.3.1 Nordenga Bru Oslo, Norway

Nordenga bridge crosses the track area for Oslo Station and connects "the new neighbourhood" Bjorvika with the old Oslo. The unique and highly visible steel structure is a clear landmark and marks the entrance of the neighbourhood of the future Oslo. [19]

Technical information:

- *Total bridge length: 306 meters.*
- *35 meter high steel truss.*
- *1900 tonnes of steel and 4200 m^3 of concrete has been used.*
- *Two bridge floors: one for vehicles and one for cyclists and pedestrians.*



Nordenga Bridge is composed of a main steel bridge built with incremental launching method and four concrete approach bridges, two of them at each side due to specific dedication to cars or pedestrians.

Main Steel Bridge

The model has been set up with Tekla Structures software package.

The model is a nice picture, well detailed and understandable. The level of detail is high, similar to "Shop Drawing". Colours are appropriately used to ease understanding.

But the spatial breakdown structure is poor: *IfcProject*, *IfcSite*, *IfcBuilding*, *IfcBuildingStorey*. Only one entity is used for each type. Therefore the same local reference is used for the whole project.

The local reference is driven by the bridge main axis, not by the site axis system. The length units are millimetres. These choices seem obvious for steel construction oriented manufacturing plant. But it is not in accordance with the choices of civil construction oriented site erection.

An additional well-documented breakdown is based on the *IfcPresentationLayerAssignment* entity. The presentation layer assignment provides the layer name for a collection of geometric representation items. It corresponds to the term "CAD layer" and is used mainly for grouping and visibility control. Unfortunately this mechanism is not based on rooted entities. Such a use is not machine-readable. The tracking of the owner of the information is not possible.

The IFC file contains 471 *IfcElementAssembly* entities, 3016 *IfcBeam* entities of which 2625 are aggregated in *IfcElementAssembly* entities, 47 *IfcColumn* entities of which 39 are aggregated in *IfcElementAssembly* entities, 1938 *IfcPlate* entities of which 1513 are aggregated in *IfcElementAssembly* entities and 347 *IfcMechanicalFastener* entities.

In addition, the IFC file contains 82 *IfcBeamType* entities, 208 *IfcPlateType* entities and 1 *IfcMechanicalFastenerType* entity.

15323 *IfcPropertySet* entities and 3031 *IfcElementQuantity* entities are defined.

19213 *IfcRelationship* entities describe the spatial structure breakdown, the aggregation of the components of the element assemblies, the assignment of the property sets and the quantities and the element types.

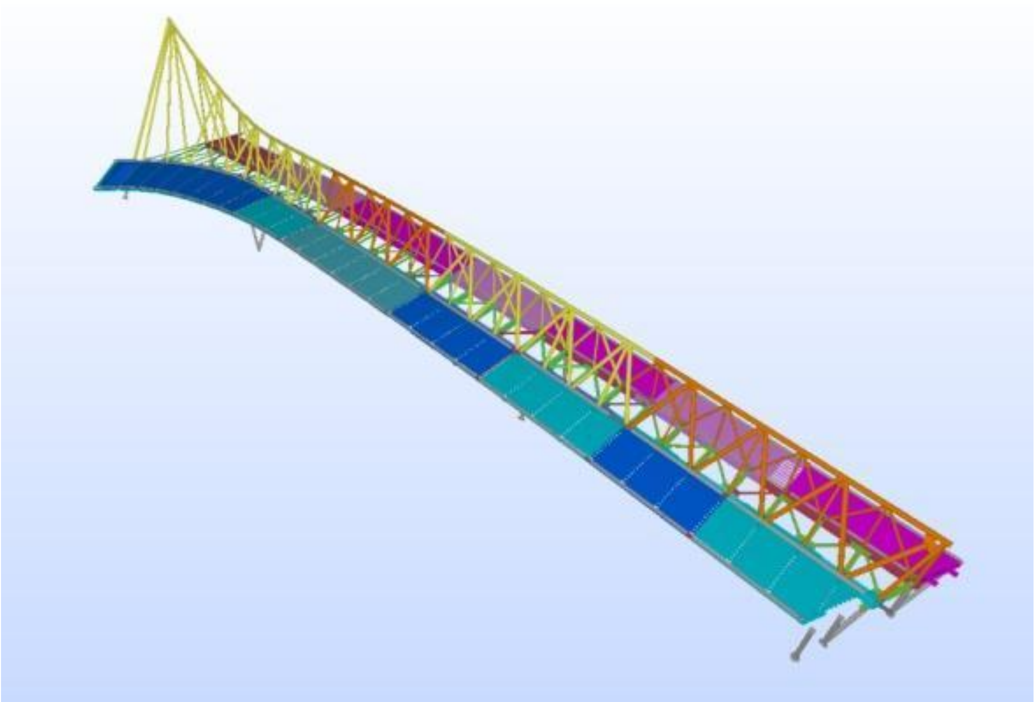
Finally 43753 entities derive from the *IfcRoot* entity and support the owner history concept.

Nevertheless this model is not machine-readable. What is missing?

All the shape representations are Faceted Boundary representations. It means a lot of faces, a lot of Cartesian points which of course provides a nice picture, but this is of no use for the construction team. It is really a pity, when at the same time, in the associated properties, one can read that the element is in fact a circular hollow section tube. Knowing the axis of the tube, the length and the circular hollow section, the element can be easily defined as a swept geometry. Of course this tube is connected to other elements and the geometry of the connection is not easy to describe except defining the Boolean operation. The viewer would be able to show the right picture and the construction team then be able to construct the single product (and all needed tools). Finally the construction team could include it appropriately in the segment that will be erected, which one connected to the whole structure.

However to derive a structural analysis model from a detailed faceted boundary representation is simply just a nightmare. On the contrary, doing the same from a geometry based on extrusions and Boolean operations is easy.

The IFC model is very rich and detailed. But unfortunately, due to the lack of breakdown structure, it is difficult to navigate inside. On one hand the deck is expected, on the other hand the different supports. Regarding the framed deck, there is a main truss beam and beams supporting the road and the footbridge. All these main beams are driven by alignments. The knowledge that is behind the use of different colours and layers is not accessible by a machine and should be translated into breakdown structures or groups. The construction sequences which are underlying should also be identified clearly.



Approach Bridges

There are nine IFC files:

1) Earthworks for the foundations
2) Foundations of the main steel bridge and foundations and piers of the two north approach bridges (road and pedestrians)
3) Abutment of the south approach road bridge
4) Abutment of the south approach footbridge
5) Abutment of the north approach road bridge
6) North approach footbridge
7) South approach road bridge
8) South approach footbridge
9) North approach road bridge

The models have been set up with AutoCAD architecture software package.

Initially the origin of the axis system was very far. All the coordinates were large values, inducing numerical discrepancies when taking the differences of large values. After changing the origin location in order to reduce digit number of the local coordinate values, the models provide nice pictures, well detailed and understandable. The level of detail is high, similar to “Shop Drawing”. Compared to the main bridge model, the colours are poor which makes more complicated the understanding.

Here again the spatial breakdown structure is very poor: *IfcProject, IfcSite* and *IfcBuilding* with only one entity used for each type. Therefore the same local reference is used for the whole project.

Model 1 contains 5548 *IfcBuildingElementProxy* entities. All the associated shape representations are Faceted Boundary representations. No semantics in this model.

Model 9 contains 25 *IfcBuildingElementProxy* entities. All the associated shape representations are Faceted Boundary representations, in particular regarding the tendons. 38970 Cartesian points are described; 267817 entities are described. No semantics in this model.

Again an additional well-documented breakdown is based on the *IfcPresentationLayerAssignment* entity. Such a use is not machine readable.

To conclude, all the entities are *IfcBuildingElementProxy* ones. All the shape representations are Faceted Boundary representations. There are no specific *IfcRelationships* between entities. In other words, there is no semantics at product level, at geometry level and at product connections.

Tendons should be a Disk Swept Solid extruded along the axis of the tendon. This axis is partly driven by the general alignment of the bridge, and more generally by the definition of the carriageway, including super-elevation and over-width along alignment curves. This comment also applies to parapets on each side of the deck. This information is mandatory to build the element, and cannot be substitute by Faceted Boundary Representations.

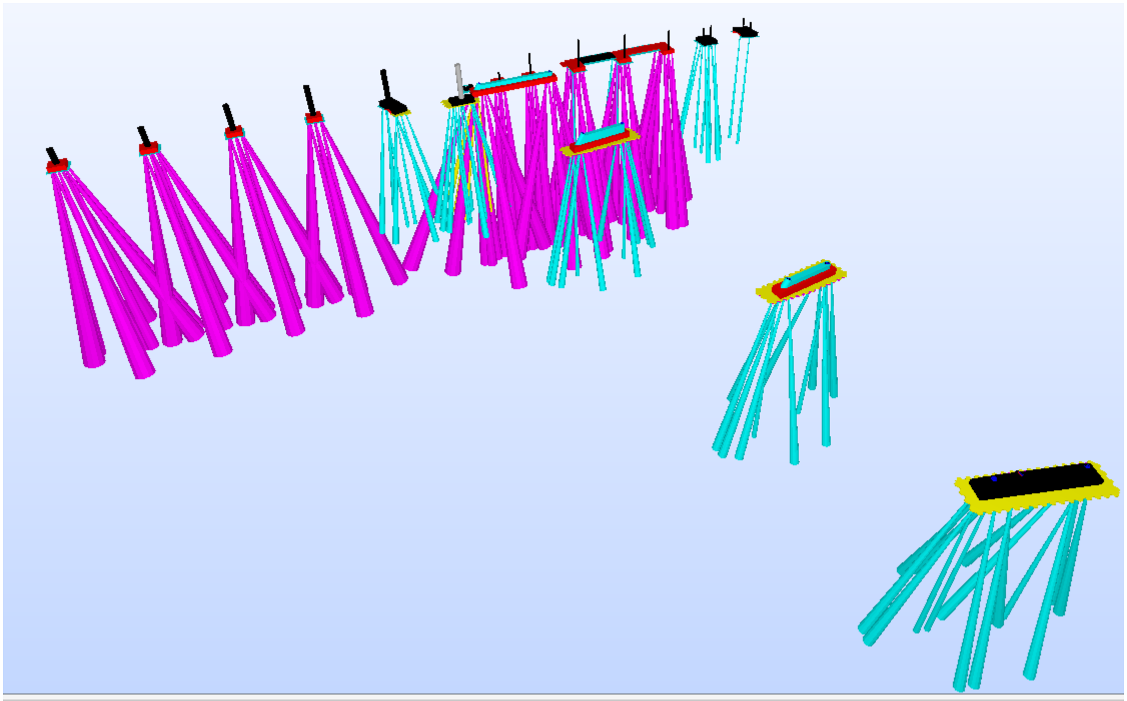


Figure 4: Foundations of the Main Bridge and the North Accesses

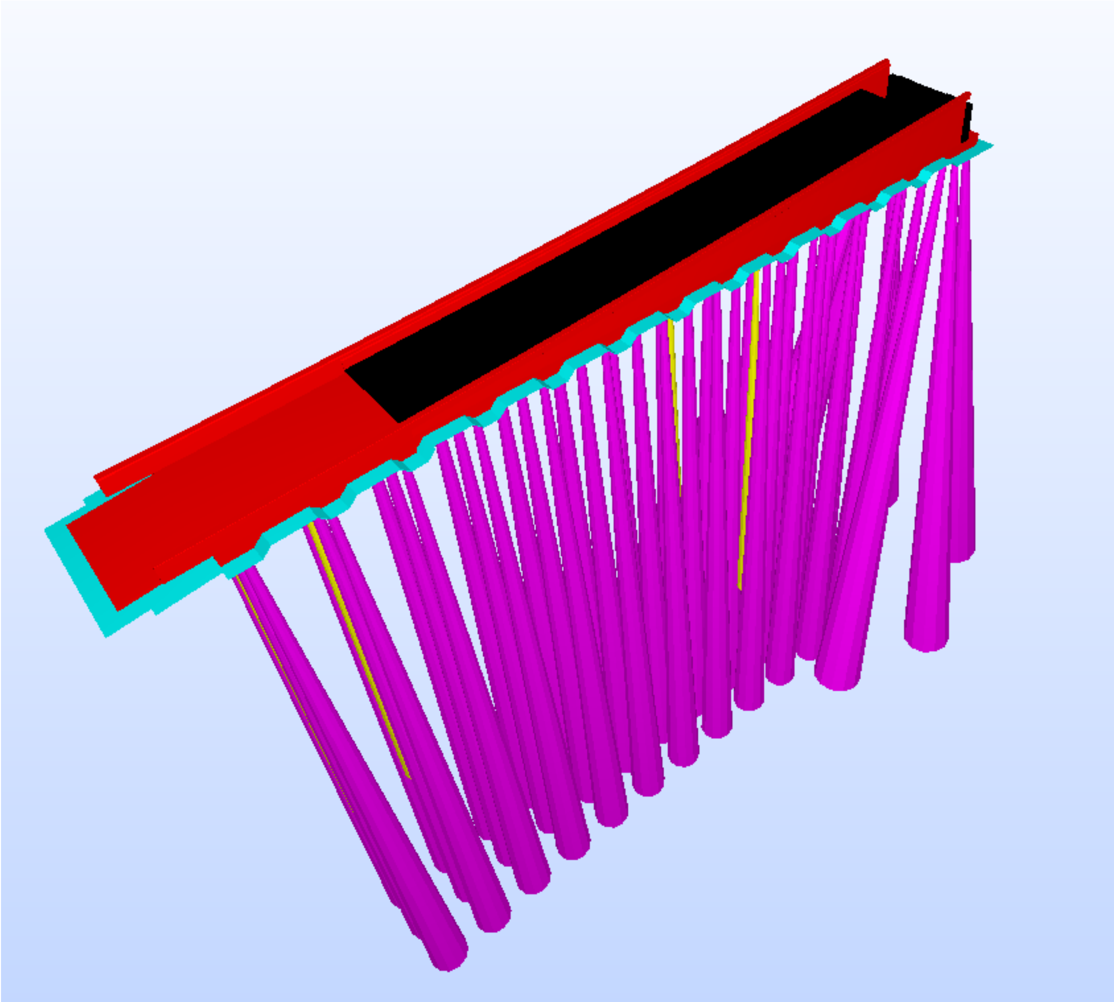


Figure 5: Access Road Abutment

3.3.2 Overpass

Nordenga Bru is a very interesting example covering various topics regarding material (steel, pre-stressed concrete, reinforced concrete), erection methods (cast in situ, incremental launching method)... Nevertheless it looks too rich for a first attempt of specific bridge needs identification.

This is the basic reason for taking a more simple structure such as a straight double spanned overpass supporting a road passing over a highway. The concrete deck has a constant cross sectional shape and a constant longitudinal slope. The overpass is not orthogonal to the highway. Therefore the central pier and the two abutments are skewed regarding the overpass.

Question: Based on the exchange information attached to the following drawings (see next figures), could we find at least the same information in the IFC file provided an authoring tool? If yes, is this information semantically rich enough to be machine readable?

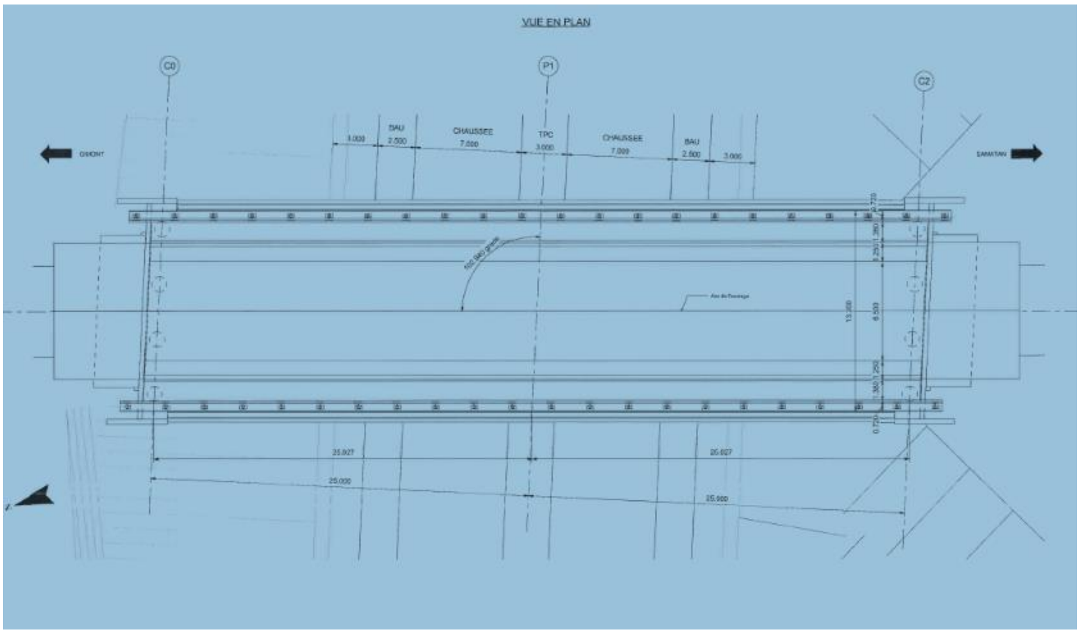


Figure 6: Plan View

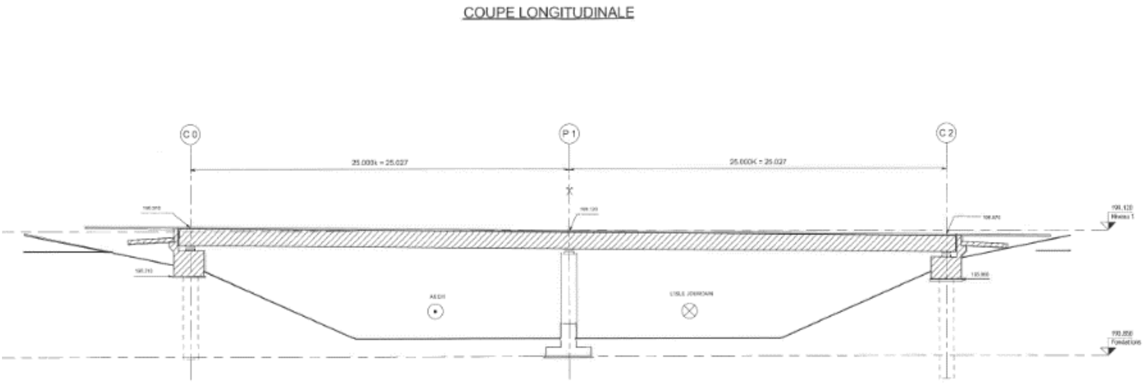


Figure 7: Longitudinal View

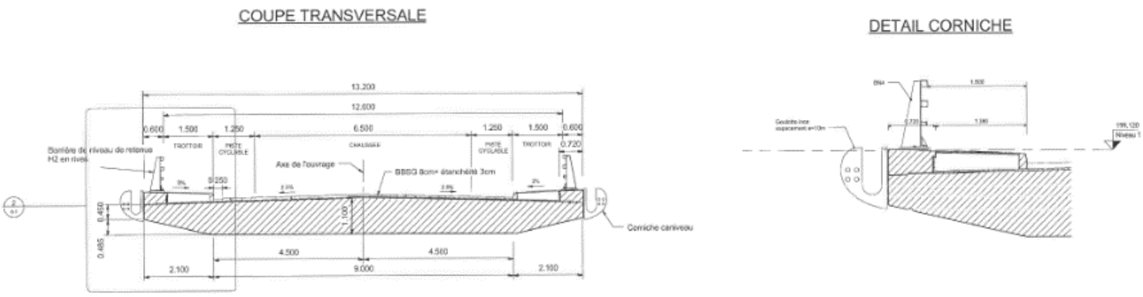


Figure 8: Detail Views

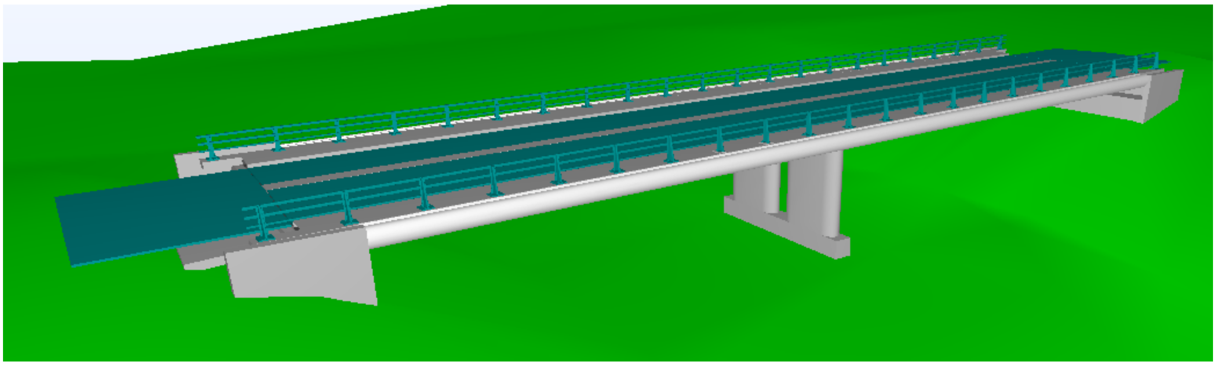


Figure 9: IFC Model view including the terrain

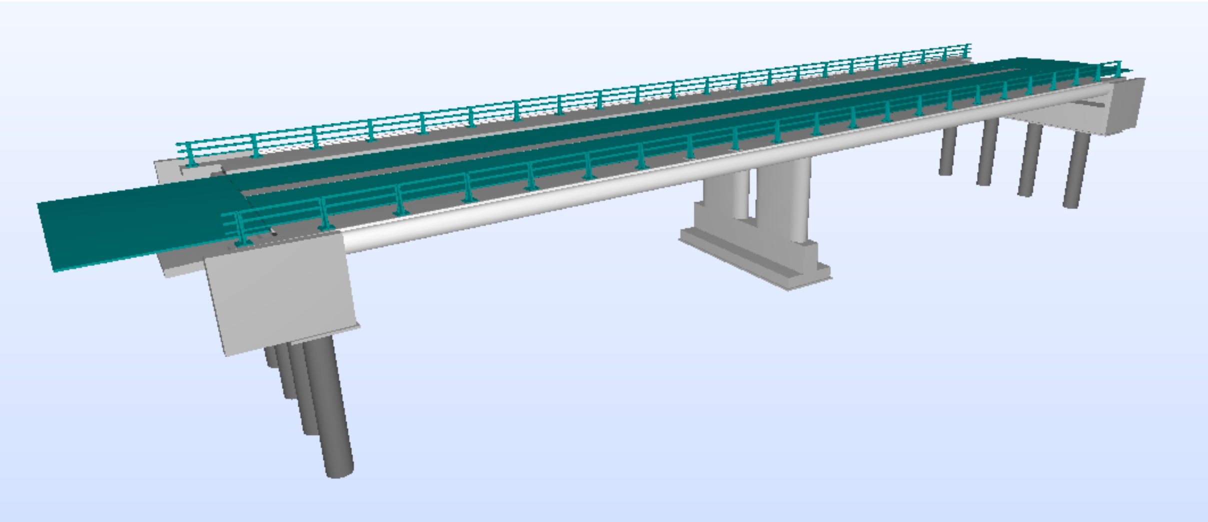


Figure 10: IFC Model view without the terrain

The answer to the above question is clearly NO.

There is no information provided regarding either the upper and under road alignments or the upper and under carriageways. There are too many geometric representation of entities based on faceted boundary representations, in particular the deck, the abutments and the central pier. The local axis system of the component are not based on the main axis of the component. For instance the footing of the central pier is a rectangle. To build this is easy when having the two main axis of the rectangle. It is not the case here.

Frankly speaking, it is a nice picture, but unusable on the construction site.

All the information mandatory for machine readable approach is missing: no breakdown structure, poor semantic at entity level, no semantic at geometric representation, no relationships between entities to define their connection.

The ambition is that the IFC file becomes the reference data model of the bridge. Here it is not the case. The above drawings cannot be produced from the IFC model, the information is not complete.

This exercise is nevertheless very helpful. It shows the work that has to be done to fill the gap. And it is encouraging to notice that in such a case, many of the existing capabilities of IFC2x3 could already be very helpful if appropriately used.

3.3.3 Underpass

Let us take another simple structure, a so-called underpass. Here it is the motorway that passes over. It is very close to a concrete building frame with walls and slabs. But here quite nothing is orthogonal. Some walls have batter.

Question: Based on the exchange information attached to the following drawings (see next figures), could we find at least the same information in the IFC file provided an authoring tool? If yes, is this information semantically rich enough to be machine readable?

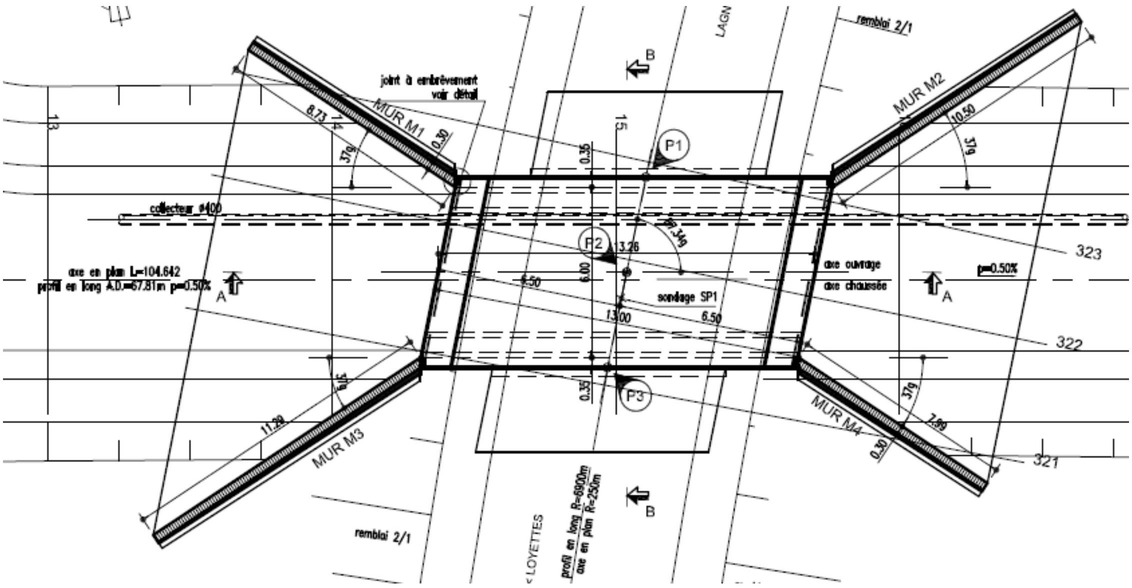


Figure 11: Underpass View Plan

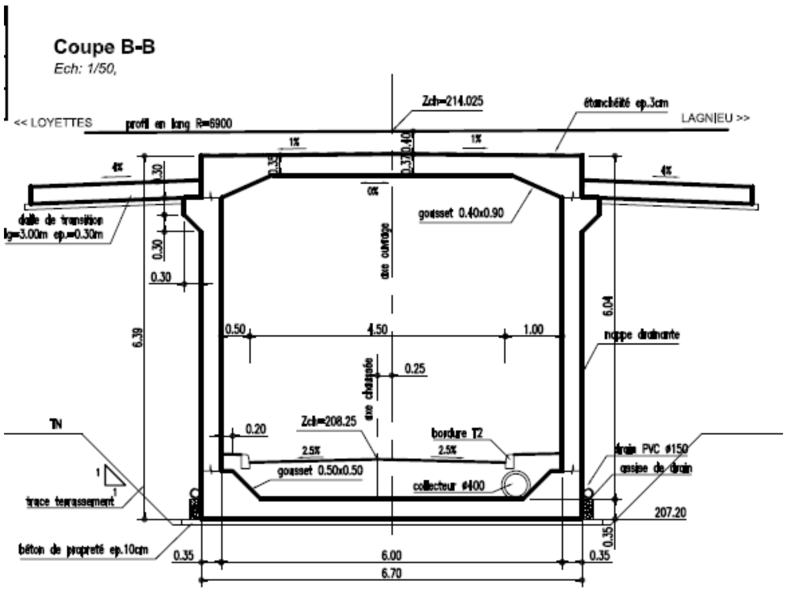


Figure 12: Underpass Cross Section B-B

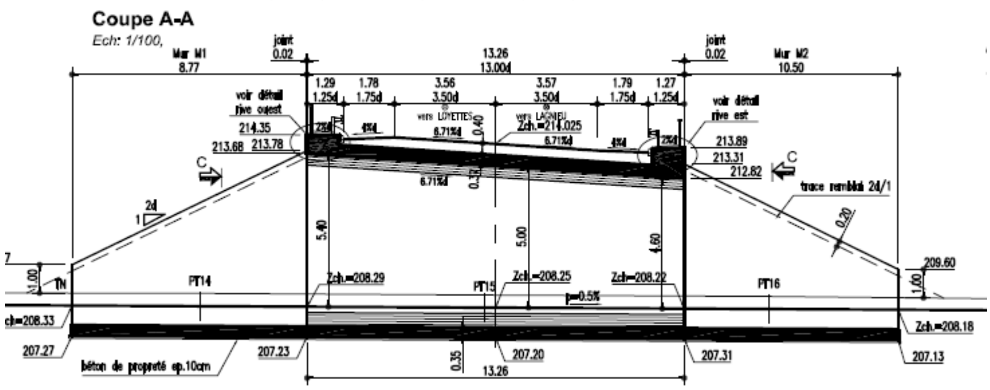


Figure 13: Underpass Cross Section A-A

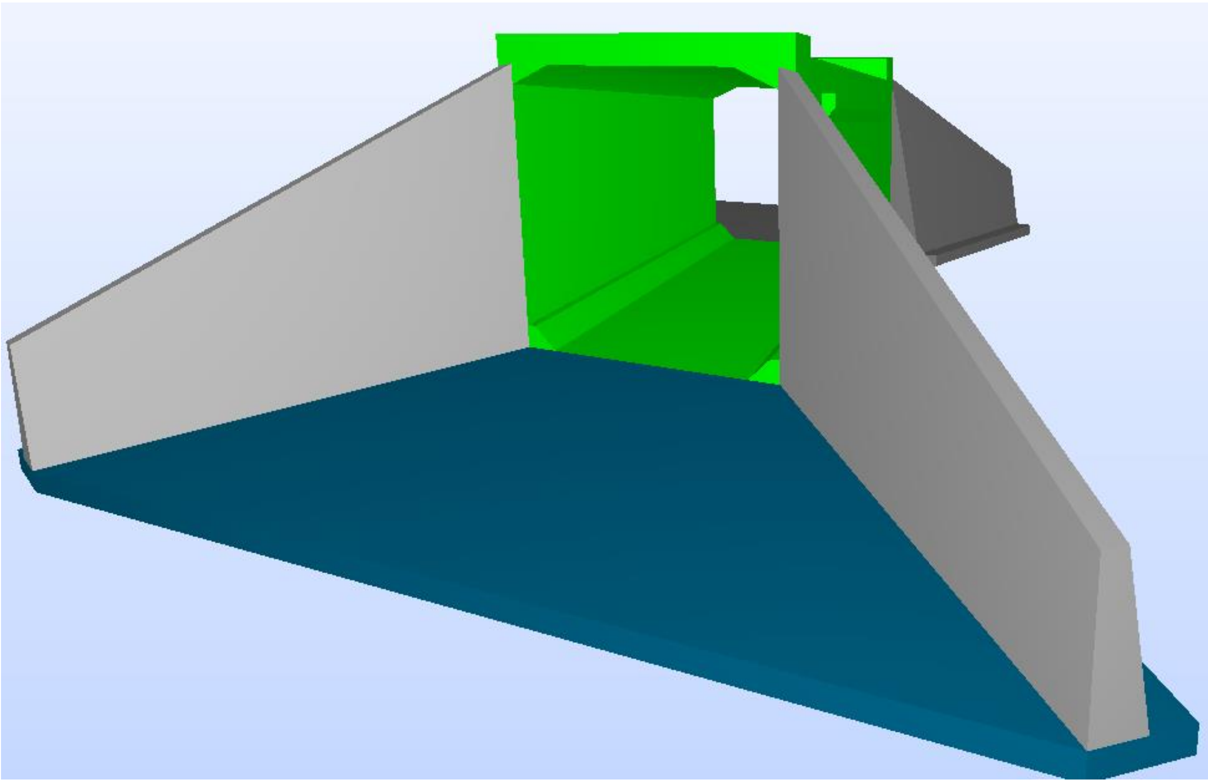


Figure 14: Underpass IFC Model view

The answer to the above question is again clearly NO.

There is no information provided regarding either the upper and under road alignments or the upper and under carriageways.

The breakdown structure is very poor and does not identify the different components of the bridge. All the shape representations are boundary representations based on faceted boundary representations. The local axis system of the component is based on the axis system associated to the bridge. It is quite impossible to understand where the walls and slabs are, what “planar surfaces with which thicknesses” are. It is impossible to define the inner reinforcements. The information to build them is completely missing.

Frankly speaking, it is a nice picture, but unusable on the construction site.

All the information mandatory for machine readable approach is missing: no breakdown structure, poor semantic at entity level, no semantic at geometric representation, no relationships between entities to define their connection. Constructive Solid Geometry (CSG) associated to Boolean operations is absolutely mandatory.

The ambition is that the IFC file becomes the reference data model of the bridge. Here it is not the case. The above drawings cannot be produced from the IFC model, the information is not complete.

This exercise is nevertheless very helpful. It shows the work that have to be done to fill the gap. And it is encouraging to notice that in such a case, many of the existing capabilities of IFC2x3 could already be very helpful if appropriately used.

3.4 Use Cases application

Having in mind that all the drawings shown in section 4.3 have been produced with a 3D CAD authoring tool, regarding IFC exchange file production and its discrepancies versus the expected quality, it is important to identify where the process fails:

a) Lack of IFC specific entities;
b) Missing information at authoring tool proprietary data base level regarding IFC needs;
c) Lack of capabilities of the IFC export application;
d) Lack of training of the operator.

To address this problem, each software editor member of the MIN^{n}D consortium was asked to do the same exercise. Starting from the drawings of the Overpass Bridge (section 3.3.2), they have to provide an IFC exchange file. They were of course aware of the comments given in section 3.3.

3.4.1 Autodesk

The example described in section 3.3.2 has been built with Autodesk Revit Structure 2015. The IFC export is based on IFC 2x3 model schema and Coordination View V2.0.

A lot of comments have been given in section 3.3.2.

Nevertheless, analyses of “building models” created with the same authoring tool (same release, same coordination view but not same user) have exhibited shape representations based on solid construction geometry and Boolean operations, large structure breakdowns, good semantics regarding entities, relationships describing connections between walls...

The key point is that Exchange Requirements are not clearly defined and consequently a Model View Definition oriented Bridge.

Following these comments and discussions about what the construction sector is expecting regarding bridges, Autodesk has provided a new “use case application”. See Annex A for more information.

3.4.2 Bentley

The example has been built with Bentley AECOsim Building Designer. The IFC export is based on IFC 2x3 model schema and CoordinationView_V2.0, QuantityTakeOffAddOnView, FMHandOverView.

The model is not really similar to the example given in section 3.3.2, but it does not matter.

The work asked to the editors is focused on addressing the first criticisms regarding the IFC output provided in section 3.3.2.

The breakdown structure is poor: *IfcProject*, *IfcSite*, *IfcBuilding* (1), *IfcBuildingStorey* (1). At least, abutment1, pier2, abutment3 and deck could have been used in order to define a local placement for the bridge parts.

The semantic is poor. Only *IfcBuildingElementProxy* are used while *IfcPile*, *IfcFooting, IfcColumn, IfcWall, IfcSlab* are already available in IFC2x3.

All the shape representations are boundary representations, with no semantics. For cylindrical piles, a disk swept solid along the axis pile would be more appropriate. The footing of the central pier is a parallelogram, and a rectangular profile extruded along a vertical axis would be more appropriate.

Following these comments and discussions about what the construction sector is expecting regarding bridges, Bentley has provided a new “use case application”. See Annex B for more information.

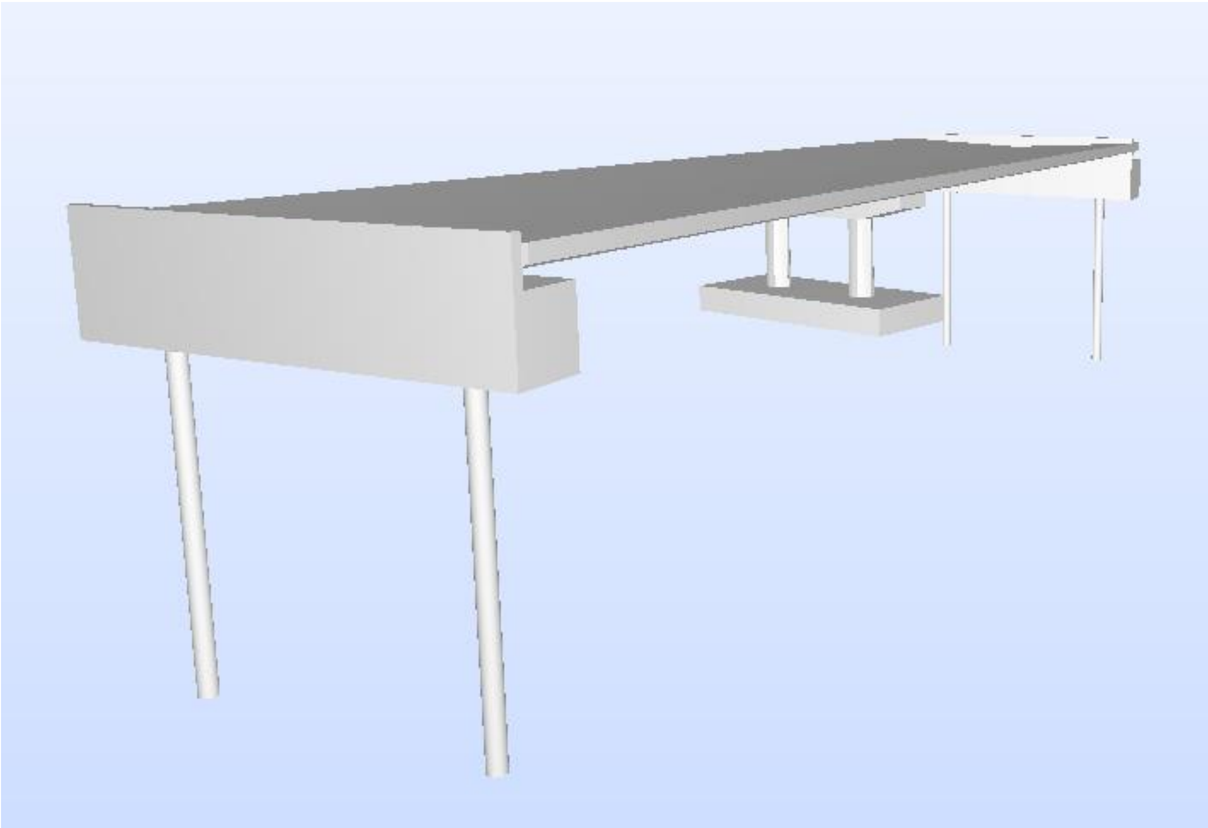


Figure 15: Bentley Overpass Model

3.4.3 Dassault Systèmes

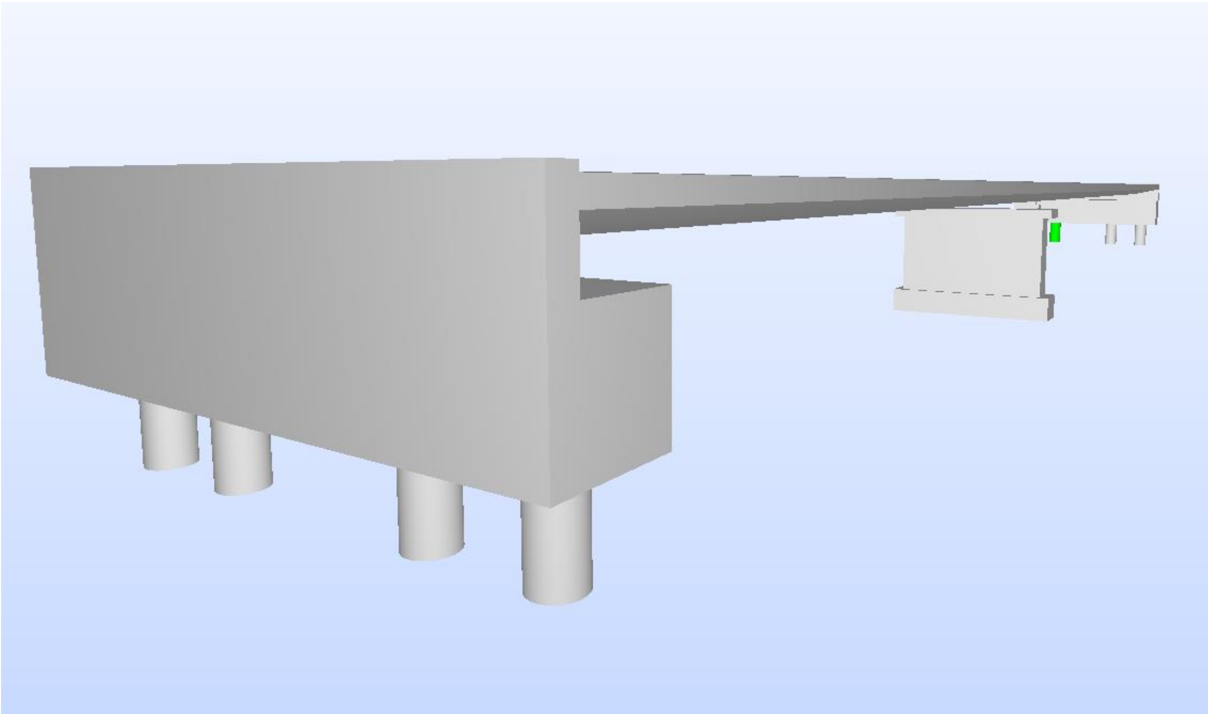


Figure 16: Dassault Systemes Overpass Model

The example has been built with Dassault Systèmes Catia V6. The IFC export is based on IFC 2x3. The model is not really similar to the example given in section 3.3.2, but it does not matter.

The work asked to the editors is focused on addressing the first criticisms regarding the IFC output provided in section 3.3.2.

The breakdown structure is good and detailed, even if *IfcBuilding* and *IfcBuildingStoreys* are used.

The semantic is good. Only few *IfcBuildingElementProxy* are used, and as often as possible *IfcPile*, *IfcFooting, IfcColumn, IfcWall, IfcSlab* are used IFC2x3.

All the shape representations are boundary representations, with no semantics. For cylindrical piles, a disk swept solid along the axis pile would be more appropriate.

Following these comments and discussions about what the construction sector is expecting regarding bridges, Dassault Systèmes has provided a new “use case application”. See Annex C for more information.

3.4.4 Allplan

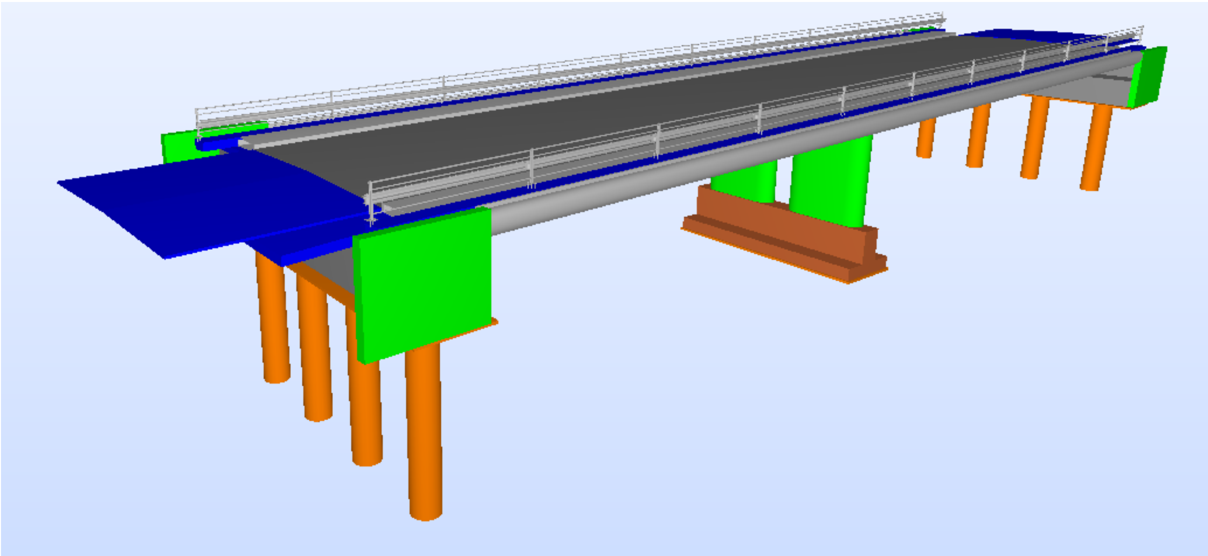


Figure 17: Allplan Overpass Model

The example has been built with Allplan. The IFC export is based on IFC 2x3 model schema and CoordinationView_V2.0.

The spatial breakdown is good. It has to be noted that an additional well-documented breakdown is based on the *IfcPresentationLayerAssignment* entity. Unfortunately, such a use is not machine readable.

The semantic based on entities is good. There are some translation mistakes between French and English. To go further, the exchange needs have to be detailed by the end-users, through a detailed Exchange Requirements document.

Quite all the shape representations are boundary representations, with no semantics. Some shape representations based on extrusions for instance regarding the footing of the central pier which is a parallelogram.

Following these comments and discussions about what the construction sector is expecting regarding bridges, Allplan has provided a new “use case application”. See Annex D for more information.

3.4.5 Vianova

The example has been built with Bentley Novapoint DCM from Vianova Systems AS. The IFC export is based on IFC 2x3 model schema.

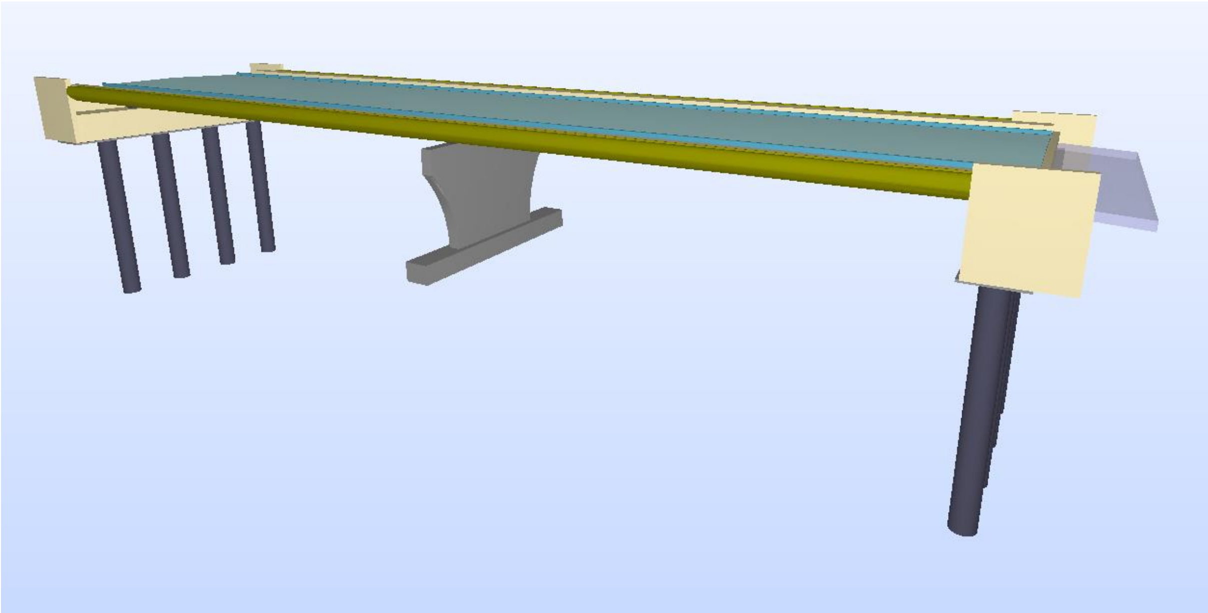


Figure 18: Vianova Overpass Model

The spatial breakdown is poor. At least, abutment1, pier2, abutment3 and deck could have been used in order to define a local placement for the bridge parts.

Regarding the entities, the semantic is rich. Some errors have been made regarding the selection of bridge parts.

All the shape representations are boundary representations, with no semantics. For cylindrical piles, a disk swept solid along the axis pile would be more appropriate. The footing of the central pier is a parallelogram, and a profile extruded along a vertical axis would be more appropriate.

There are no *IfcRelationships* that means no semantic regarding objects to objects.

Following these comments and discussions about what the construction sector is expecting regarding bridges, Vianova has provided a new "use case application". See Annex E for more information.

3.4.6 First conclusions

Let us come back to the question raised up at the beginning of this section: having in mind that all the drawings shown in section 3.3 have been produced with a 3D CAD authoring tool, regarding IFC exchange file production and its discrepancies versus the *expected quality*, where does the process fail?

First of all, there is a clear need of definition of the Exchange Requirements. An *expected quality* of the IFC exchange has to be detailed. If not, the result could only be a so-called nice picture. Roughly speaking, the need is to exchange information defined at Design Stages hat is usable for producing components and assembling them for a tangible construction. In addition, information must be machine readable to allow efficient support by dedicated software applications and not only by human brains. Nevertheless, it is surprising to see that such a process is even not yet applicable when the designed structure is similar to a building one.

It is clear that specific IFC entities and concept are missing, the first of them being the carriageway definition. This relates to the work carried by *IfcAlignment* project and *IfcBridge* project.

Up to now, no missing information has been identified at the authoring tool level.

A large use of boundary representations and a lack of relationships between entities have been identified during the survey, but it is first due to a lack of Exchange Requirements.

3.5 IFC-Alignment

Alignment is seen as “a reference system associated to linear constructions, such as roads, rails, bridges, used to position elements, such as road, rail or bridge elements or other feature elements, positioned along an alignment”. [15, 16, 17]

A single alignment can be represented as:

- A horizontal, a vertical and a resulting 3D alignment,
- A horizontal and a vertical alignment,
- Only a horizontal alignment,
- Only a 3D alignment (e.g. from surveying).

Having a look on Nordenga Bru, for instance on the main steel structure made of beams along the road alignment and beams orthogonal to the road alignment, we can conceive something like a ***Grid*** for infrastructure.

This new Grid concept could be helpful for the Architectural domain as well as for the Structural domain.

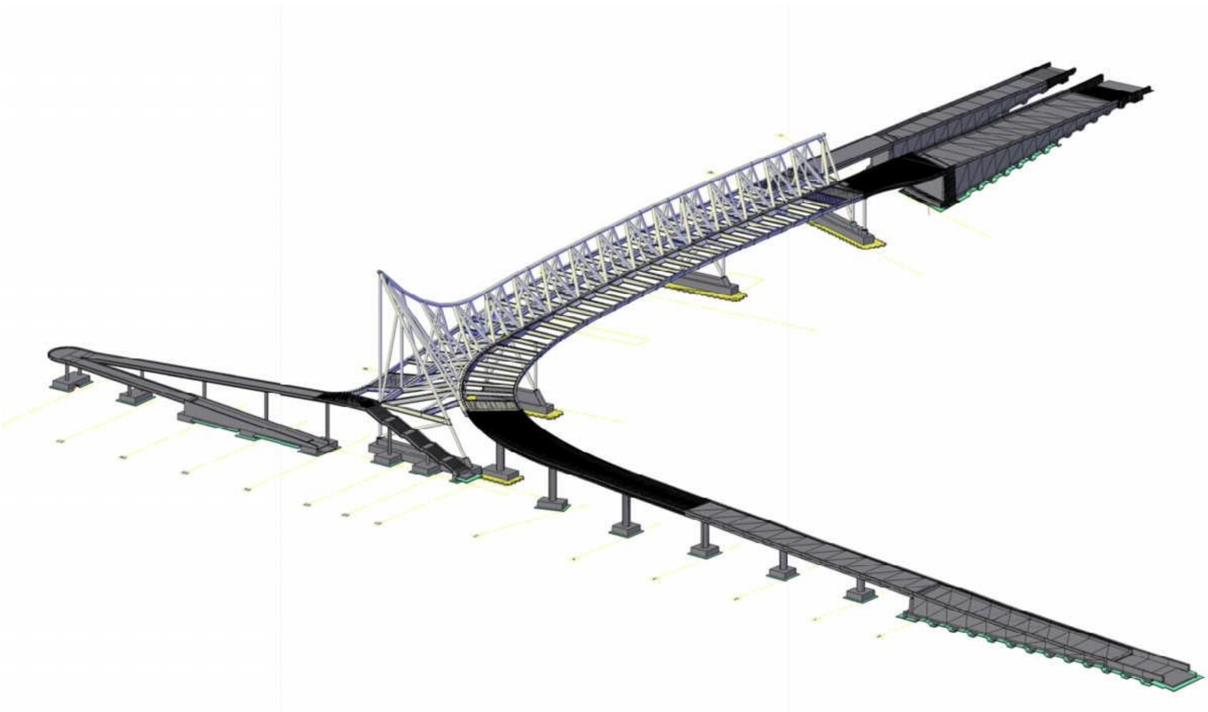


Figure 19: Nordenga Bridge simplified model

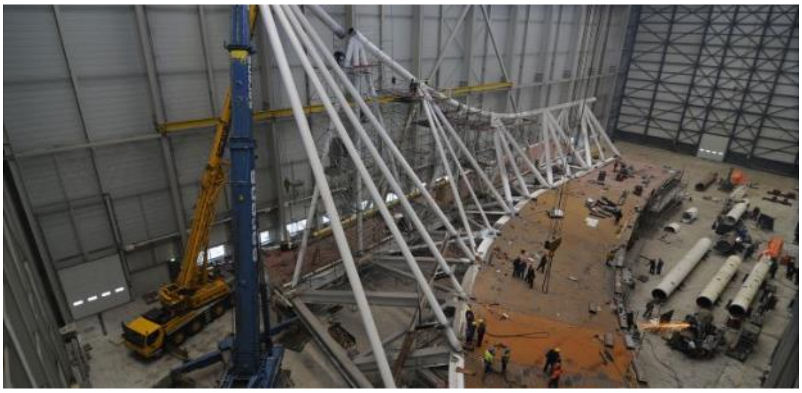


Figure 20: Nordenga Bridge construction sequence

Having a look on Nordenga Bru, for instance on the pre-stressed concrete approach bridge, how could we use the *IfcAlignment* entity to describe more easily the reference line of the "blue" tendons?

The deck alignment is first a straight line and then a curve. In the curve the deck has super-elevation to compensate centrifugal forces and is widened to ease driving in the curved part.

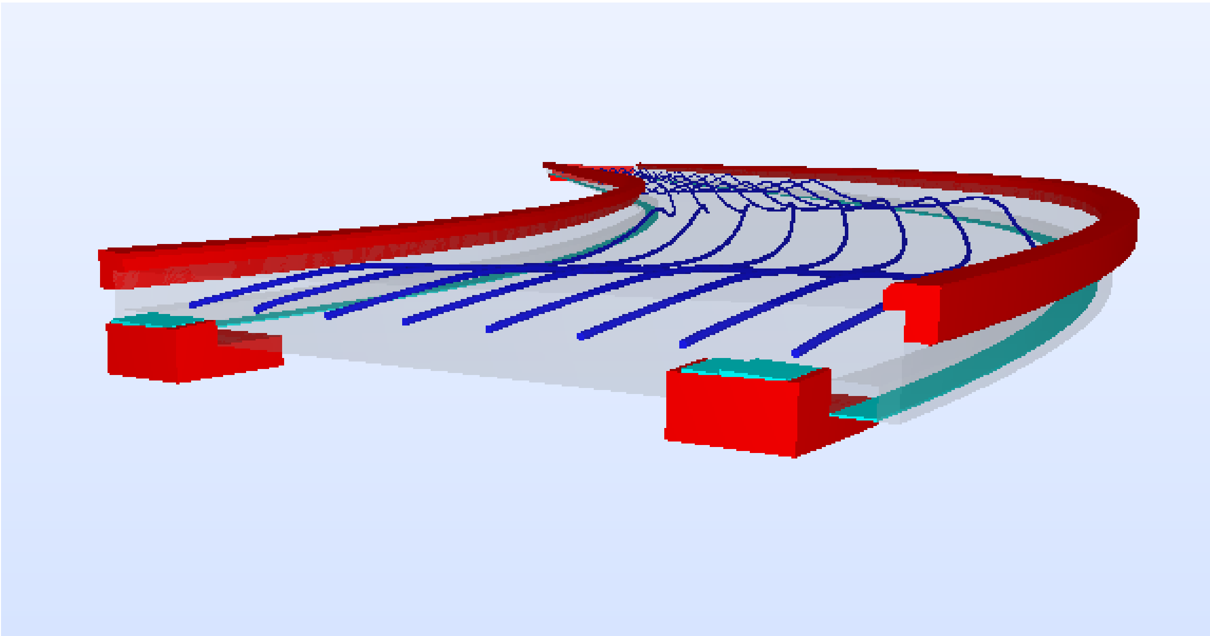


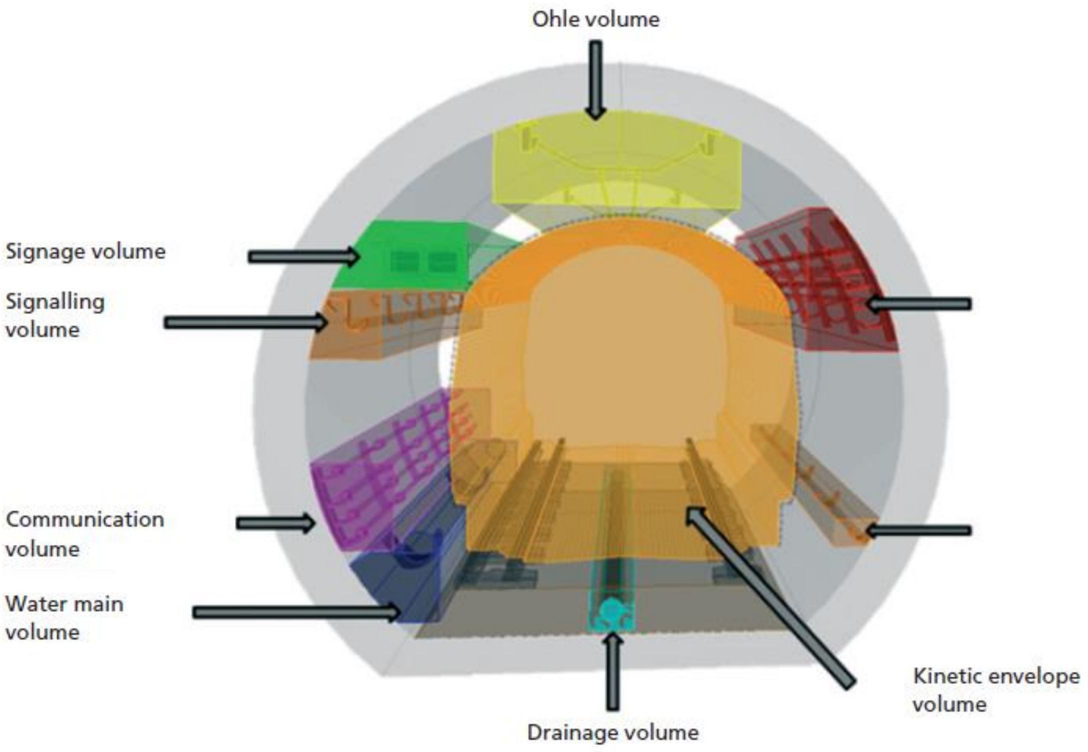
Figure 21: Nordenga Bride: pre-stressing details

How could we describe the "red" parapets whose cross section has the same profile all along the bridge? The right answer is to extrude the cross section along the border of the carriageway. This kind of concept has to be included in the development of *IfcAlignment* and to have as well as possible the possibility to derive alignments of components of the deck such as the parapet or the tendons.

More generally the study of the bridge examples in section 3.3.2 has shown that the driver of a bridge design is the vehicles supported by the bridge deck. The key point is not only the alignment of the road, but more generally the carriageway, which obviously is depending on the alignment. But its definition needs also additional information, which is lacking in the current project. The overpass has also emphasized the fact that a bridge supports a road but also flies over an obstacle, which can be another road. The carriageway of the under road has a clear impact on the overpass at least at the bridge support level. But under road also exhibits the need of clearance over the carriageway, which is linked to the kinetic envelope volume in a tunnel. This concept is illustrated in the figure hereafter.

PAS 1192-2:2013

Figure 11 – Volumes within a tunnel design for spatial co-ordination



NOTE 1 An example of volumes for spatial co-ordination in a tunnel design is shown above. Volumes are organised by discipline around the periphery of the tunnel (e.g. catenary volume, evacuation walkway and emergency accessway, etc.)

NOTE 2 Soft Volumes shall also be taken into account for spatial co-ordination. Such items as the "kinetic envelope" should be provided and owned.

Figure 22: Clearance concept

3.6 IFC-Roads

Infra BIM Schema Specification provides some additional information to IFC-Bridge. [18]

The focus of this document is mainly oriented towards entity semantics.

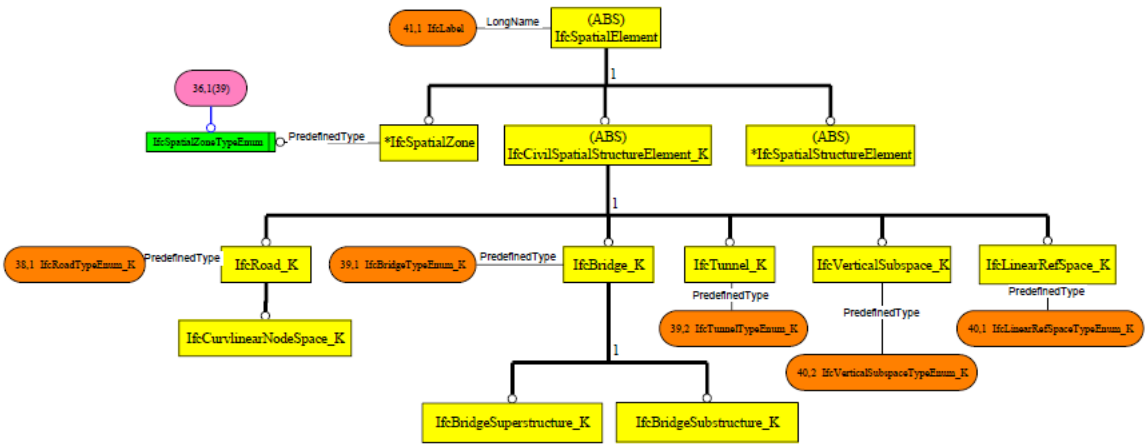
Alignment topics are linked to *IfcAlignment.*

Some additional details could be found in section "6 *IfcSharedCivilServiceElements*" regarding Element Component.

Unfortunately, the focus is put on formal semantics. Work related to semantics addressing the domain entities attributes or relationships between entities is missing. It is important to have in mind that machine readable information exchange is expected. These needs could only be solved with domain specifics semantics. In particular, neither specific information about geometry description (*IfcProductRepresentation*) nor semantic proposals about geometry representation which is not only based on Boundary Representation (BRep) are provided.

No specific information is given about relationships that could increase the interpretability of the exchange model.

Some use case would be welcome to illustrate the proposed concepts.



EXPRESS Specification:

```
ENTITY IfcBridge_K
  SUPERTYPE OF (ONEOF(IfcBridgeSuperstructure_K, IfcBridgeSubstructure_K))
  SUBTYPE OF IfcCivilSpartialStructureElement_K;
    PredefinedType : OPTIONAL IfcBridgeTypeEnum_K;
END_ENTITY;
```

IfcBridgeTypeEnum

- ARCH_BRIDGE
- CABLE_STAYED_BRIDGE
- PREFLEX_GIRDER_BRIDGE
- PSC_BOX_GIRDER_BRIDGE
- PSC_HOLLOW_SLAB_BRIDGE
- PSC_I_GIRDER_BRIDGE
- PSC_SLAB_BRIDGE
- RAHMEN_BRIDGE

- RC_BOX_GIRDER_BRIDGE
- RC_HOLLOW_SLAB_BRIDGE
- RC_T_BEAM_GIRDER_BRIDGE
- STEEL_BOX_GIRDER_BRIDGE
- STEEL_PLATE_GIRDER_BRIDGE
- SUSPENSION_BRIDGE
- TRUSS_BRIDGE
- OVERPASS
- RAMPBRIDGE
- APPROACHBRIDGE
- USERDEFINED
- NOTDEFINED

EXPRESS Specification:

```
ENTITY IfcBridgeElement_K
  SUPERTYPE OF (ONEOF(IfcBridgeDeckPlate_K, IfcBridgeTower_K, IfcBridgeGirder_K,
IfcBridgeCable_K, IfcBridgePier_K, IfcBridgeAbutment_K))
  SUBTYPE OF IfcCivilStructureElement_K;
     BridgeType : OPTIONAL IfcBridgeElementTypeEnum_K;
END_ENTITY;
```

3.7 Conclusions

At this point of the State of The Art, it is time to remember what a bridge is: [14]

> *A **bridge** is a structure built to span physical obstacles such as a body of water, valley, or road, for the purpose of providing passage to a particular traffic or function over the said obstacle. There are many different designs that all serve unique purposes and apply to different situations. Designs of bridges vary depending on the function of the bridge, the nature of the obstacle, and of the terrain where the bridge is constructed and anchored, the main material used to make it, the way the works are carried out and the funds available to build it.*
>
> *For instance, a bridge can be categorized by what it is designed to carry, such as trains, pedestrian or road traffic, a pipeline or waterway for water transport or barge traffic. An aqueduct is a bridge that carries water. A road-rail bridge carries both road and rail traffic.*

When a bridge carries trains or cars, it means that the bridge structure carries a “surface” allowing rail or road traffic according to given conditions. This surface is defined by the road alignment and a cross sectional profile depending on the expected traffic, the surface drainage conditions, the super-elevation and widening due to curves all along the alignment. In fact the surface should be rather a volume if clearance is included to guarantee a clash free traffic.

If the bridge spans over a road, it is also important to know the associated volume. In general there are skew angles (horizontally and vertically) between the two alignments which impact the shape of the bridge supports.

In addition there could be constraints on the support locations at ground level due to soil conditions or space already occupied by other facilities.

A bridge is first of all a structure built to span large physical obstacles. Since the early design, structural analyses are carried out in order to check the structural behaviour of the bridge during operation and during the construction sequences.

A building design is mainly driven by the organization of its different spaces. A bridge design is mainly driven by its ability to carry road traffic by providing passage over a physical obstacle for which the existing passage should be guaranteed.

As already said, the bottle neck is the Exchange Requirements description. It is the key point to be able to define the Information delivery manual (IDM) and therefore the specific Model View Definition (MVD).

The different stages of the lifecycle have to be detailed, defining the actors, the information that is exchanged, what is mandatory, who is the owner, who is the receiver, the level of detail regarding the components, regarding their attributes, how the shape representations are described, which properties are defined, which relationships between entities are mandatory. The aim is to describe openBIM and machine readable information.

As default rule, avoid using Boundary Representation to define the shape representation. In solid modeling, boundary representation - often abbreviated as BRep - is a method for representing shapes using the limits. A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid. If such a representation provides a nice picture, very close to what is needed by a viewer, on the contrary all the mechanical information are lost, such as neutral axis, cross section, principal axes of inertia, center of gravity, dimensions, quantities... which are critical in the manufacturing workshops and on the construction site.

BRep descriptions need also a lot of surface elements and nodes which lead to large IFC files and visualization problems when the size of the surface elements is not in accordance with the global size of the whole model.

During bridge design there is a continuous strong link between the architectural model and the structural analysis model. Most of bridge components are curvilinear elements whose more appropriate geometric description is an extrusion along a curve.

The use of *IfcRelConnects* entities is also of key importance. Regarding the architectural models, clash detection can identify an element penetrating another one, and therefore the user can decide if it is really a clash or not. With an *IfcRelConnects* entity, the machine knows that a given beam sits on a given column, and check if this is correct regarding the respective geometries. In addition this means that in the additional structural analysis model there must be a common structural node between the two associated structural members.

4 Missing Concepts

4.1 Exchange Requirements

A bridge is a structure carrying vehicles and built to span physical obstacles. Carrying cars means that the bridge structure supports a “surface”, the so-called *carriageway*, whose definition is driven by the traffic conditions. In practice, this surface is defined by the road alignment and a cross sectional profile depending on the expected traffic, the surface drainage conditions, the super-elevation and widening due to curves all along the alignment.

In addition to the carriageway, a volume should be added if clearance is included to guarantee a clash free traffic with the bridge seen as an obstacle.

If the bridge spans over a road, it is important to know the associated volume of the road passing under. In general there is a skew angle between the two alignments which impacts the shape of the bridge supports.

In addition there could be constraints (to be expressed again as gauges or calibres) regarding the support locations at ground level due to soil conditions or spaces already occupied by other facilities. This means that out of the environment that can be described without semantics at all, some elements need to have a proper definition with envelopes and possibility of relations through gauges with elements of the bridge.

First of all, a bridge is a structure built to span large physical obstacles. The structural behaviour is of critical importance. Since the early design, structural analyses are carried out in order to check the structural behaviour of the bridge as well as when completed during operation or when only partially erected during the construction sequences.

If a building design is mainly driven by the organization of its different spaces, a bridge design is mainly driven by its ability to carry road traffic and providing passage over a physical obstacle. It would even be beneficial to start from a more or less topological description (schematic structural representation without necessarily accurate geometric dimensions and representations) of the bridge main components

The first problem to be solved by the designer is related to axis systems. The terrain in which the bridge is located is defined at country level. The alignments of the roads passing over and under the bridge are related to the whole road, based on a curvilinear abscissa. The bridge located at the cross-roads is defined locally such as for a building. Due to the size of the bridge and the inter-distance between main elements, the supports have their own local axis systems defined relatively to the bridge local axis system. And the components of the bridge structure have their own local axis system. What seems to be complexity is necessary regarding the different actor’s point of view: the existing Geographic System (GIS) is defined at a large scale; a road is defined at the network level; a bridge is defined to be constructed locally; a component is defined to be manufactured in a plant or cast in situ and then to be assembled relative to local coordinates. But all these different points of view must be consistent and linked to each other.

In addition, it is important that a bridge, such as a road, is a curvilinear structure, which means that its geometry is derived from a cross-section moving along a curve. When the curve is a straight line, the geometry could be obtained from an extrusion. When the curve is really a curve (with both torsion and curvature), definition of an extrusion along a curve similar to an alignment becomes necessary.

Last but not least, it is important to have in mind that the axis system related to the associated structural analysis model has to be the same for all the elements included in the structural analysis model. That means that this specific associated axis system is very close to that of the whole bridge.

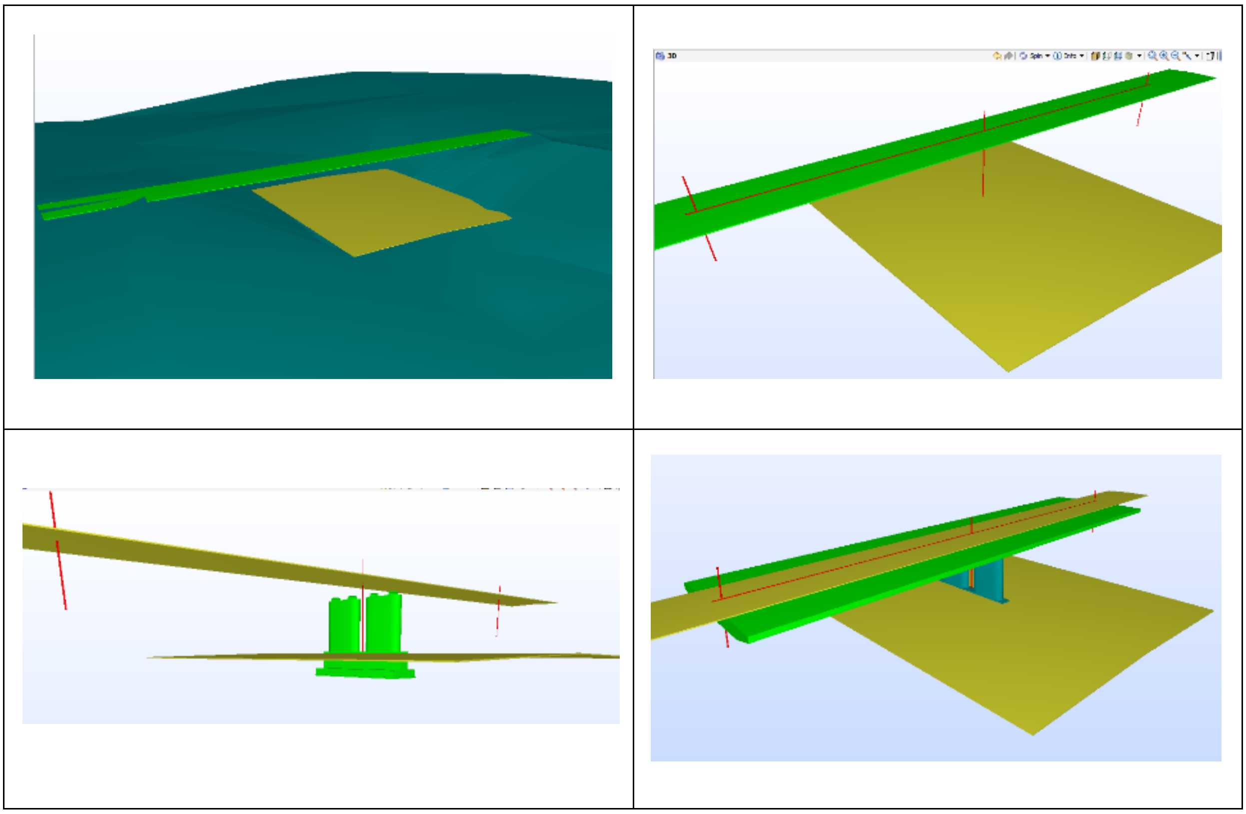
The second problem to be solved is related to the ground. The bridge sits on the ground. The ground is fully part of its structural behaviour. It is linked to the support conditions and the foundation types of the structural analysis model, including the ground stiffness. It impacts strongly the geometry of the support, in particular the abutments and the approach structures (often embankments). To build a bridge means necessary cuts and fills to connect the existing surrounding terrain and the sustained traffic to the new bridge.

A bridge design shows only the bridge completed ready for operation. It does not include the construction sequences. However, the construction sequences are critical for a bridge and cannot be avoided. And, in particular, the earthworks needed for the bridge have to be described. The Digital Terrain Modelling (DTM) associated to the *IfcSite* shape representation represents what will not change during the construction process. It is only input information to detail the constraints on the design and the construction. Ground entities should be able to define the modifications of the existing terrain, including ground cutting for the piles, ground excavations for the footings, embankments for the approach structures... Last, but not least the bridge construction will surely require temporary works and structures (sheet piling, cofferdam, dams, additional supports, etc.). By the way, properties and quantities could be associated to the entities, 4D viewers could show the different sequences of the construction.

The third problem to be solved is the close link between the architectural model and the structural analysis model. On one hand there is a model defined by an assembly of components defined relatively to a local axis system implemented in the global model. The components are derived from *IfcRoot*, but the local axis system is just an attribute of the entity as the shape representation. On the other hand there is a model defined by nodes derived from *IfcRoot* and members derived from *IfcRoot* and connected to nodes.

4.2 IFC

4.2.1 Bridge



The above picture shows the following steps to implement the bridge. In picture 1 (top left), there are the existing terrain (in blue), the under carriageway (in yellow), the upper carriageway (in green). In picture 2 (top right), there are the alignment of the upper road and the verticals on that alignment associated to the supports: the central pier and the two abutments. In picture 3 (bottom left), the central pier with its foundations is installed, and also the abutment's vertical alignments installed in picture 2. Finally in picture 4 (bottom right), the deck is installed. It is an extrusion of a profile along the alignment. Then Boolean operations should be applied to the geometric extrusion in order to take into account the consequences of the skew angle between the upper and under alignments.

Regarding a bridge data model, ***IfcAlignment*** is a very important concept because it is the basement of all the data defining the bridge. In addition, there are specific stations on the alignment that should be captured, stored and addressed as basic data, which means as entities derived from *IfcRoot*. In particular, are concerned the location of the bridge supports.

More generally, we must have in mind that data described in attributes should only be used by one entity only **but** should be addressable indirectly via the entity. All entities derived from *IfcRoot* have an owner history attributes. That is not the case for attributes, particularly regarding geometry description. Therefore modifications cannot be traced!

Regarding a structural analysis model, an *IfcStructuralCurveMember* entity is linked to an *IfcStructuralPointConnection* entity at each end. This relationship is described by an *IfcRelConnectsStructuralMember*. In parallel the associated shape representation is described by attributes. To ensure the same coordinates, the example provided in IFC4 documentation[4] uses the same *IfcCartesianPoint*, which is not possible if the data providers are different. Anyway, the consistency is based on the authoring tools. It cannot support consistent modification.

An *IfcProduct* entity has two attributes regarding its geometry description: an object placement and a representation. The representation is described in a local axis system defined by the object placement. *IfcLocalPlacement* has two attributes: the first one (optional) is an *IfcObjectPlacement*, the second one (mandatory) is an *IfcAxis2Placement3D*. The first one allows (or not) to describe the second one relatively to the spatial entity containing the product. The containment is defined with an *IfcRelContainedInSpatialStructure* relationship. But the needed *IfcObjectPlacement* of the spatial entity has to be redefined or shared by hand!

Regarding the architectural domain and the structural analysis domain, there are two contradictory ways to define the geometric representation: on one hand (structural analysis domain), the member is limited by two nodes; on the other hand, an *IfcLocalPlacement* is used and for instance an extrusion along a given direction on a given length. To manage these two domains in a consistent way could be easily a nightmare. To solve this problem, the geometry description of the *IfcProduct* should be derived from *IfcStructuralCurveMember* geometry, thru an extrusion along the member axis, completed by Boolean operations at the ends.

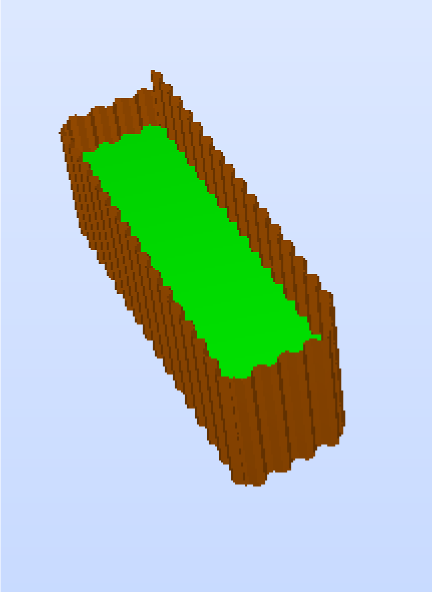
More generally, the data model schema is able to describe all stages of the project life cycle. Consequently many of the entity attributes are optional. But in order to guarantee a consistent and usable exchange, it is mandatory, for each stage, to clearly define which attribute is mandatory and which one is absolutely forbidden. When an attribute can be covered by different entities (the best example is the geometry representation), the only one that could be used has also to be defined. Relationships are critical to allow machine readable information. Here also, the mandatory relationships have to be listed according to a given stage. Properties and their restricted content have also to be clearly defined.

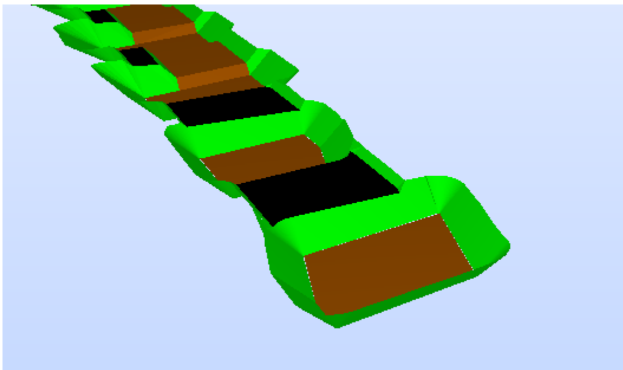
Such a need has been already identified and tried to be addressed through the Level of Definition (LOD) approach. But we have to go more in detail. If this work is not carried on, we will continue to produce nice pictures, but certainly not machine interpretable information that could be used efficiently. And we will pave the way to proprietary exchange formats which are therefore more efficient but unfortunately not open and dependant on the software editor’s policy and lifetime. We also need records than can be read in fifty or even hundred years.

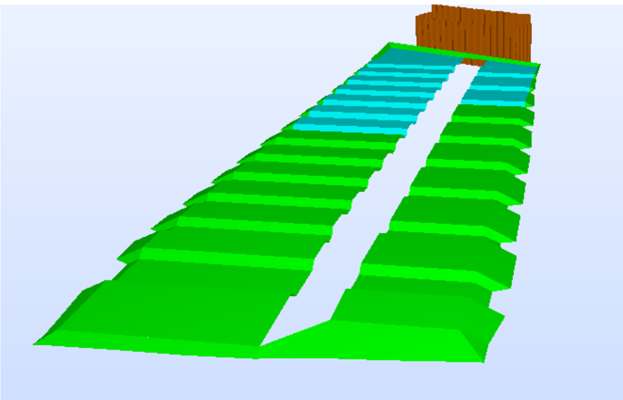
A bridge sits on the ground, sometimes in water... The ground can be divided into two parts: the part that will be modified by the bridge construction and the part that will not be modified but could be impacted by the bridge. The part of ground that will not be modified could be represented with a faceted surface (Digital Terrain Model). **The part of ground that will be modified has to be described with specific IFC entities**. Spatial elements are needed to locate the areas where the foundations will be located. Ground elements have to be defined to describe the cuts, borings and fills associated to earthworks for foundations. Geometric representations and quantities are needed. Soil properties are necessary for the structural analysis. Water associated to a river should also be described as well as the works to protect the piers. Parts of the access roads are embankments. They should also be defined. Specific relationships should define the connections between these different entities.

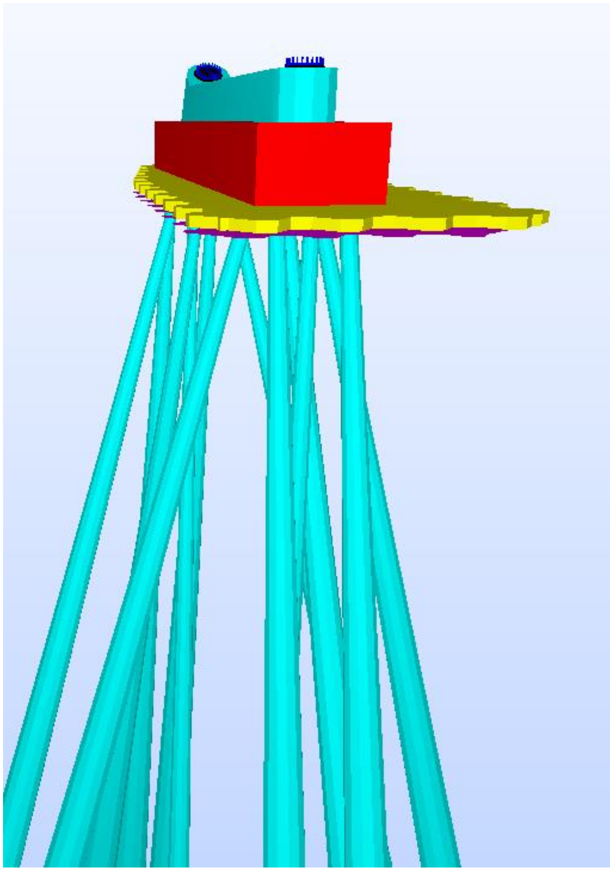
Some examples issued from the Nordenga Bru are given here after.

[4] structural_analysis_curve.ifc









Regarding **drainage and distribution networks** (water, gas, electricity...), entities already developed for buildings could be used.

Regarding equipments such as barriers**, railings, kerbs, signs, lightning, pavement, rail tracks** and so on, existing and new entities have to be used or defined.

Steel bridge components are first built in plants like manufacturing products and then prefab (prefab may even lead to cutting and re-welding manufactured products: I-beams cut in web along a longitudinal broken periodic line and re-welded after translating one half according to the half period) and assembled on site. Up to now these steps are not really modelled. The focus remains on the architectural structure delivered at the delivery of the bridge. Due to the flexibility of the steel structure, the constructed geometry is different of the final geometry.

The relationships describing the connections between the different parts are also critical for obtaining a machine interpretable model. A lot of small parts have also to be included in order to describe the whole structure. A clear breakdown structure is therefore very important to avoid merging small parts with large structural parts.

Concrete bridges have often decks made with pre-stressed concrete. The pre-stressing system has to take into account the construction sequencing and the fact that a single tendon could influence more than one segment or beam. It is not the same scenario as for a precast pre-stressed concrete beam or slab used in a building. Tendons have to be seen as something similar to an *IfcDistributionSystem*. The tendon is contained in a duct-based system connected to the structural elements. Inside the duct-based system is the tendon. The axis geometry of the duct-based system is linked to the alignment of the deck with additional deviations to compensate the deflection of the deck behaving the loads applied on the deck. Regarding the structural analysis model, a tendon has to be seen as a specific distributed load applied to the structural elements connected to it, varying in time due to creep and shrinkage of the concrete.

Suspended bridge specificities are mainly the suspension cables and the hangers connected to the suspension cable and the deck. The suspension system is very flexible and its shape is sensitive to the loads applied on the deck, the external temperature and the construction sequencing. The reference of the geometric representation is the bridge with applied dead loads at the end of the construction. The detailed definition of this geometry is driven by the structural analysis of the construction steps. Specific parts are necessary to describe the components ensuring the connections between the deck and the hangers, between the hangers and the suspension cable, between the suspension cable and the top of the pylon...

Cable stayed bridge specificities are mainly the stay cables. Stay cables are elements of the structural analysis model. Their geometric representation is depending on the tension faced by the stay cables.

In seismic regions, special connecting elements have to be included generally with visco-elastic types or responses. BRep representations accommodating behavioural rules (extension of piston …) should be sufficient.

Reinforcements of concrete bridge structures are in general more important and therefore more numerous than in buildings. Their placement in the concrete components is sometimes difficult due to their density and the presence of tendons. Clash detection could be helpful. The geometric representation must be an extrusion along an axis. Longitudinal reinforcements are driven by the alignment of the deck, the piers or the abutments. Cross sectional reinforcements are placed along the longitudinal alignments. The different shapes of the reinforcement could have been selected from a library, but their real geometry is important regarding clash detection, in particular in high density areas.

The **Structural Analysis Model** should be a close representation of the main structural elements of the architectural model. The structural analyses are checking the behaviour of the bridge during operation according to specific load cases and the behaviour of the bridge during all of the construction steps. In addition, the structural model is also used to compute the expected deflections of the bridge during the construction and then to adapt the dimensions of the different components in order to fulfil the shape defined for the end of construction. Therefore, it is necessary to inform sufficiently the structural analysis model in order **to be able to simulate all the construction steps**.

To simulate all the construction steps regarding the **project scheduling**, IFC4 allows the definition of tasks and resources that could be associated to bridge elements. Therefore by associating a work schedule to the tasks, it is possible to obtain a 4D model of the bridge.

By associating quantities to the bridge elements and **costs to these quantities**, it is also possible to obtain a 5D model of the bridge. How these quantities have been computed is not the problem of the exchange.

4.2.2 Civil structures

The extensions of the data model schema to bridge could also be applied to other civil structures such as tunnels or retaining walls along roads or railway lines. These structures are all driven by an alignment and generally concrete made (although not all: hydraulic structures with large sluice valves, wood bridges, wood shutters for arch bridges…).

An underpass bridge looks like a short tunnel (see section 3.3.3). A cut and cover structure looks like a tunnel; the structure is composed of walls and slabs, such as an underpass bridge.

*A **tunnel** is an underground or underwater passageway, dug through the surrounding soil/earth/rock and enclosed except for entrance and exit, commonly at each end. A pipeline is not a tunnel, though some recent tunnels have used immersed tube construction techniques rather than traditional tunnel boring methods.* [20]

The description of the surrounding soil is of key importance for tunnel design and construction, including the description of the different soil layers and not only the terrain surface modeling.

The extensions could also be applied to so-called industrial structures, such as nuclear power plants or sewage plants. These structures are not driven by an alignment, and are more looking like buildings. The drivers are the huge and numerous ducts used by the industrial process. But due to the thick walls of pre-stressed concrete, these structures are also close to bridge structure construction problems.

4.2.3 Earthworks

***Earthworks** are engineering works created through the moving or processing of parts of the earth's surface involving quantities of soil (native or imported) or unformed rock. The earth may be moved to another location and formed into a desired shape for a purpose. Much of earthworks involve machine excavation and fill or backfill, with machines running on the built surface.* [21]

The simplest earthwork is an excavation to sit a foundation on a soil layer able to support the structure. This excavation modifies the terrain surface locally. A 3D geometric representation is needed to describe the geometry of the excavation. But the initial surrounding terrain surface (DTM) is sufficient for the part that is not impacted by the excavation. The shape of the excavation is generally a simple a truncated pyramid. The difficulty is the Boolean operation between the truncated pyramid and the Digital Terrain Modeling that implies an hypothesis upon the stability slope (itself depending on the geotechnical characteristics of the crossed layers) and on the possible temporary works or structured used (sheet piling, cofferdam, …) that will result from the "excavation" up to a certain depth. The fill operation is a rather inverse operation to the excavation resulting into a new ore reinstated ground surface than to a void. Backfill operations have to be forecasted as well in the volume defined by excavation less superstructure up to original ground level.

Infrastructures earthworks could be seen as a series of cuts and fills along an alignment according to the alignment position above or under the terrain surface. Traditionally, the cuts and fills are described as successive cross-sections along the alignments. The shape of the cross-sections is driven by the characteristics of the soil layers and limited by the existing terrain surface and or soil layers interfaces. And the final geometry could be seen as an *IfcSectionedSpine* entity. Such an approach nevertheless ***exhibits the lack of clarification*** regarding the use of the *IfcSectionedSpine* entity to describe body geometries when the different associated cross-sections do not have the same shapes.

4.2.4 Terrain

IFC entities describe a construction (the project) that will be designed, built, operated and finally demolished. But this construction is located on the Earth and will interact with the surrounding vicinity. The so-called terrain is the existing ground level surface before the project starts. It has to be divided into three parts: the first one that will be modified by the project; the second one that will not be modified directly by the project but impacted by the activity related to the project; and the third one that will neither be modified nor impacted.

4.2.5 Geographic Information System

In addition to terrain modelling, the interest of GIS is its capability of topological modelling and representing geographically networks.

A GIS can recognize and analyze the spatial relationships that exist within digitally stored spatial data. These topological relationships allow complex spatial modelling and analysis to be performed. Topological relationships between geometric entities traditionally include adjacency (what adjoins what), containment (what encloses what), and proximity (how close something is to something else).

Geometric networks are linear networks of objects that can be used to represent interconnected features, and to perform special spatial analysis on them. A geometric network is composed of edges, which are connected at junction points, similar to graphs in mathematics and computer science. Just like graphs, networks can have weight and flow assigned to its edges, which can be used to represent various interconnected features more accurately. Geometric networks are often used to model road networks and public utility networks, such as electric, gas, and water networks. Network modelling is also commonly employed in transportation planning, hydrology modelling, and infrastructure modelling.

4.2.6 Structural Domain

[to be developed]

4.2.7 Construction Methods and Scheduling

[to be developed]

4.2.8 Cost Analysis

[to be developed]

4.3 IDM

An IFC View Definition, or **Model View Definition (MVD**) defines a subset of the IFC schema that is needed to satisfy one or many **Exchange Requirements** of the AEC industry. The method used and propagated by buildingSMART to define such Exchange Requirements is the **Information Delivery Manual (**IDM) (also ISO 29481).

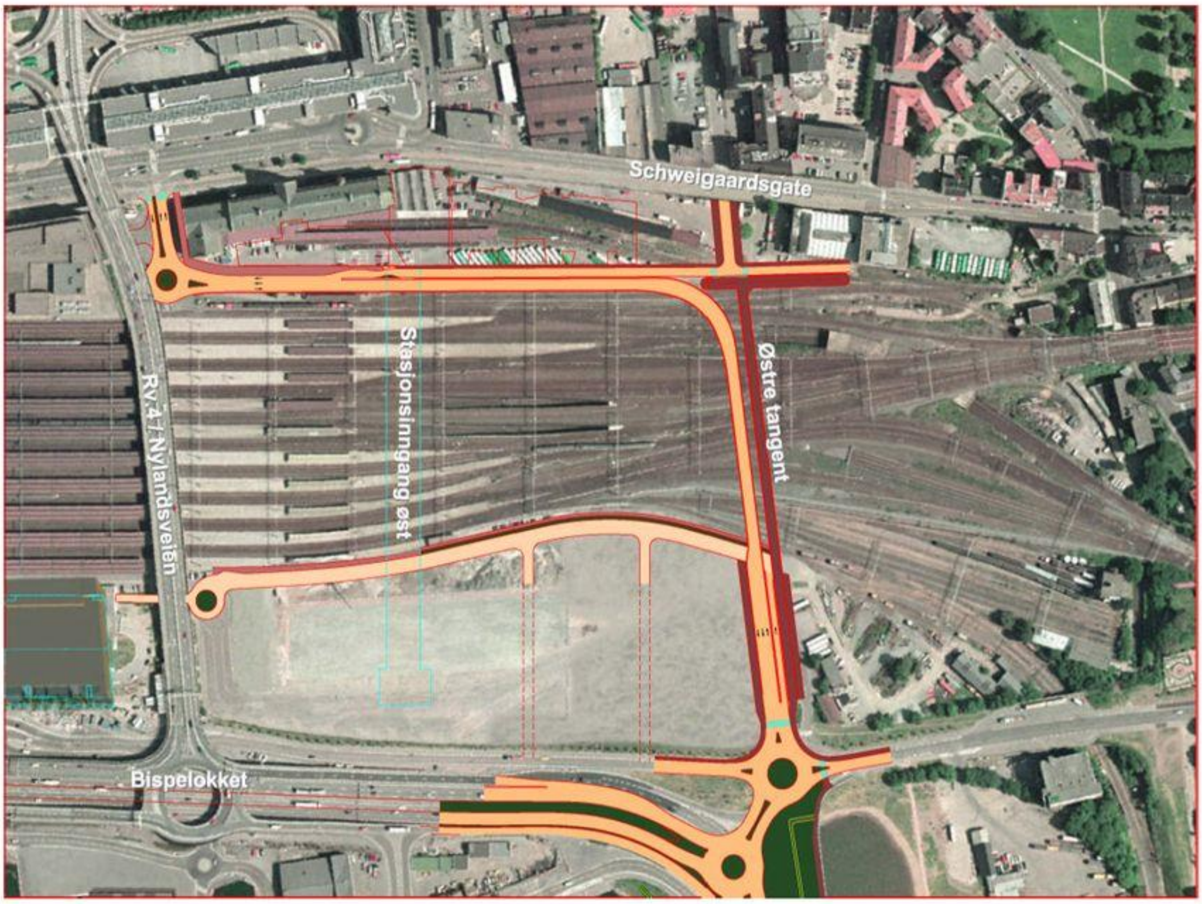
The Information Delivery Manual (IDM) aims to provide the integrated reference for process and data required by BIM by identifying the discrete processes undertaken within building construction, the information required for their execution and the results of that activity. It will specify: [12]

- where a process fits and why it is relevant
- who are the actors creating, using and benefitting from the information
- what is the information created and used
- how the information should be supported by software solutions

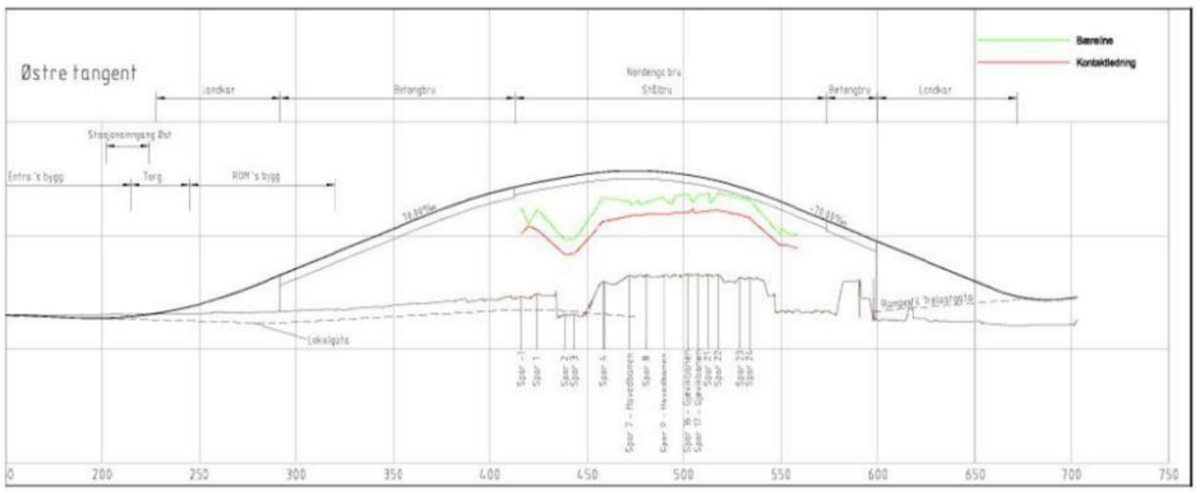
Coming back to the Nordenga Bridge, the followings Exchange Requirements could be identified: [22, 23]

It is an urban bridge. What is the existing city, the foreseen city around the future bridge location? This input information has to be included in the IFC model.

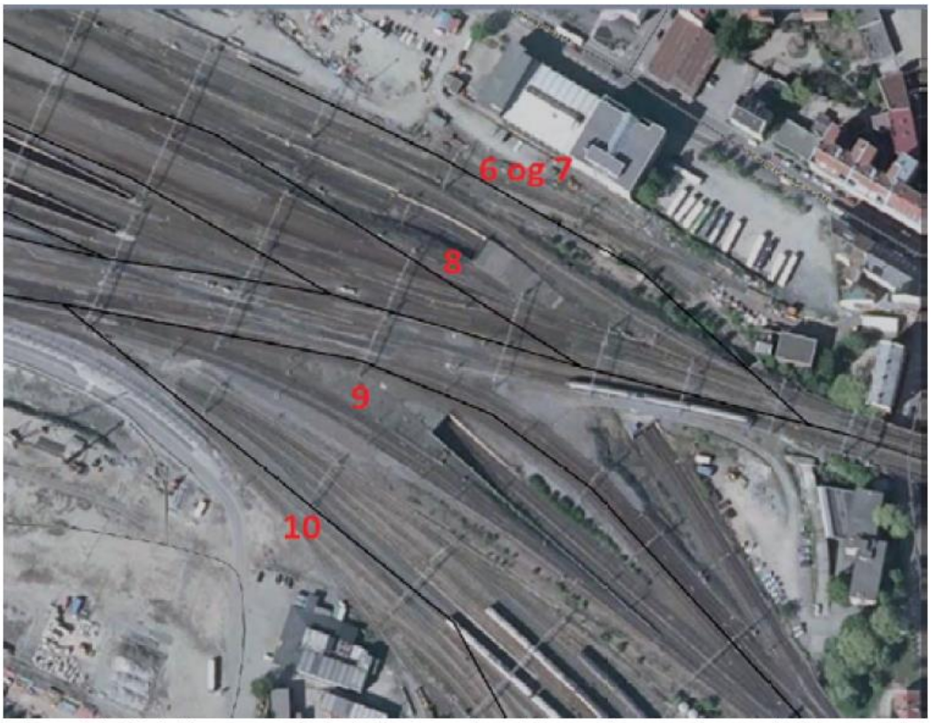
What's about the roads and the bridges alignments?



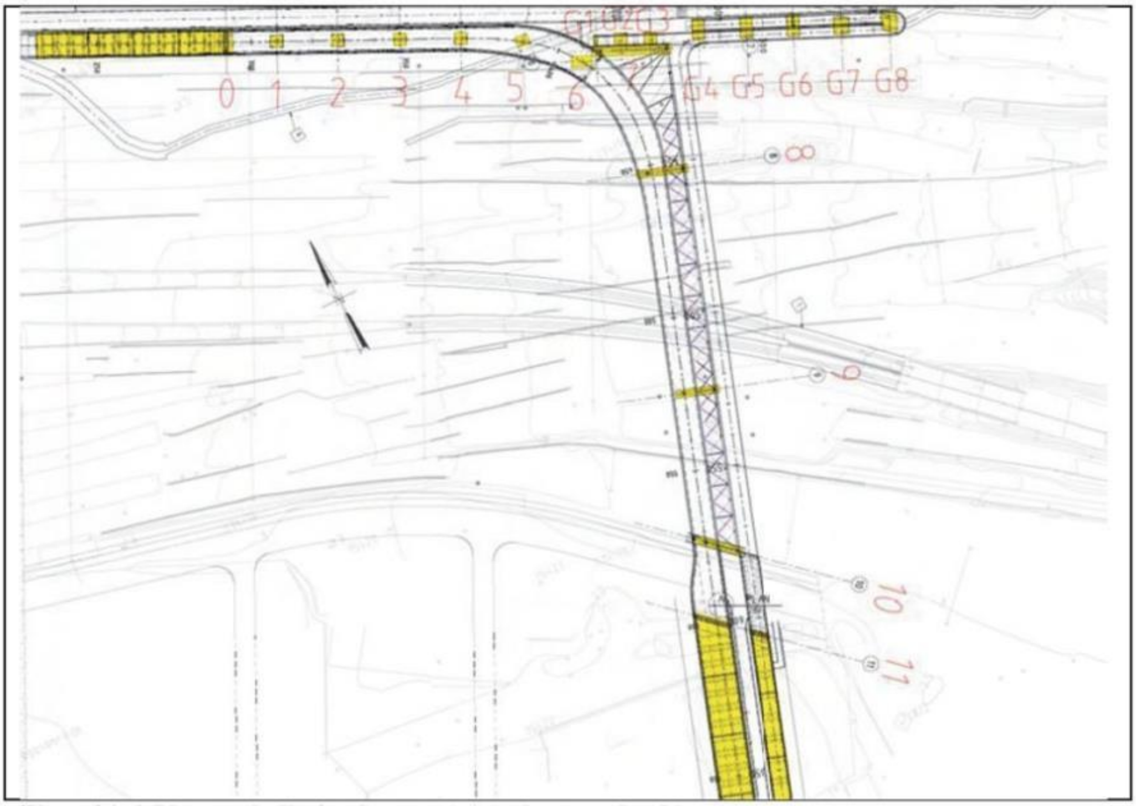
What's about the clearance required by the trains travelling on the under railway lines?



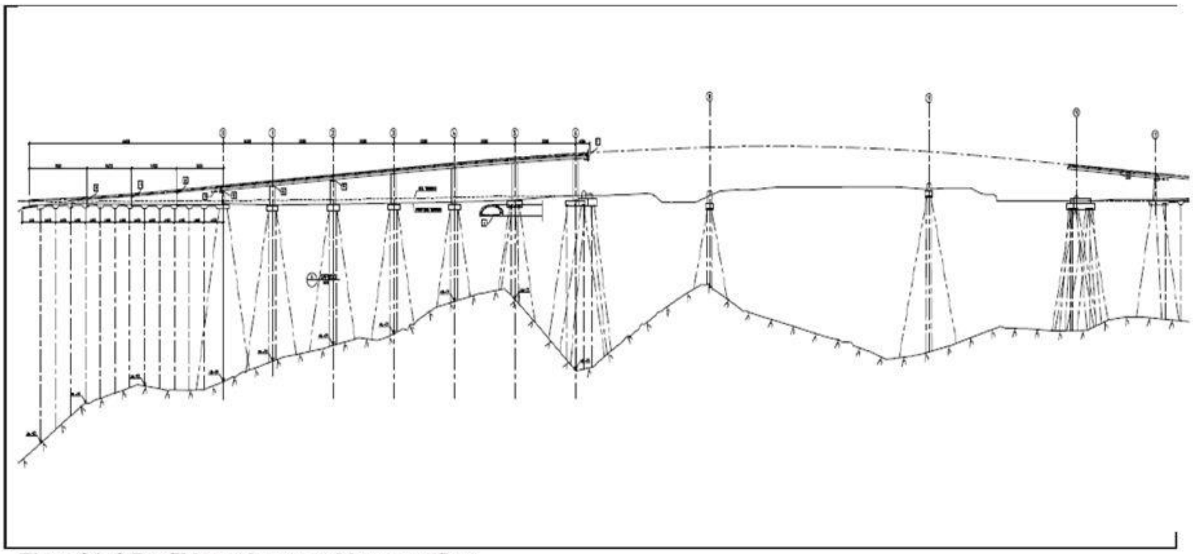
What's about the possible foundation areas in this dense railway lines network?



Figur 34- 1 Flyfoto over Oslo S før bygging. Plassering av akse 6 til 10 er angitt



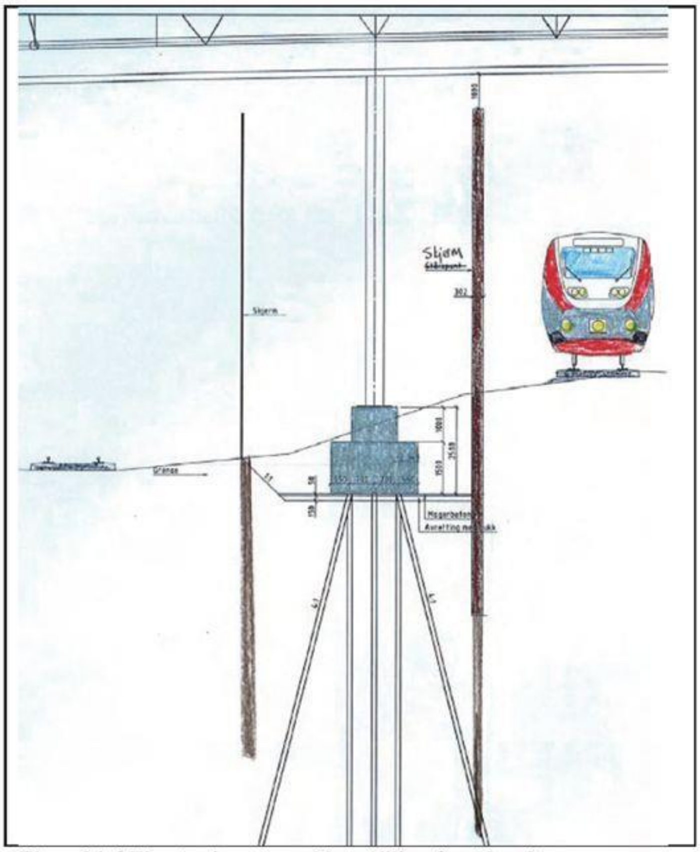
Figur 34- 2 Plan med alle fundamenter (markert med gult)



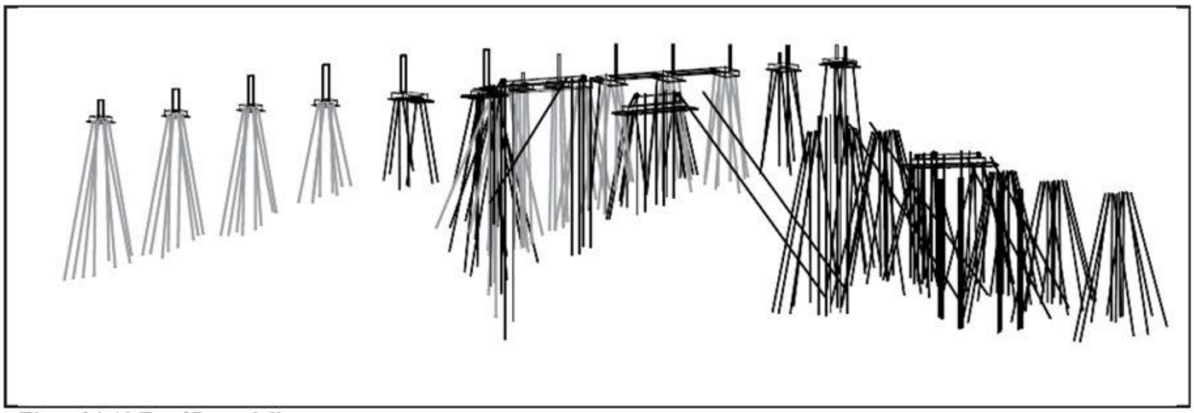
Figur 34- 3 Profil langs brua med bergoverflate

Figur 34-4 Oversiktsbilde sporområdet ved Akse 6, 7 og 8

What's about the foundation choices?



Figur 34-6 Illustrasjon av problemstilling for Akse 8

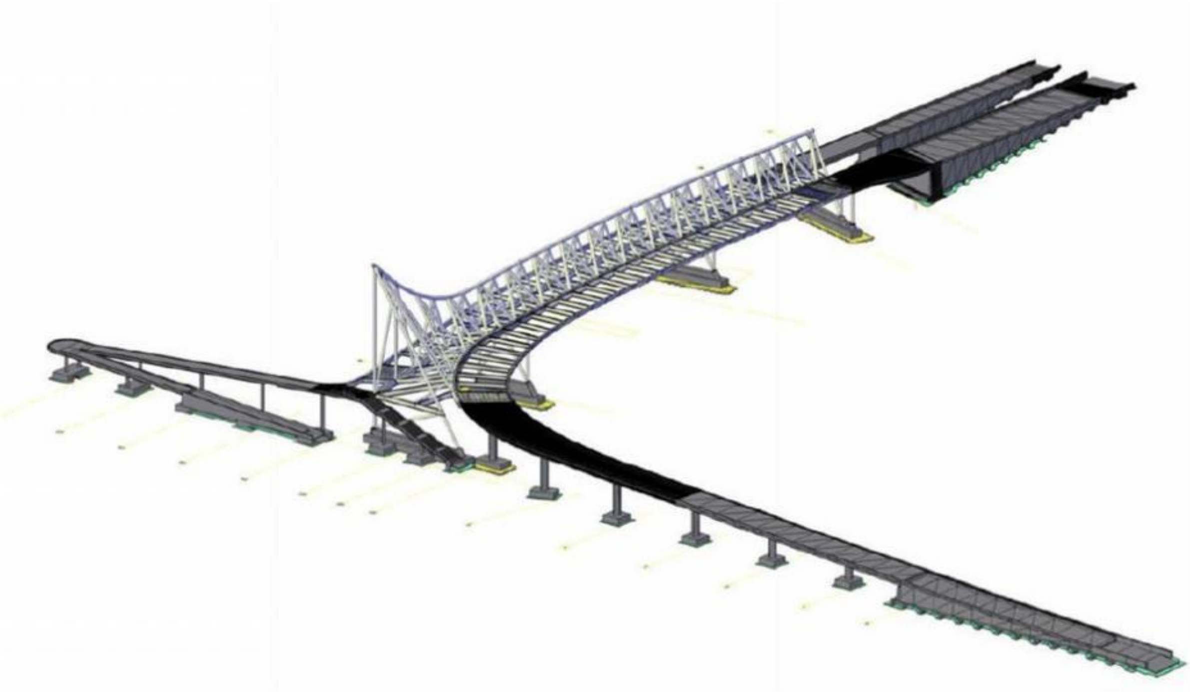


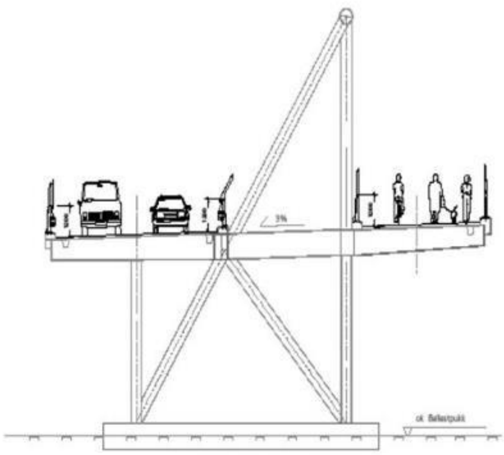
Figur 34-10 Fra 3D-modellen

What's about the design?

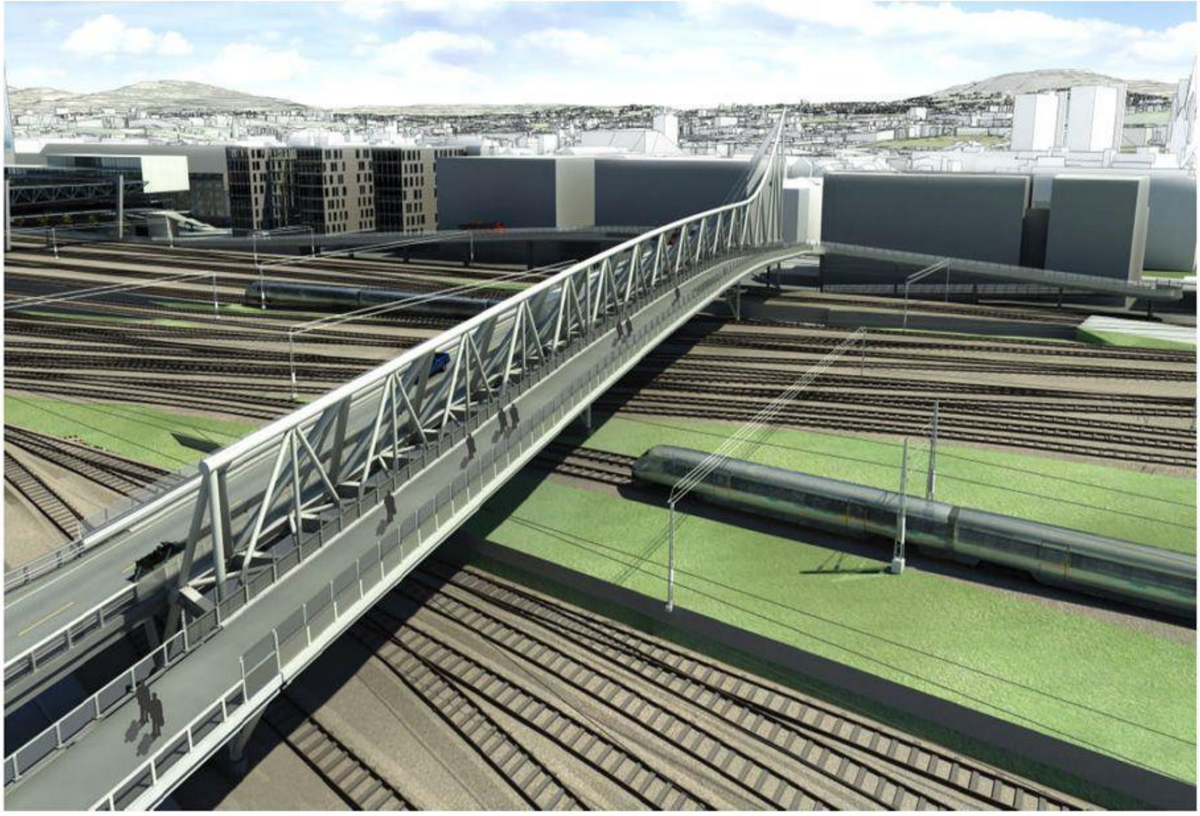
Statens vegvesen

Østre tangent

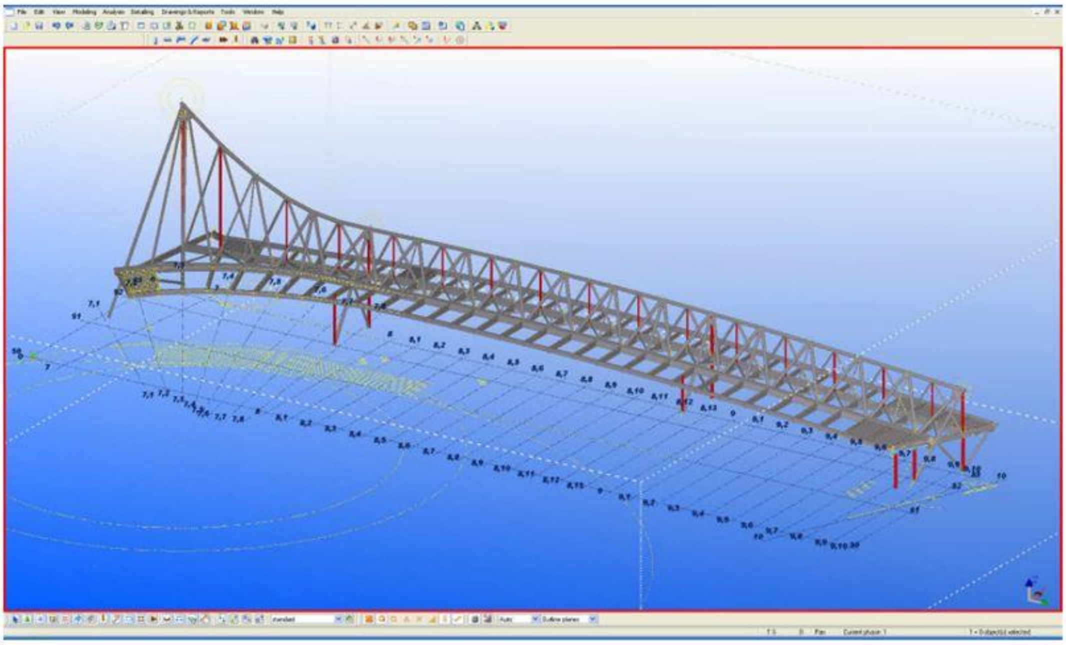




Prinsippsnitt



What's about the structural analysis model?



What's about the construction process?

Figur 34-11 På vei fra Rotterdam til Oslo (foto: NLI)

Figur 34-13 Første del av brua lansert ut over sporområdet


Figur 34-14 Sveising av del 1 og 2, mens del 3 venter

Figur 34-15 Fra åpningsdagen 26.08.2011

4.4 MVD

An IFC View Definition, or **Model View Definition**, **MVD**, defines a subset of the IFC schema that is needed to satisfy one or many **Exchange Requirements** of the AEC industry. The method used and propagated by buildingSMART to define such Exchange Requirements is the **Information Delivery Manual**, IDM (also ISO 29481).

5 Conclusions

The national project MINnD will continue in 2016, and the Use Case 3 dealing with IFC-Bridge will provide new contributions to finalize the IFC-Bridge development, with a larger expert panel group. A proposal has been agreed by the InfraRoom steering committee.

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[17] Ifc IfcAlignment- ifcxtension-fs.pdf, BuildingSMART, Th. Liebich, March 2015

[18] Infra BIM Schema Specification.pdf, ver. 0.5, Korea Institute of Construction Technology

[19] www.implenia.no/en/references/statens-vegvesen/nordenga-bridge.html

[20] https://en.wikipedia.org/wiki/Tunnel

[21] https://en.wikipedia.org/wiki/Earthworks_(engineering)

[22] http://nff.no/wp-content/uploads/2014/05/16223-Bok-Fjellsprengningsdagen-2012_del6.pdf, Nordenga Bridge – Challenging foundation across the railway lines at Oslo Central Railway Station

[23] http://www.stalforbund.com/Staldag2008/KaareKirkevik.pdf

[24]

Annex A: Autodesk Use Case Application

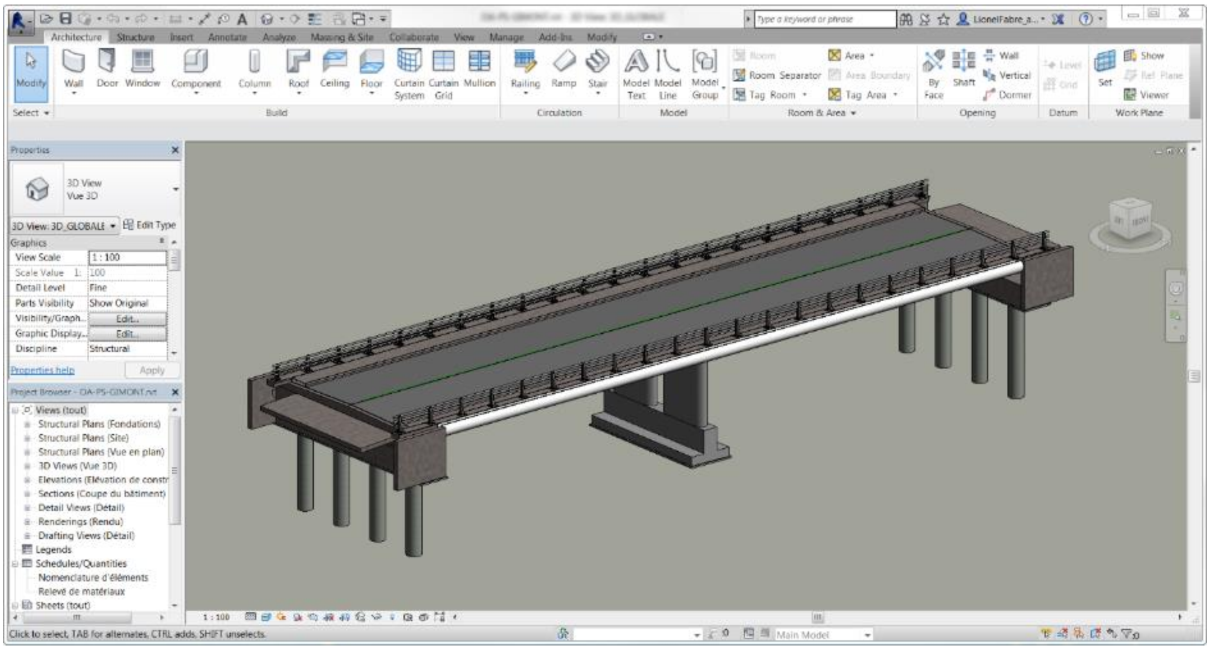
A.1 What product has been used?

Revit 2015 has been used for the state of art for the IFC bridge modeling.

A.2 Project organization

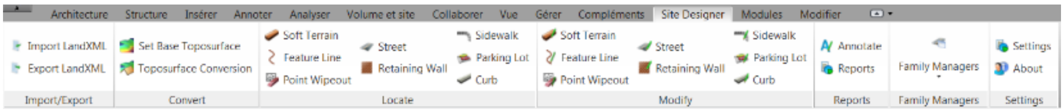
Autodesk® Revit® software is a BIM application that utilizes a parametric 3D model to generate plans, sections, elevations, perspectives, details, and schedules. Drawings created using Revit are not a collection of 2D lines and shapes that are interpreted to represent a building; they are live views extracted from what is essentially a virtual building model. This model consists of a compilation of intelligent components that contain not only physical attributes but also functional behavior familiar in architectural design, engineering, and construction.

Elements in Revit are managed and manipulated through a hierarchy of parameters. These elements share a level of bidirectional associativity—if the elements are changed in one place within the model, those changes are visible in all the other views. If you move a door in a plan, that door is moved in all of the elevations, sections, perspectives, and so on in which it is visible. In addition, all of the properties and information about each element are stored within the elements themselves, which means that most annotation is merely applied to any view and is transient in nature.



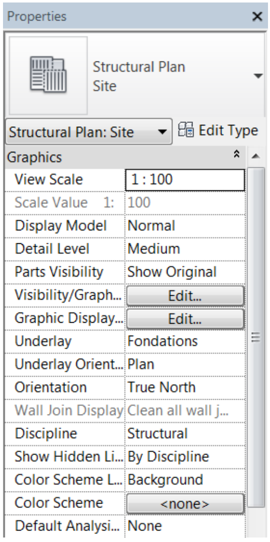
A.3 Ground modeling

In REVIT, different functions are available for the creation of the DTM. A specific function called "Site Designer" is dedicated to the creation of the DTM (hereunder the image of the ribbon)

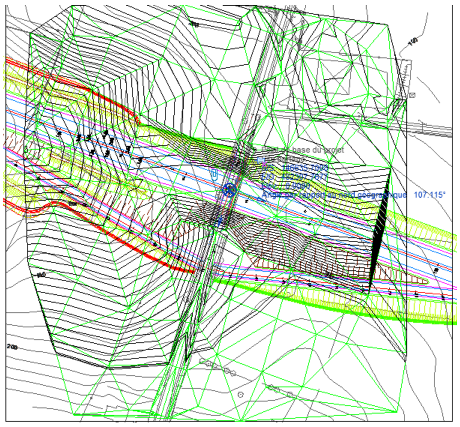


And the "Site Modeler" (shown below) used for the Minnd model which is allowed the creation of the DTM from DWG.

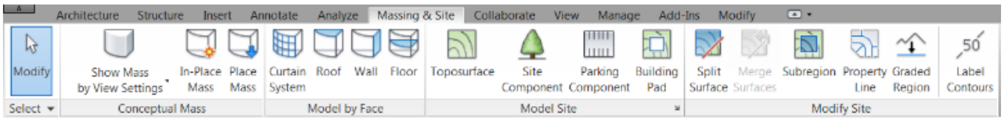
1. Configure the base point for the model
2. Activate the site view
3. In the properties of the view, change the orientation to "Northern"



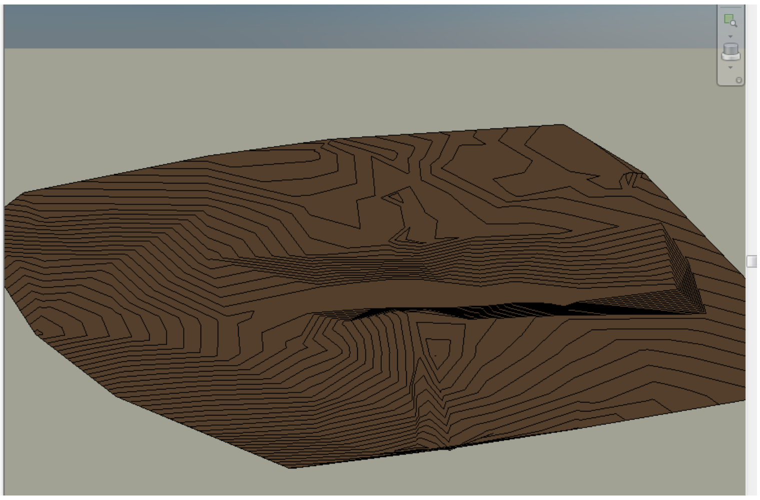
4. In the insert menu, select "Link CAO" option then point the topographical file to be imported and run the import (shown below the result)



5. Activate the volume and site tab in the ribbon and select the tool "topographical surface" (hereunder)



6. From the adapted menu, select the imported DWG and the Autocad Layers then validate (hereunder a 3D view of the result)

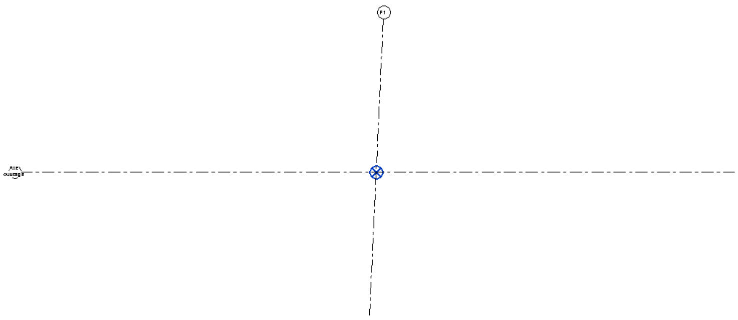


A.4 Modeling mass geometry

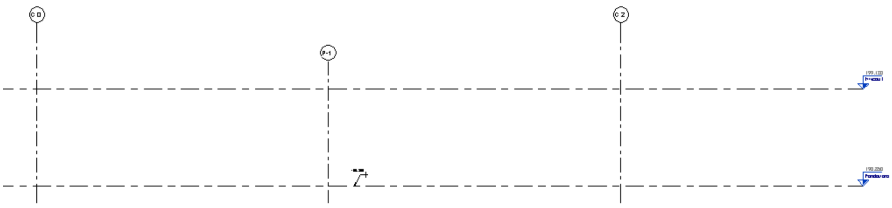
A.4.1 Defining long section of the bridge

The definition of the longitudinal section will be done by creating a model line which will correspond at the project top surface and will follow the horizontal alignment.

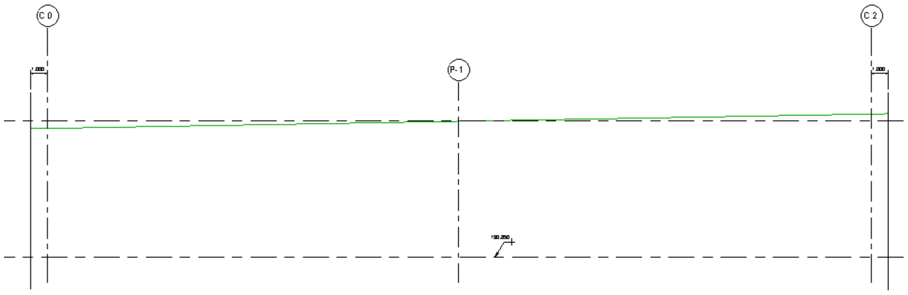
1- In plan view, draw the two axis (main line and crossing road). The angle between the two axis has to be respected.



2- Modify the elevations with the finished level values of the crossing road and optionally, the level of the foundations.



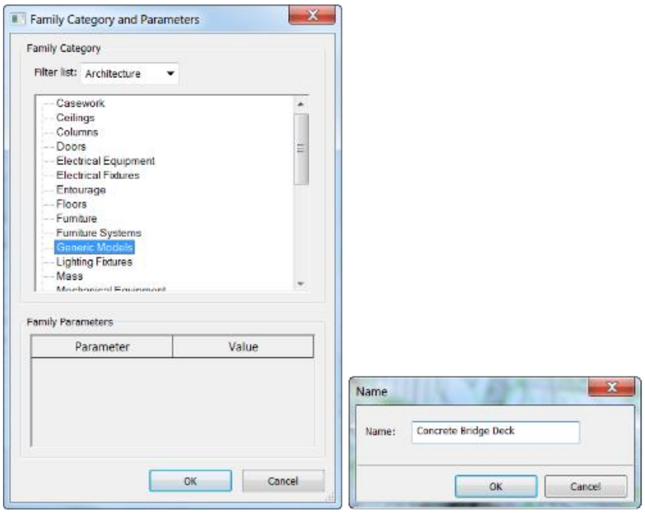
3- Draw the longitudinal profile.



A.4.2 Creation of the bridge deck and the railing components

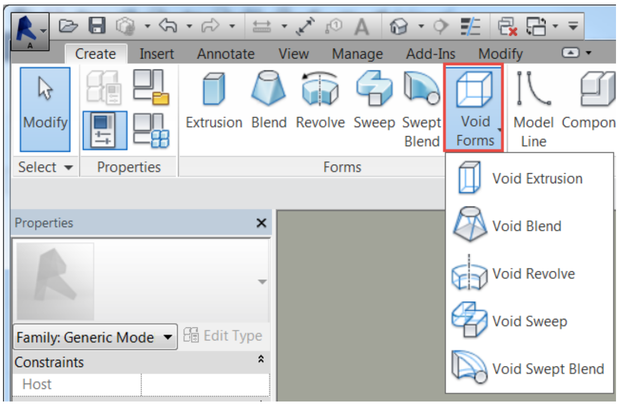
The bridge deck can be designed through the option « Model in place » from the menu « Structure ».

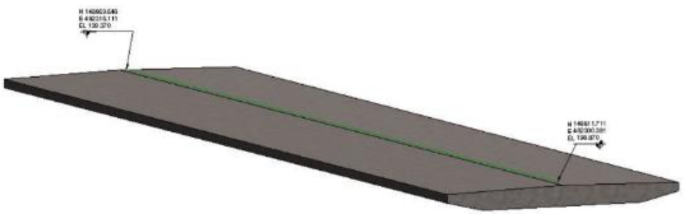
1- Select the Revit family category « Generic Model »



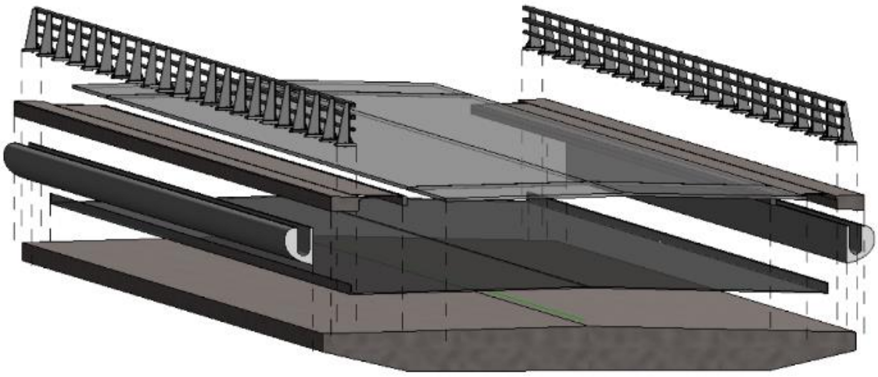
2- Through the adapted menu (extrusion by path), extrude the bridge deck using the model line as reference

3- Create a Void Forms in order to clip the bridge deck



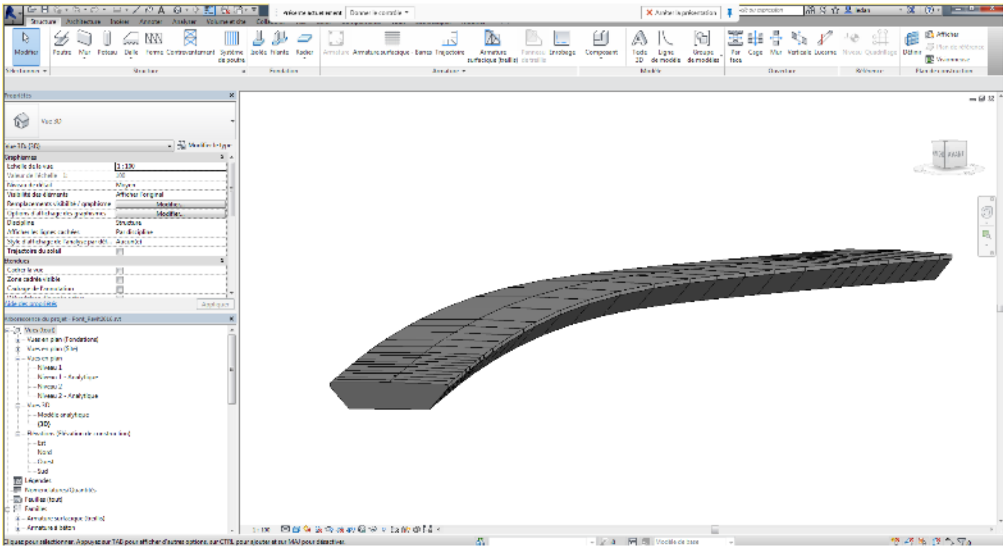


4- Using the same method, create the different models (Kerbs, railing, …), eventually the networks all along the deck (Utilities, water)



5- Clip the two abutments of the deck in order to respect the swept angle using two verticals plan

For the experimentation, the horizontal alignment of the bridge deck is straight but in the case where the horizontal geometry is more complex, with spirals for example. Autodesk Dynamo can be connected to the model in order to get the result expected as shown below.



A.4.3 Creation of the abutments and piers

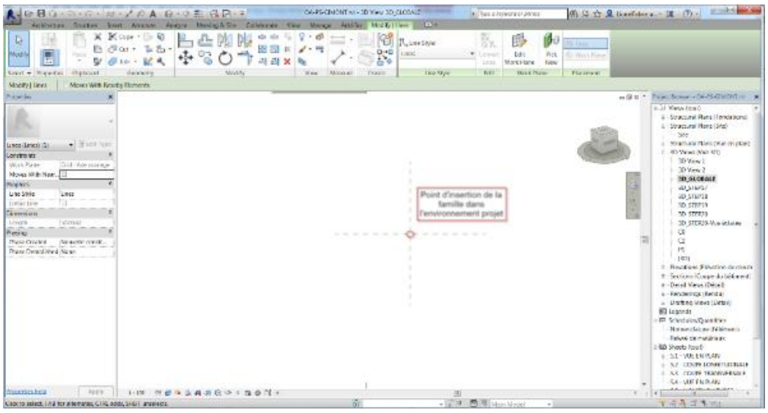
The abutments and piers are designed with external parametric families. So, they will be created separately and load in the project.

1- Creation of the parametric families.

In Revit Structure, all the elements are members of a family. The term "family" is a concept used throughout Revit Structure to facilitate data management and changes. For each element of a family, it is possible to define several types, each with its own size, shape, materials and different variables configured by the designer of the family. Even if a family can be a group from types whose appearance is entirely different, they are connected and have the same origin, hence the use of the term "family". Changes of the definition of a family type are reflected in the overall project and in every instance of the family or in the type shown in the project. This system ensures the homogeneity of the entire project, without requiring manual intervention to update all its components and nomenclatures.

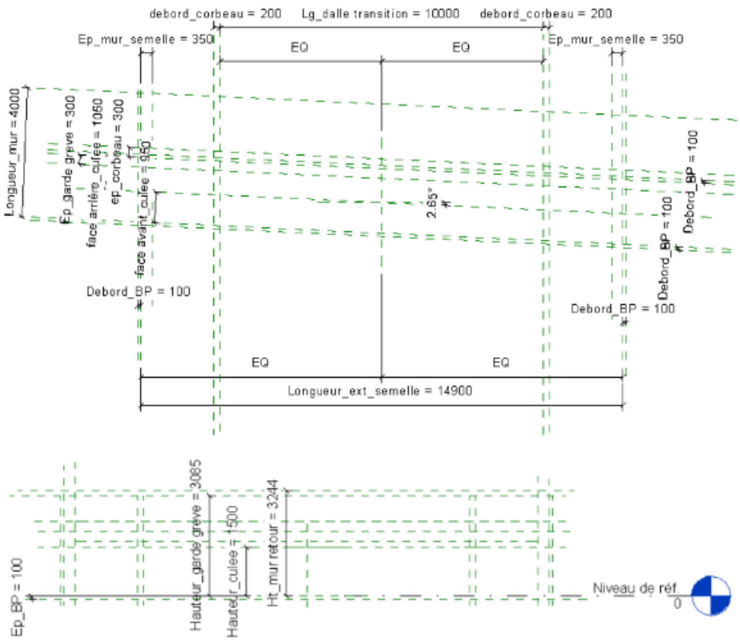
The Family Editor is a graphical editing mode in Revit Structure to create families to be included in a project. In order to create a family, first open the template to be used in the editor. This template can be composed with multiple views, such as plan views and elevation. The interface of the editor is the same than the classical project Revit Structure environment. However, the design bar and the options are different, depending on the chosen template, you can open multiple views.

2- Define the insertion point of the family in the project environment



3- Creation of the different parameters

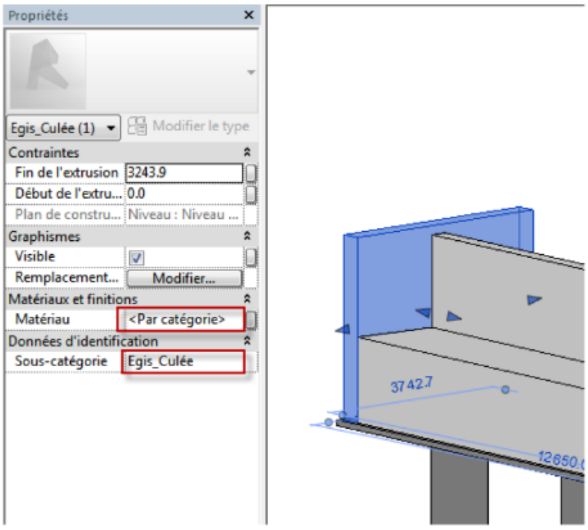
All the views should be completed with positioning datum associated to the dimensions



4- Extrusion

Now, all the extrusions can be done based on the datum created before in order to get a parametric object whose dimensions will be guided by the values of parameters.

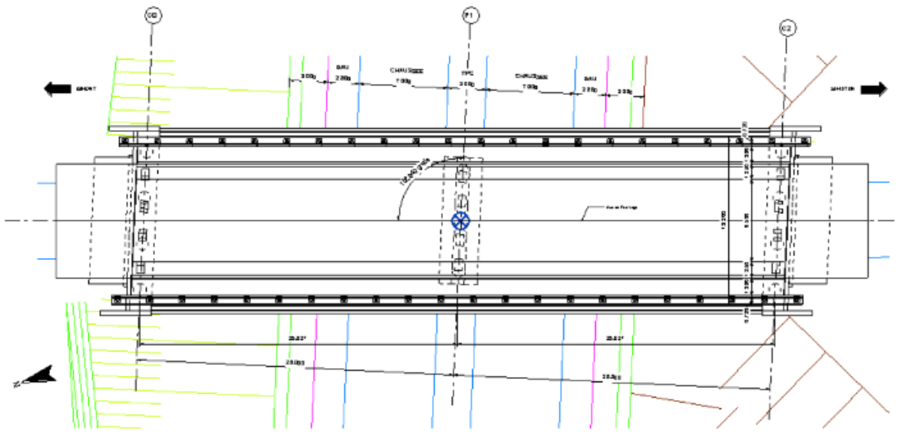
Each extrusion should be given a material and a sub-categories



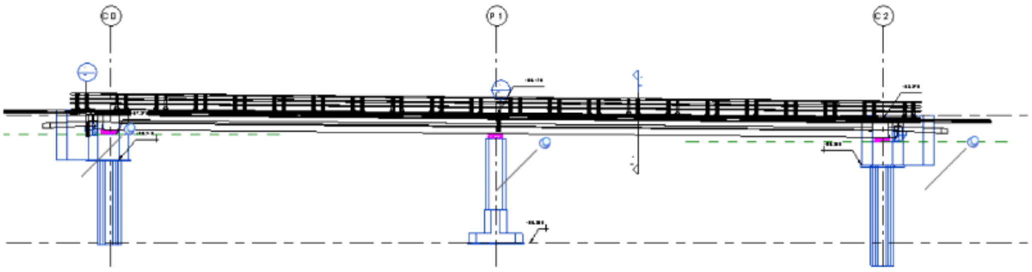
The same method will be used for the others objects (piles for instance)

A.4.4 Positioning of the abutments and piers

Activate a view in order to place the parametric elements created:

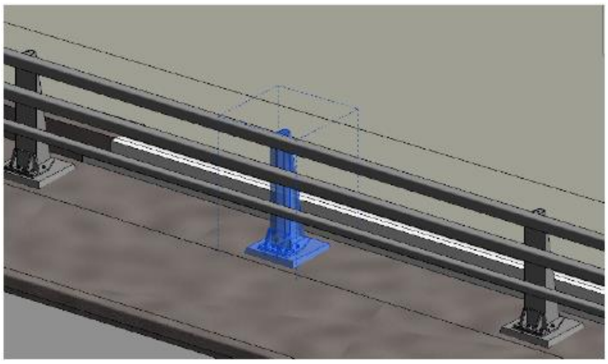


Using elevation views or sections, specify the positioning of these elements vertically (along the Z axis). Locking the objects in order to avoid an unwanted move.

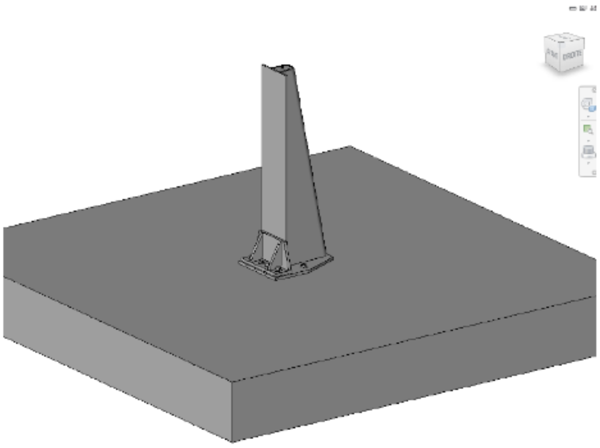


A.4.5 Adding CAO components

You can use many types of existing CAD files to improve the model. For modeling the safety equipment of this bridge deck, an Inventor library has been used (Pots BN4)



This element has been exported from Inventor and reimported as a Revit Family.



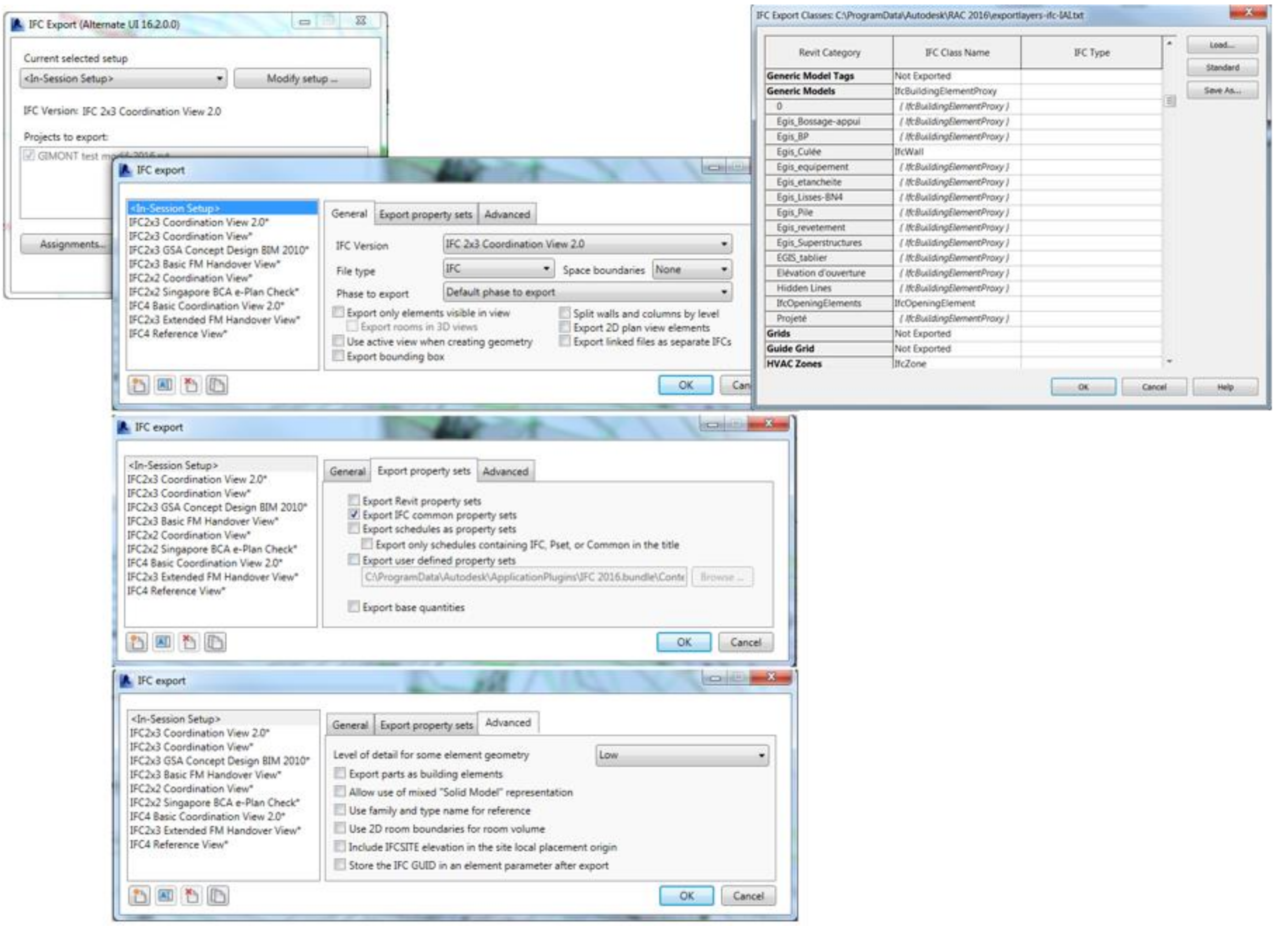
Following the positioning of those elements in the project environment, railings have been modelling "In situ" using the project model line created before in order to have vertical poles and railings that follow the longitudinal profile of the bridge.

A.5 Reinforcement modeling

Obviously, this is possible to create 3D reinforcement in Revit, but it has not be implemented for this experimentation.

A.6 IFC object

Before exporting the model it is important to verify and modify the IFC export parameters in order to get the maximum of information in the IFC output file. With Revit, it is possible to connect the Revit categories to the IFC class.



A.6.1 Export the model

Once the elements set correctly, just export the model. Many parameters are available to filter which entity or not has to be exported.

The IFC export is based on IFC 2x3 model schema

A.7 Findings

Hereunder are the conclusions made by C. Dumoulin from Bouygues Travaux Publics after the first export of the model.

"The example described in section 3.3.2 has been built with Autodesk Revit Structure 2015. The IFC export is based on IFC 2x3 model schema and Coordination View V2.0.

A lot of comments have given in section 3.3.2.

Nevertheless, analyses of "building models" created with the same authoring tool (same release, same coordination view but not same user) have exhibited shape representations based on solid construction geometry and Boolean operations, large structure breakdowns, good semantics regarding entities, relationships describing connections between walls...

The key point is that Exchange Requirements are not clearly defined and consequently a Model View Definition oriented Bridge."

From Section 3.3.2

Question: Based on the exchange information attached to the following drawings, could we find at least the same information in the IFC file provided an authoring tool? If yes, is this information semantically rich enough to be machine readable?

The answer to the above question is clearly NO.

There is no information provided regarding either the upper and under road alignments or the upper and under carriageways. There are too many geometric representation of entities based on faceted boundary representations, in particular the deck, the abutments and the central pier. The local axis system of the component are not based on the main axis of the component. For instance the footing of the central pier is a rectangle. To build this is easy when having the two main axis of the rectangle. It is not the case here.

Frankly speaking, it is a nice picture, but unusable on the construction site.

All the information mandatory for machine readable approach is missing: no breakdown structure, poor semantic at entity level, no semantic at geometric representation, no relationships between entities to define their connection.

The ambition is that the IFC file becomes the reference data model of the bridge. Here it is not the case. The above drawings cannot be produced from the IFC model, the information is not complete.

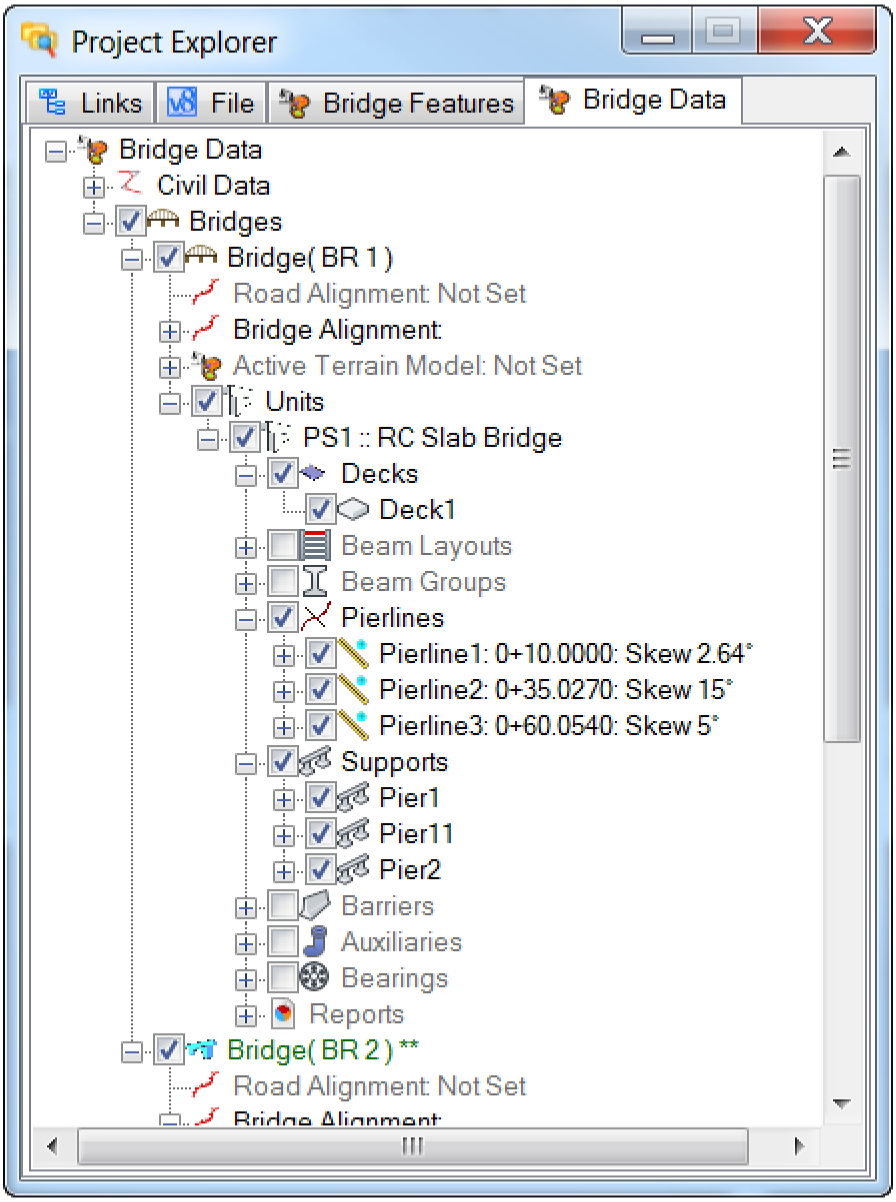
This exercise is nevertheless very helpful. It shows the work that have to be done to fill the gap. And it is encouraging to notice that in such a case, many of the existing capabilities of IFC2x3 could already be very helpful if appropriately used.

Annex B: Bentley Use Case Application

Bridge Structure in Open Bridge Modeler by Bentley

B.1 Project

OBM provides the user with a tree organization:



This organization rests first on Civil Object organization defined in Open Roads technology.

The objects used by OBM from Open Roads are the following:

- Horizontal alignment based on geometric components (lines, arcs, spirals) and their derived geometry (parallels and variable offsets)
- Vertical alignments based on geometric components (lines, arcs, parabola) and their derived geometry

- 3D alignment defined by Horizontal and active vertical Alignments
- Superelevation rule along the alignment by lane
- DTM modelization by a triangulated network

On top of this OBM add some specific Bridge objects:

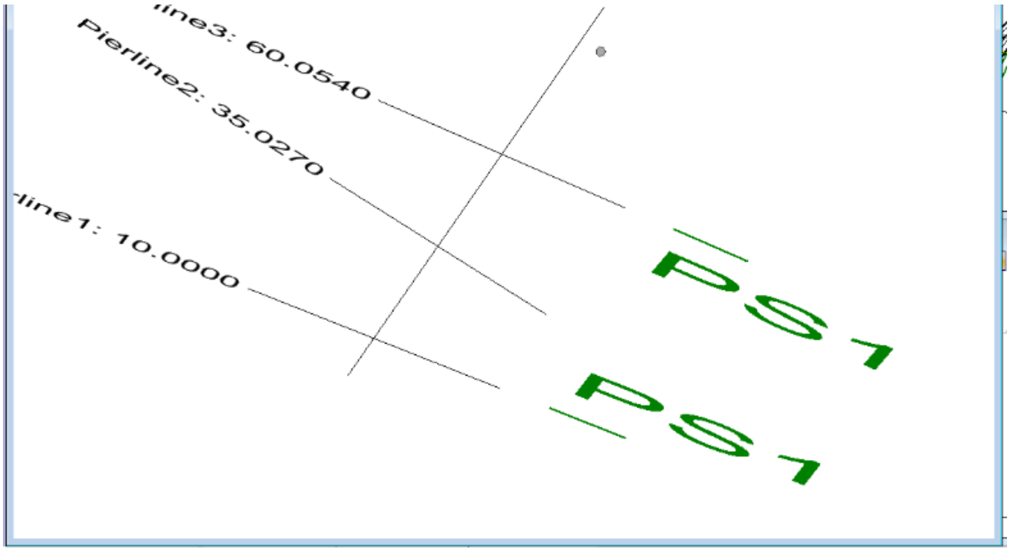
- Bridge, is a continuous structure of different units from different technology. A bridge may start with approach viaduct, continues with different main structures and ends with a final approach viaduct
- Unit, is a structural unit defined by different spans, but having a common technology, slab with or without beams, concrete or metallic box, cantilever based, segmental or non segmental.
- Deck, is describing the main “beam” of the bridge, either standalone (box girder) or supported by beams.
- Beams, in the case of a beam supported deck, the beams are defined by a beam layout, on which each beam can have a unic variable definition
- Supports, defined on Pier lines, the support atr in 2 groups, abutment and Piers which are both modeled with solid objects. They are linked to the deck by skew lines at a given elevation.
- Barriers, this object describes any continuous solid template based objects that rud along a part or the complete deck.
- Auxiliaries, these objects are unit objects placed on or along the deck. Attached to a precise point of the deck with offset, they can be repeated based on spacing or number.
- Bearings, these objects are between deck and support, or between Beams and support. They are defined by a given bearing definition and can be adjusted on both face with a concrete dice or concrete prismatic part that takes into account elevation difference, longitudinal or transversal slope.

B.2 Modeling Methodology

In order to model a bridge, the user just have to follow usual way of designing a bridge. As any object can be modified afterward, there is no definitive choice to input during modeling.

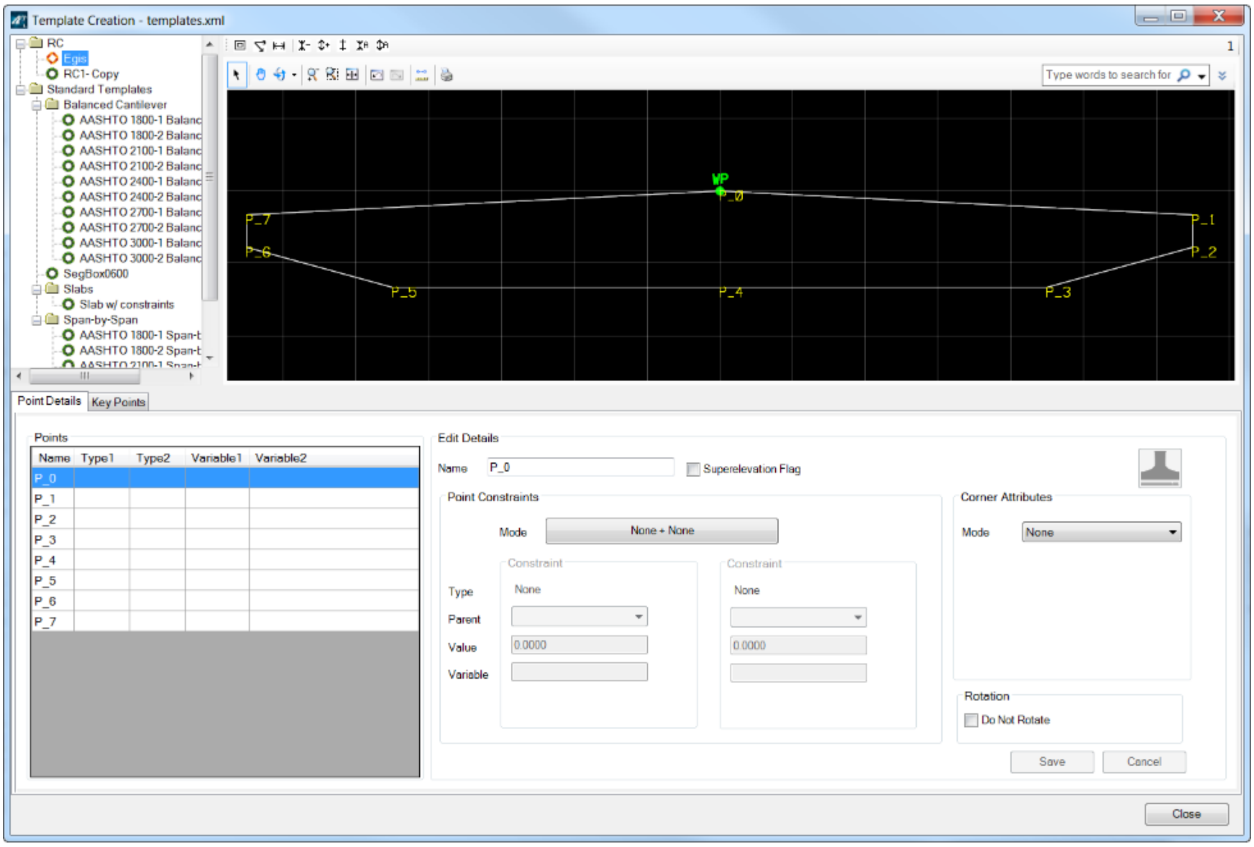
Everything starts with a civil project defined by an horizontal alignment, vertical alignment and DTM.

This can be reduced in the first step to an horizontal line and a given elevation for both deck and bottom of support. These limits can be reassigned afterward to more realistic data.

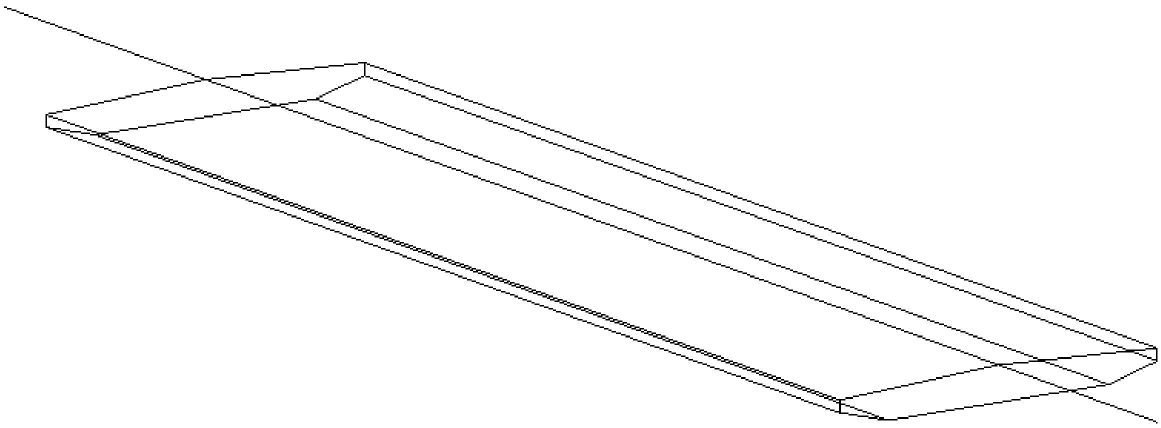


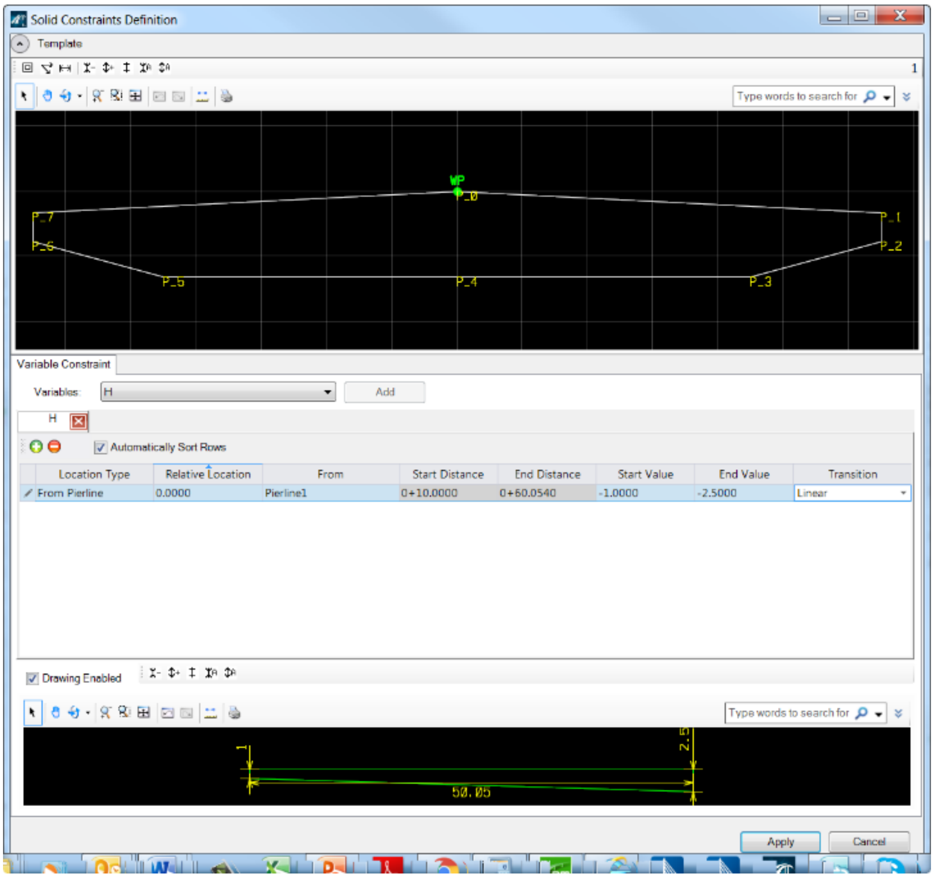
Definition is starting by limits of the unit, beginning end end stion and localization of pier lines (abutment and intermediate support). Each of them defined by a station can also be skewed.

Then the deck is defined by a given template:



The cross section template is defines by points, lines and arcs. Each point or side can be constrained by rules as distance from, offset, angle… allowing variation along the bridge; These variables can then be defined by tables:

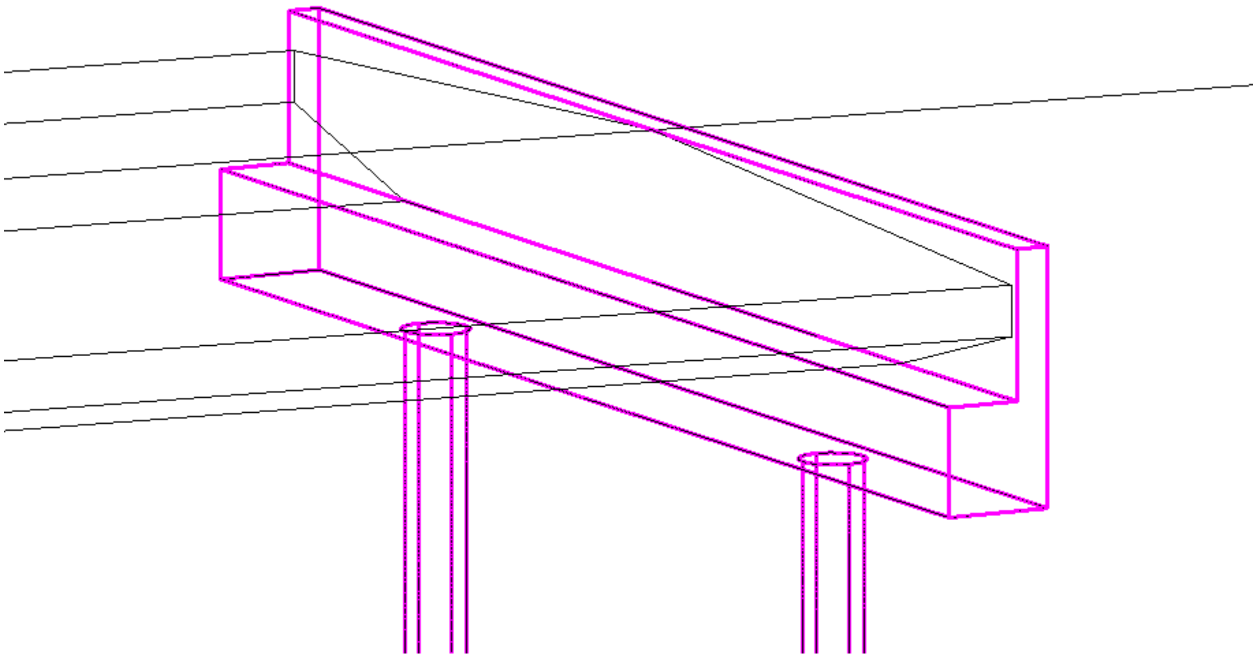




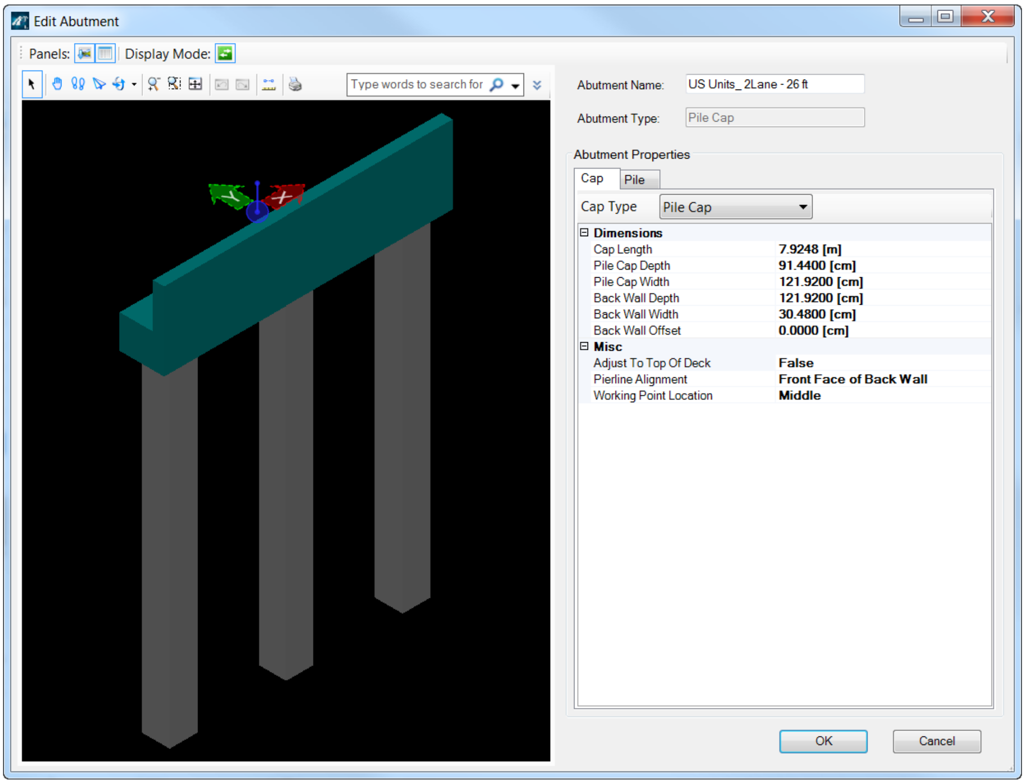
Every Variable can be defined along the alignment of the bridge.

B.3 Support definition

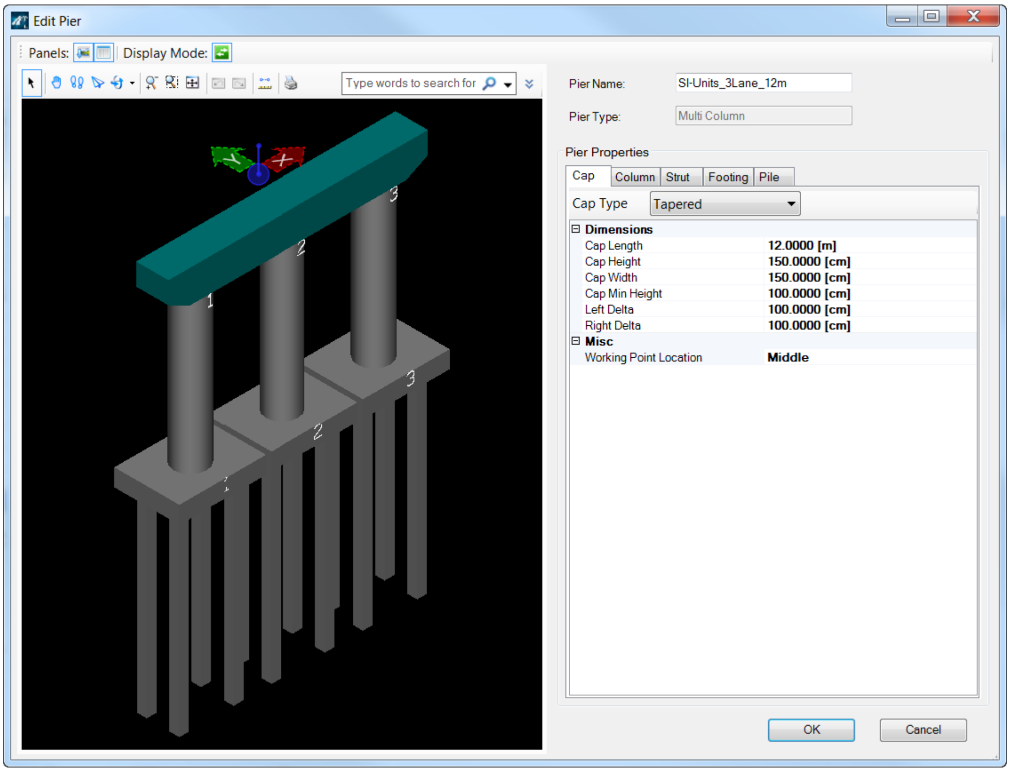
Abutments and Piers can then be placed, linked to a pier line, with several variables set by the deck in place:

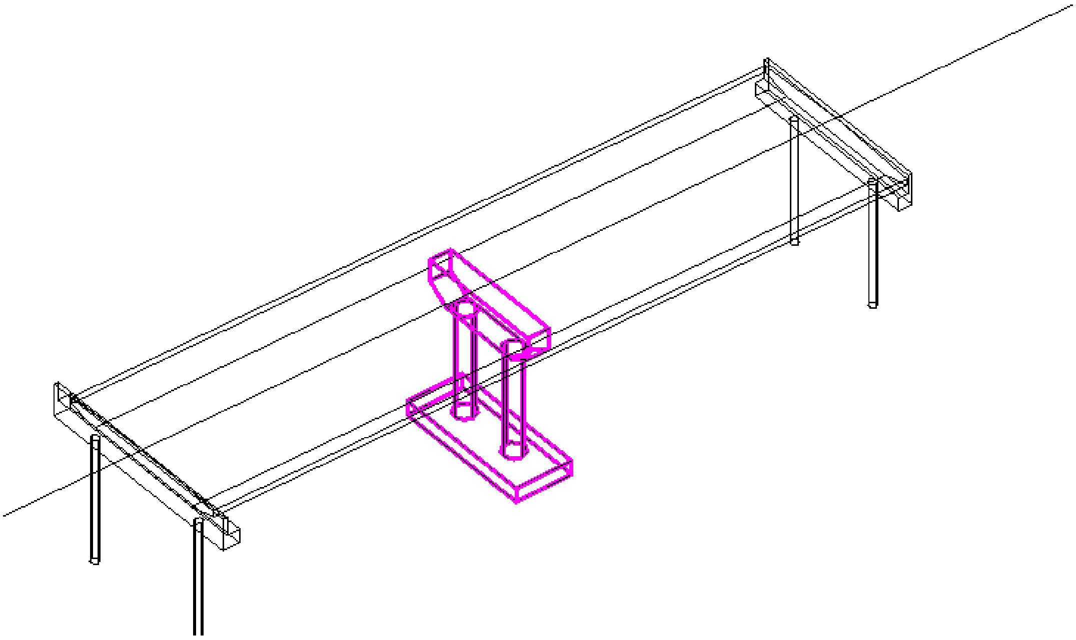


All variables can be defined

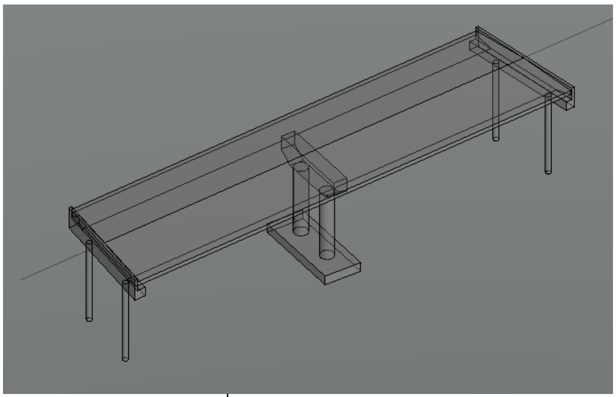


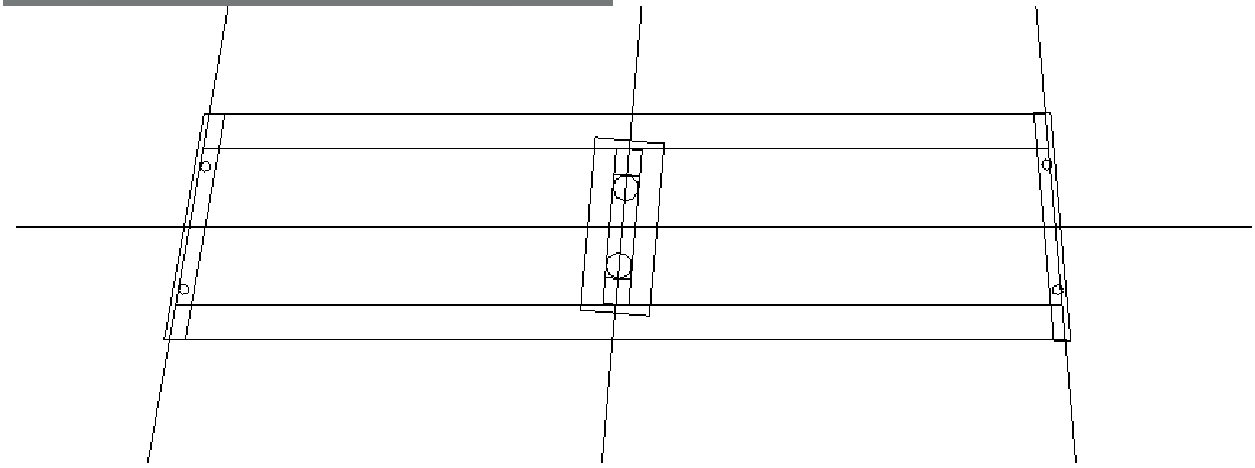
The same can be done for the piers:



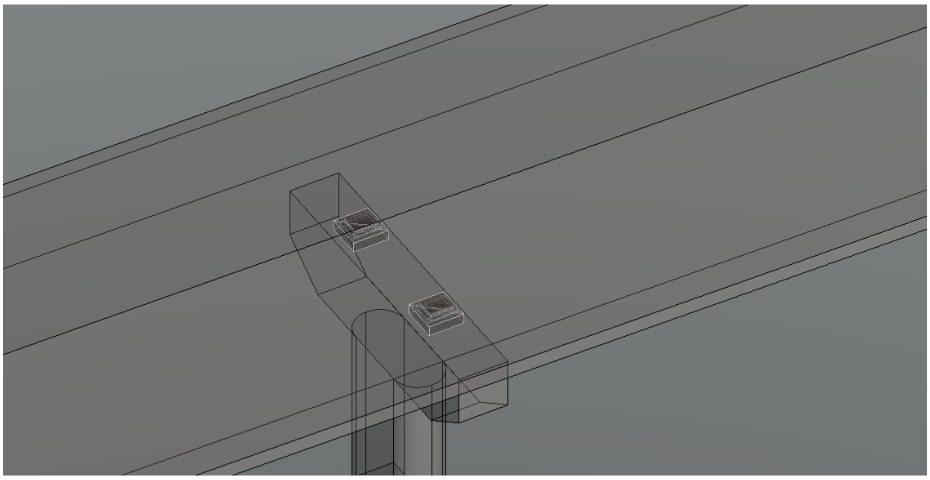


Once elements are placed, skews ofr places of supports can be changed:



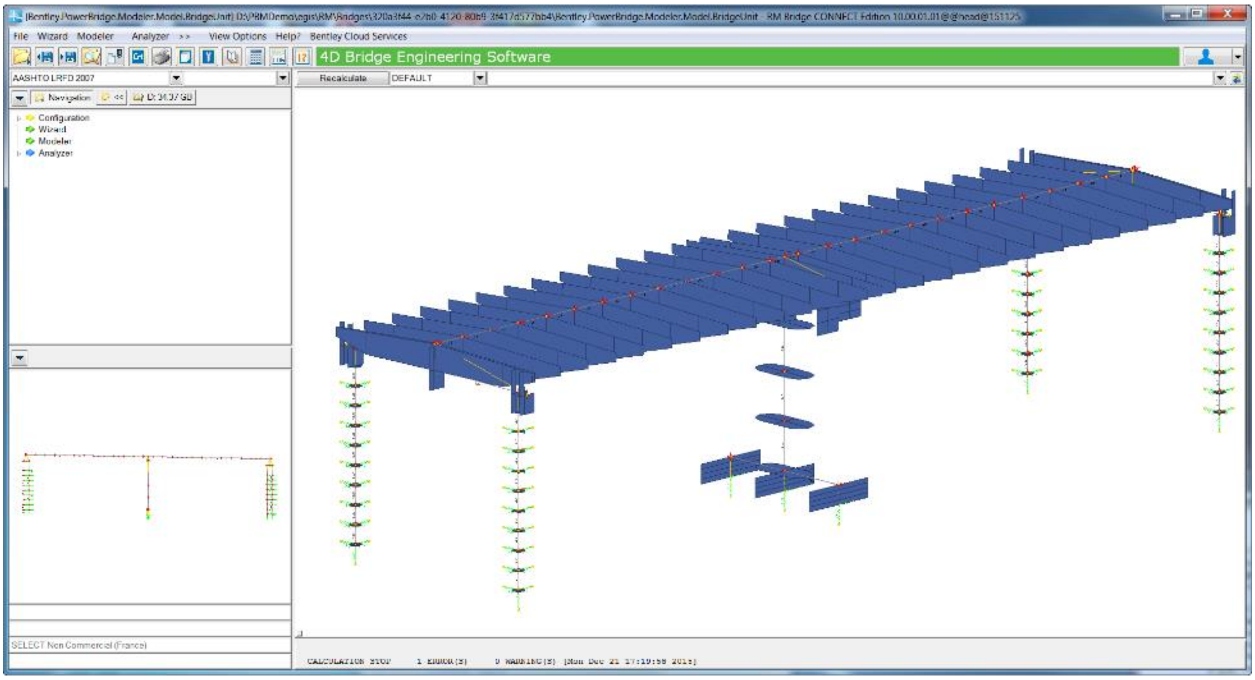


Bearings then can be placed between support and deck:



B.4 Export of the model

An automatic export can be done to Finite Element designing software RM bridge by Bentley



B.5 Interface with IFC

Direct Interface with IFC will be done in version 2. The only interface available today is the one from architectural software leading in very poor organizational tree.

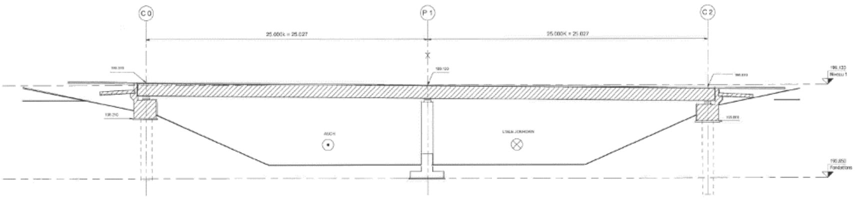
Annex C: Dassault Systèmes Use Case Application

C.1 Project context

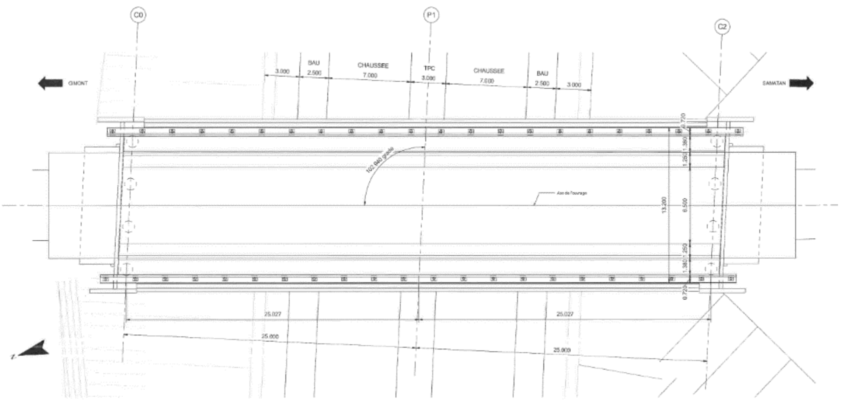
As part the Use Case #3, it has been asked to software editors to do the modeling of a simple overpass bridge.

Data have been provided by EGIS in a PDF form.

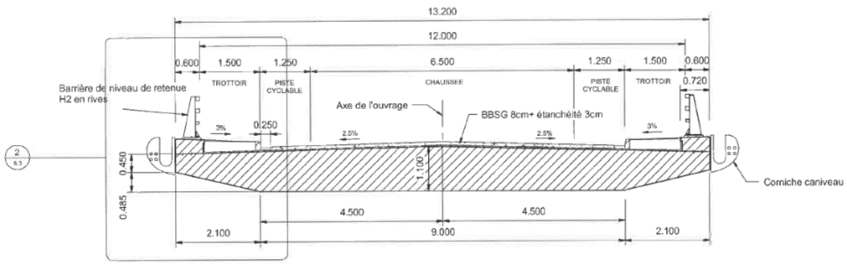
COUPE LONGITUDINALE



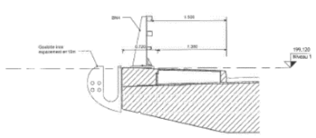
VUE EN PLAN



COUPE TRANSVERSALE



DETAIL CORNICHE

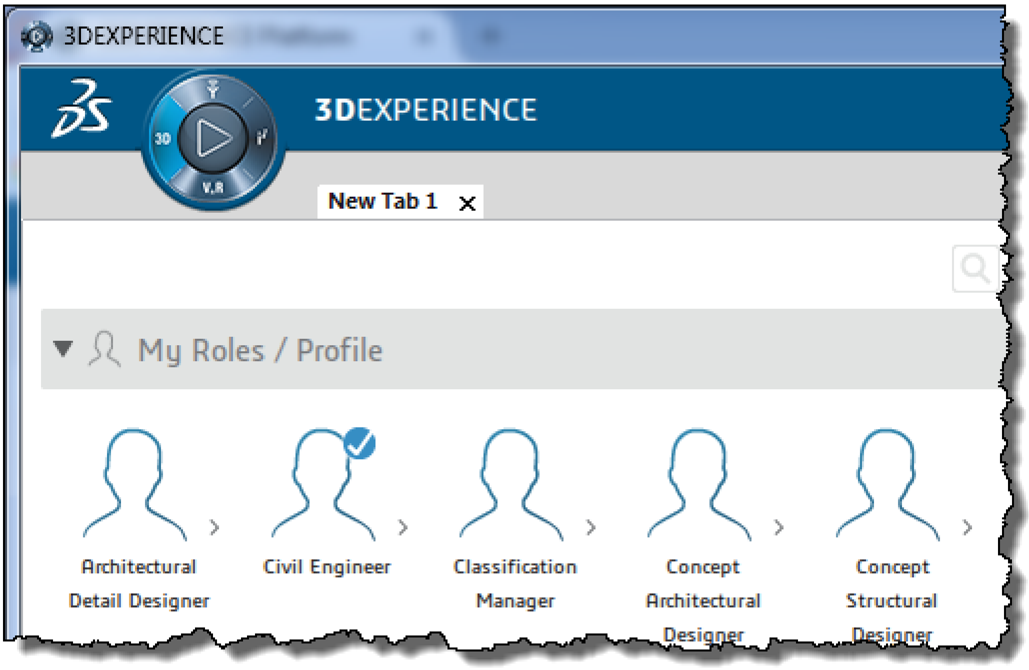


C.2 Modeling using CATIA Civil Engineer Role

C.2.1 Platform

3DEXPERIENCE R2015X platform have been used without any customization.

Roles used: Civil Engineer



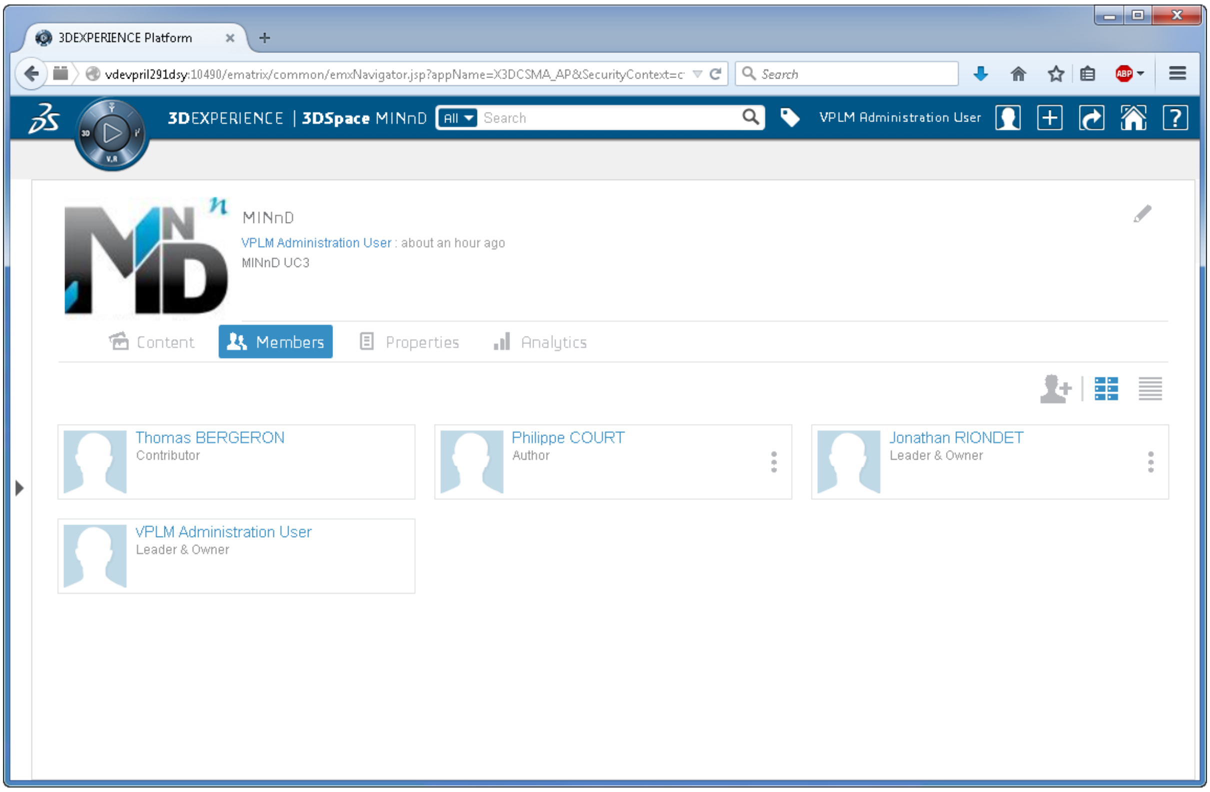
Main Apps used:

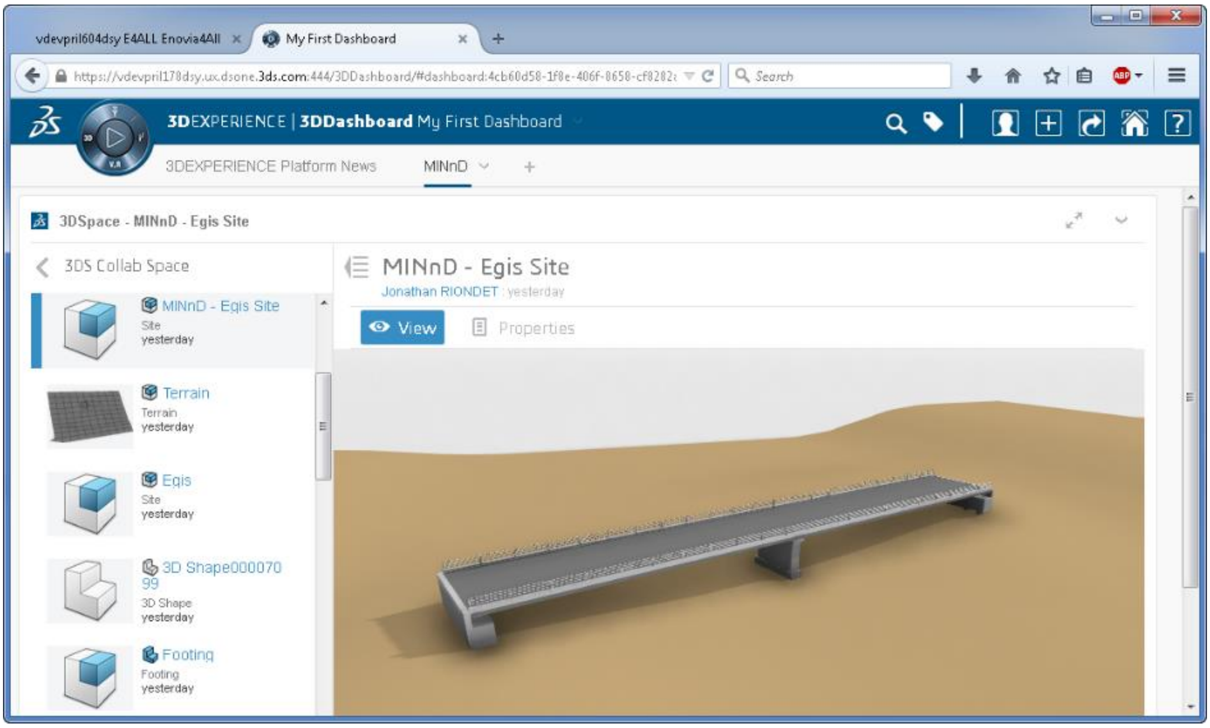
To create the product structure, geolocate the site, associate BIM attributes and define scale limits

To create geometries, constraints and rules

C.2.2 Collaborative Space

A project collaborative space has been created. All data will be stored in this on-line secured space. User can be invited and be assigned with a specific context by the BIM Administrator. For example, a *Contributor* will have some limited rights compare to a *Leader* or an *Owner*, depending also on the type of Collaborative Space and Maturity of the parts

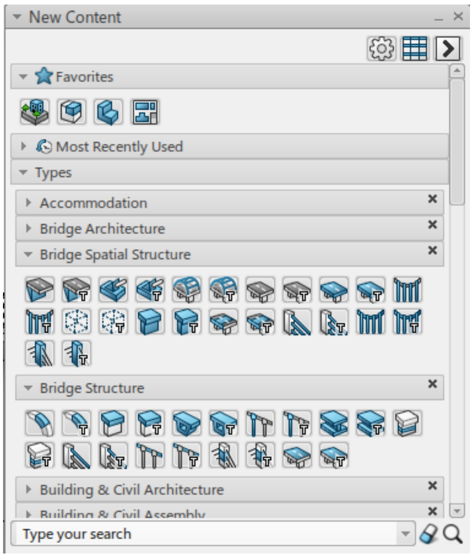




C.2.3 Product Structure

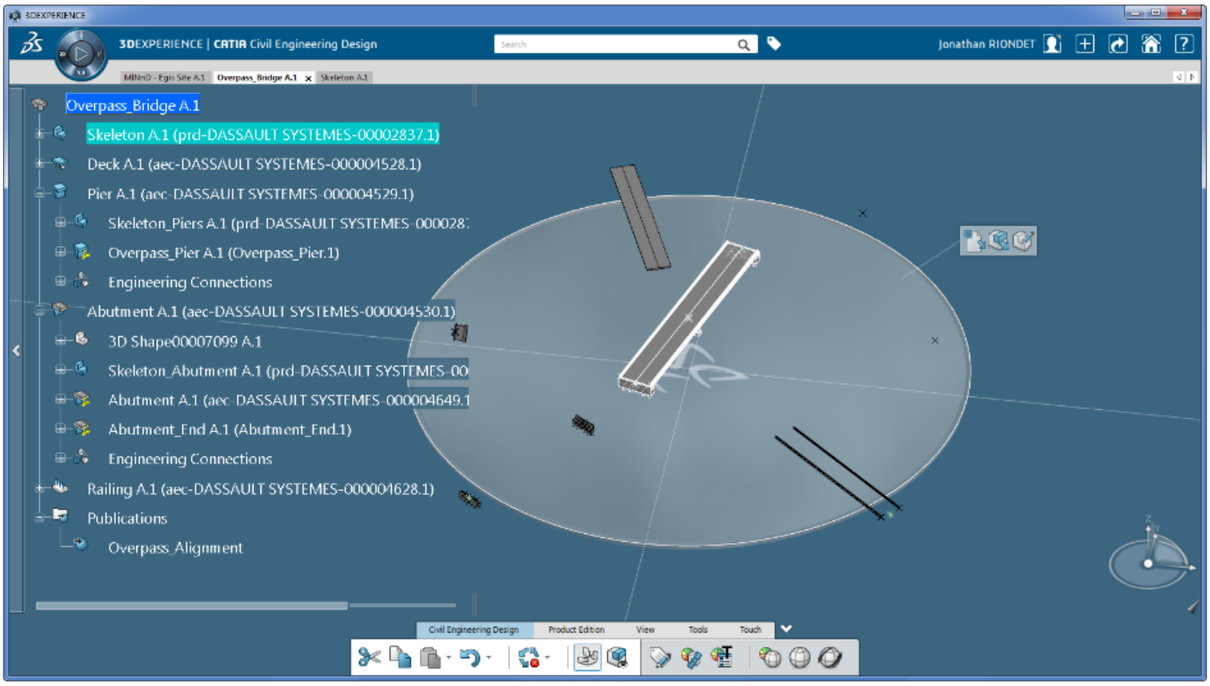
AEC Data Model has been used.

Some types that already exist on the IFC classification such as terrain, Site, Slabs etc but some that don't exist yet such as Bridge, Abutment, Pier

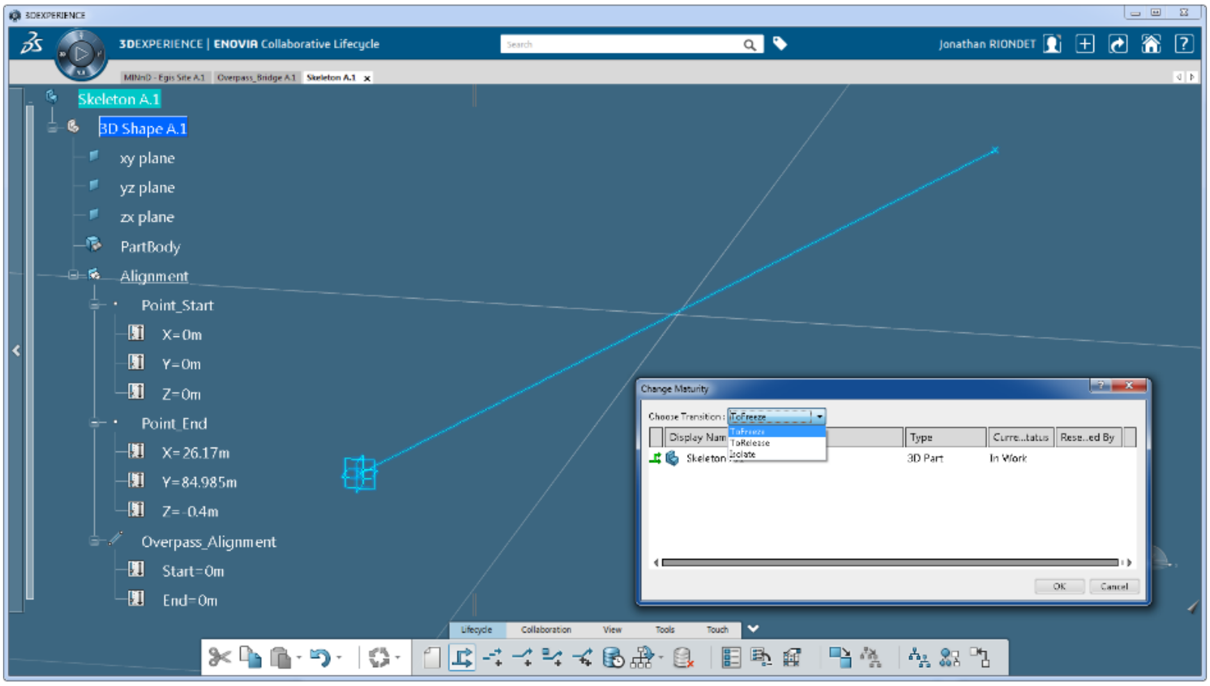


C.2.4 Modeling

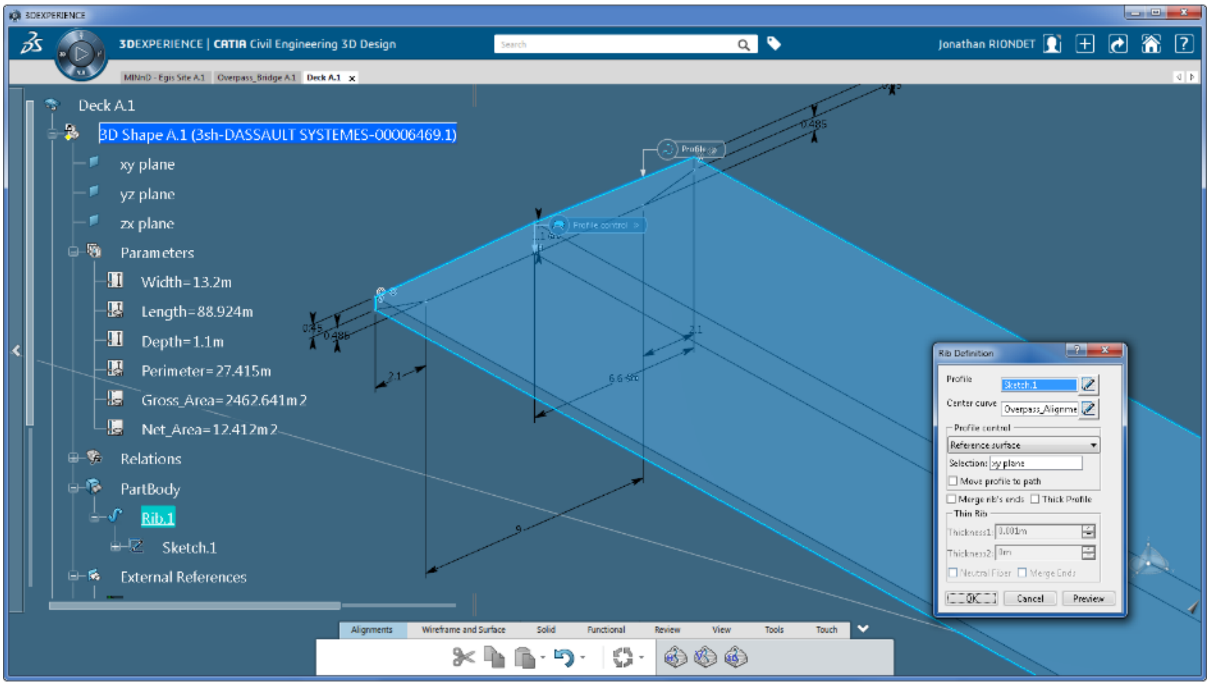
The bridge is made of different types. In the view below we see the Deck, the pier made of piers, Abutment that contains abutments and railings. All those elements are children of the Bridge element and their position is relative to the bridge. All elements can be opened individually by any user who as the right to open it (depending on his role)



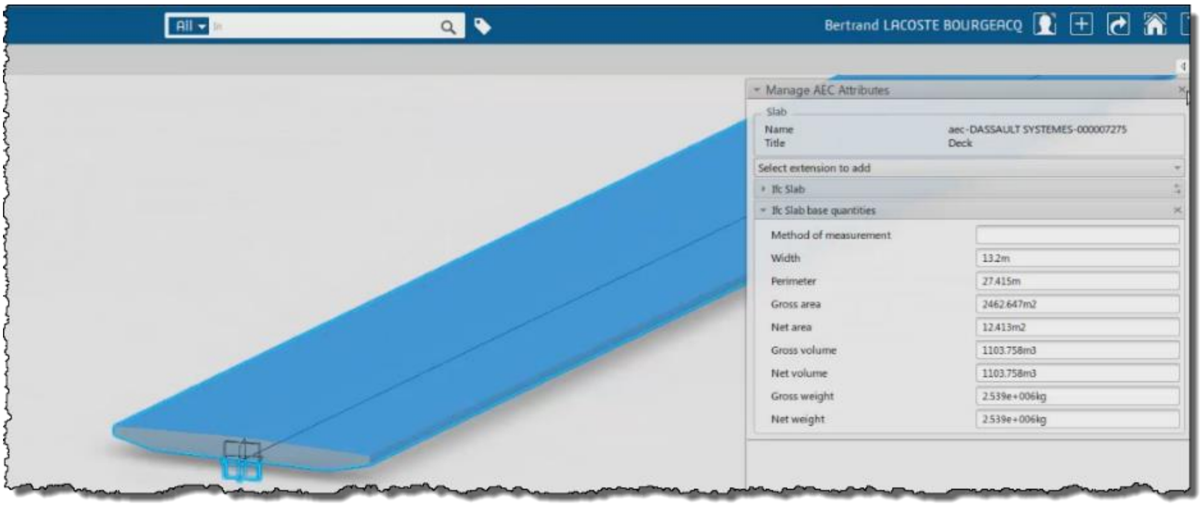
The Skeleton captures the redline of the bridge. The bridge is straight. We defined a Point_Start and a Point_End by coordinated/ A Line (Overpass_Aligment) connects those two points. This line will be used to drive bridge profile (and other elements). Everything is parametric and will be edited/changed at any time depending on the maturity of the selected element.



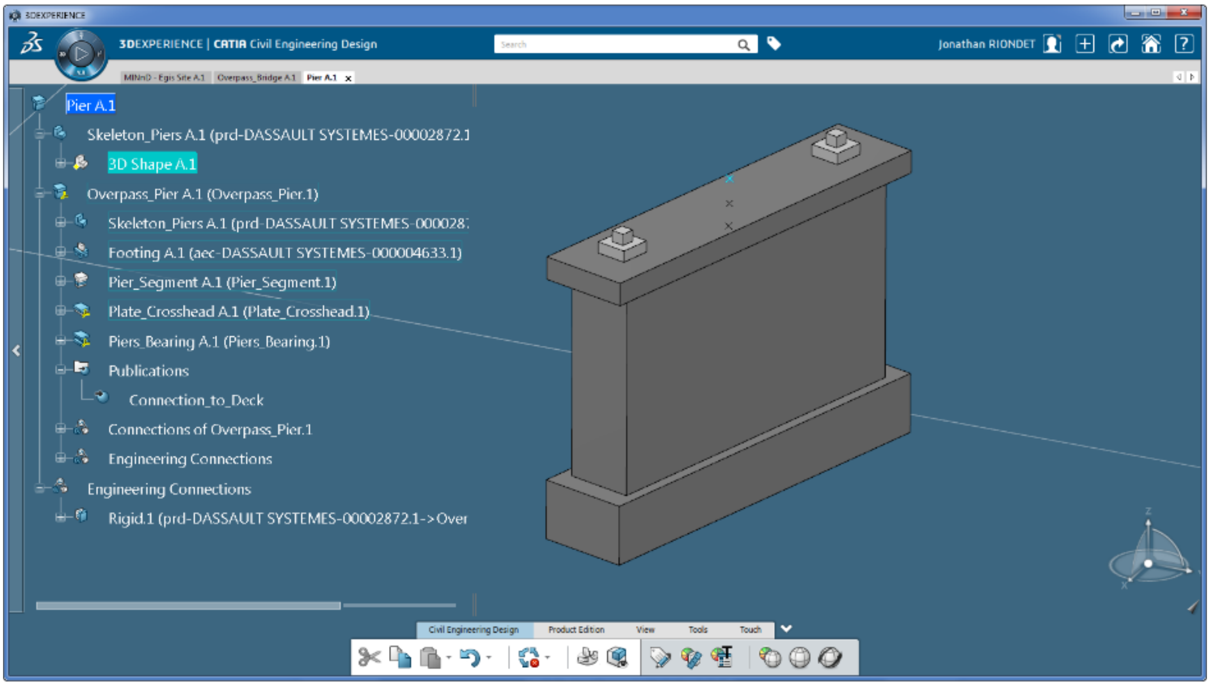
The bridge section is made by a sketch that is constrained. Then this sketch is extruded (we use a Rib) along the red line. Quantities are automatically computed and can be associated to a custom property set (as no Ifc Standard one exists yet for such element).



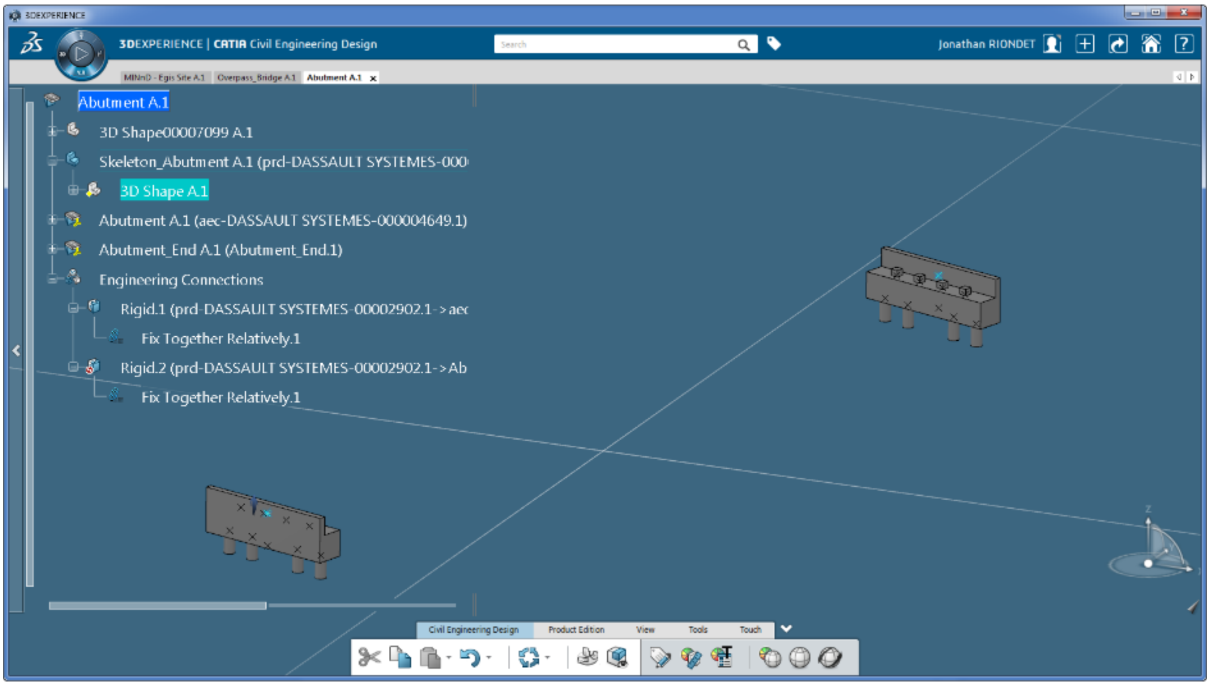
If we use a Slab type then we can also use standard Ifc property set to output the quantities in an IFC file



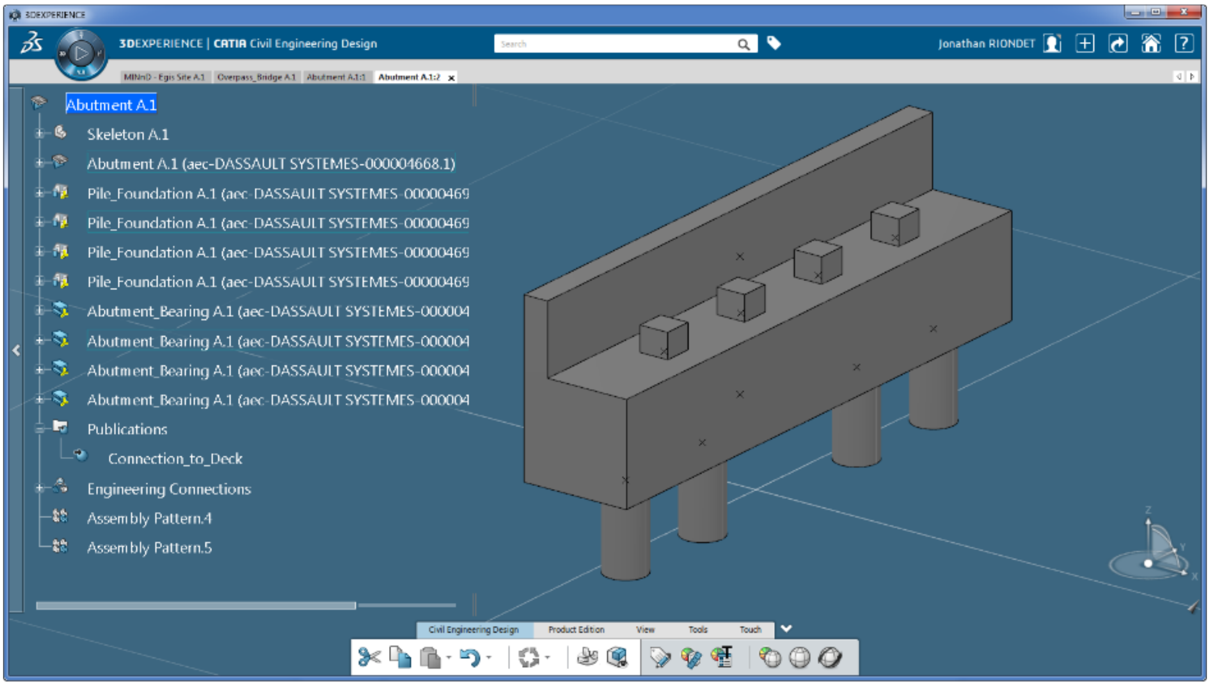
The Pier is made of a pier segment, a crosshead (plate type), bearings (other bridge structural element) and a footing. Engineering connections help to connect those elements with rules and parameters. A Skeleton helps to define the location of the reference point with the Deck (Connection_to_Deck publication).



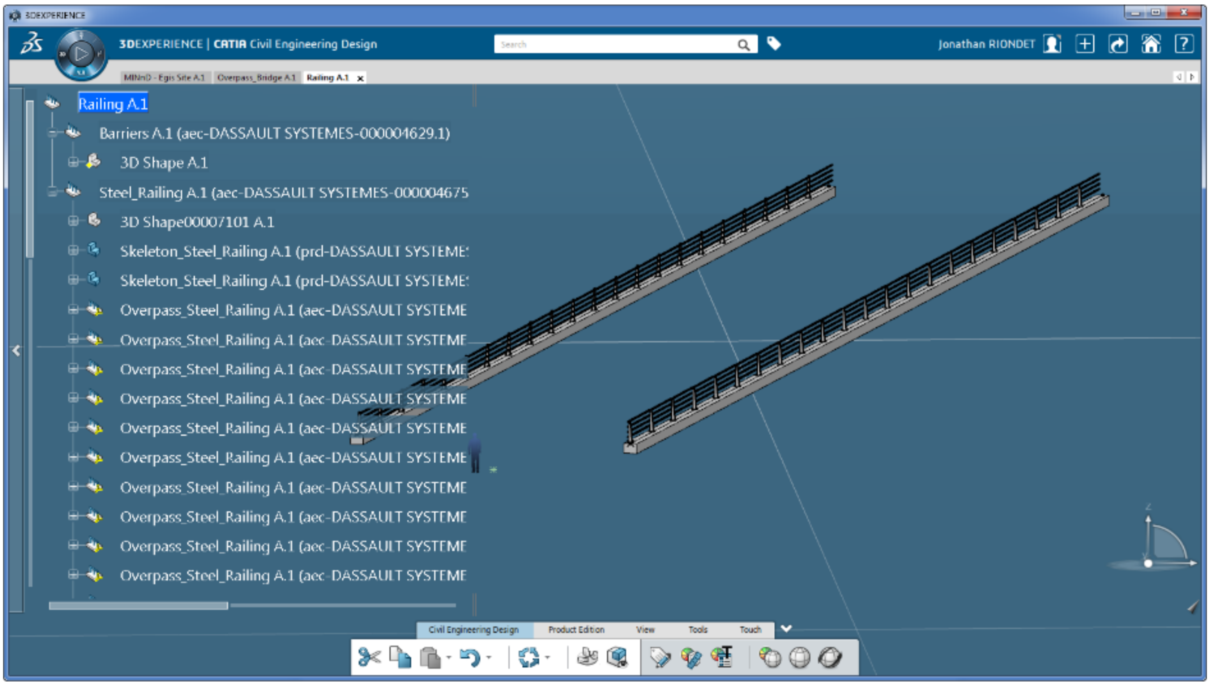
An Abutment contains the two symmetrical abutments. Skeletons help to position the abutments according to the bridge redline. Engineering connections helps to connect the abutments with the Deck



Each abutment will be made of piles, bearing and the abutment itself.

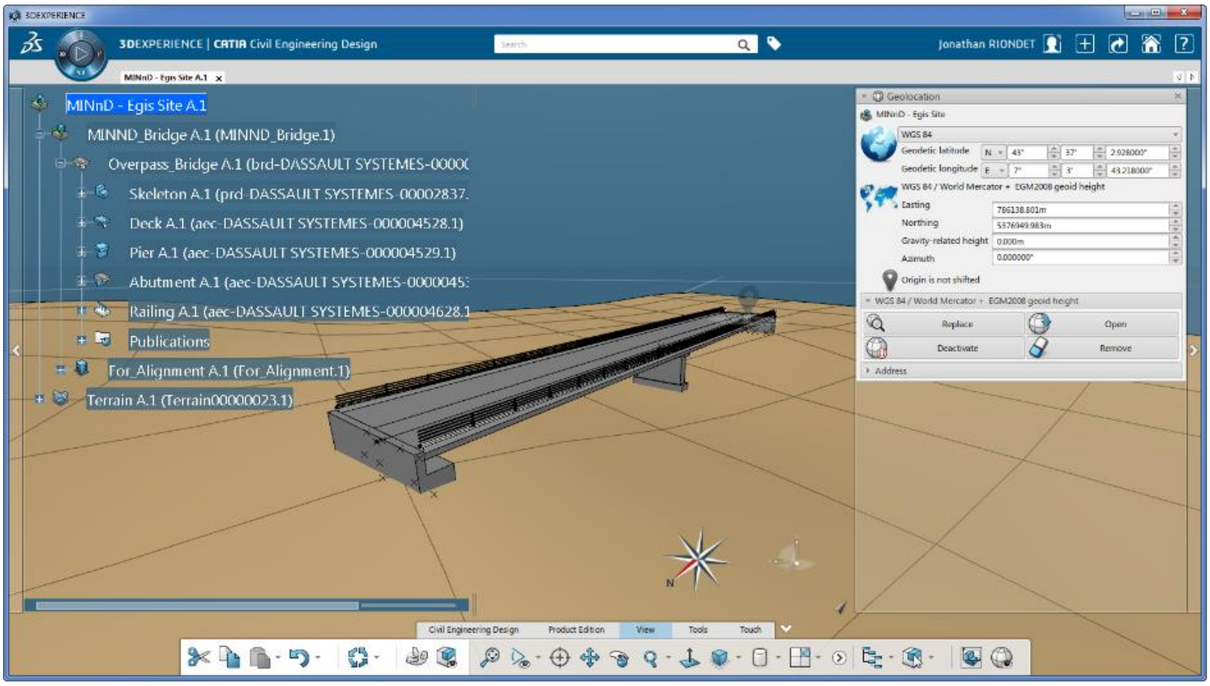


We also made the railing that is composed of a steel railing reference and a barrier reference.



The bridge is inserted inside a Site (we use AEC Site type to be mapped with IFC Site type).

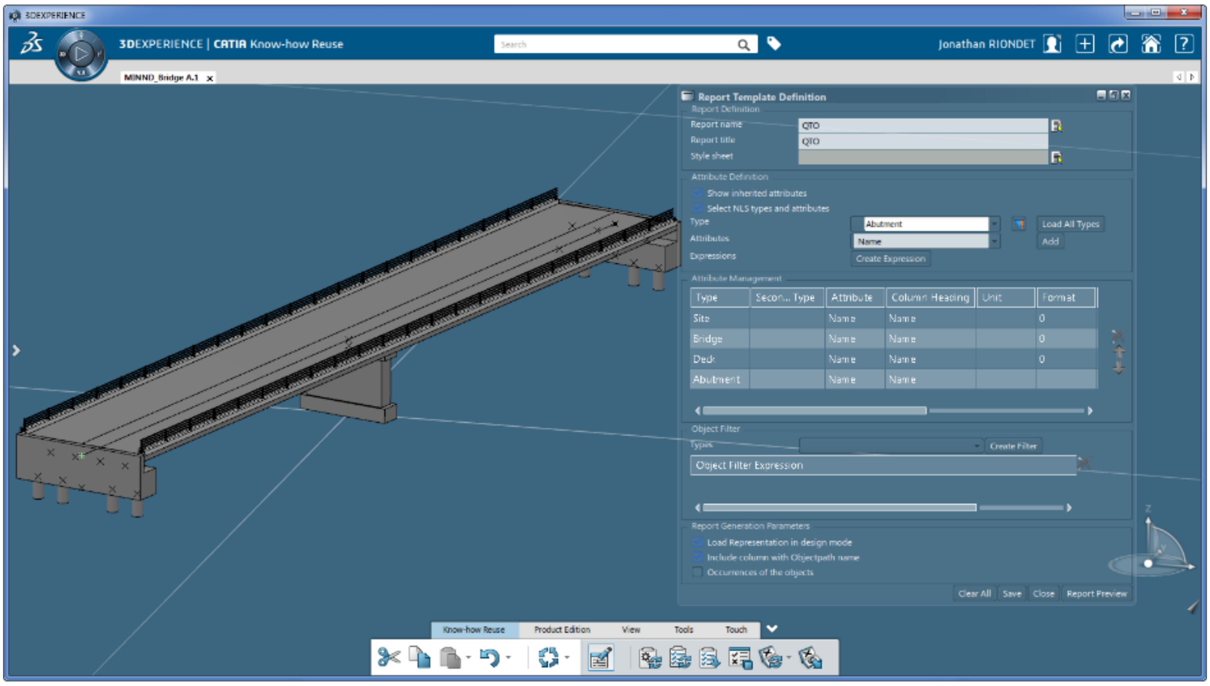
The site can be geolocated (so all sub-elements will also be geolocated) and can contain other types such has a Terrain.



C.2.5 Results

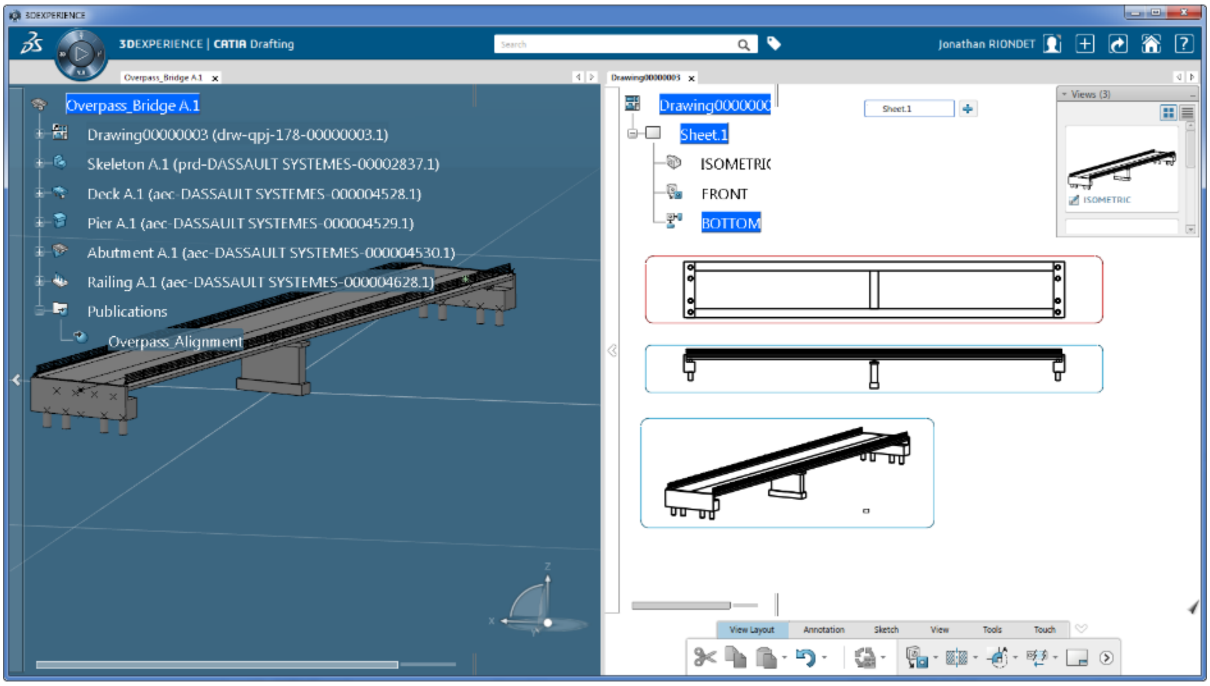
Mainly data can be extracted from the BIM/DMU model such to create BOM (QTO).

Using Know-how Reuse app (Report generation tool)



C.2.6 Drawings

Using Drafting App, projections, isometric view, front views etc can be automatically generated and are always associated with the native 3D BIM model.

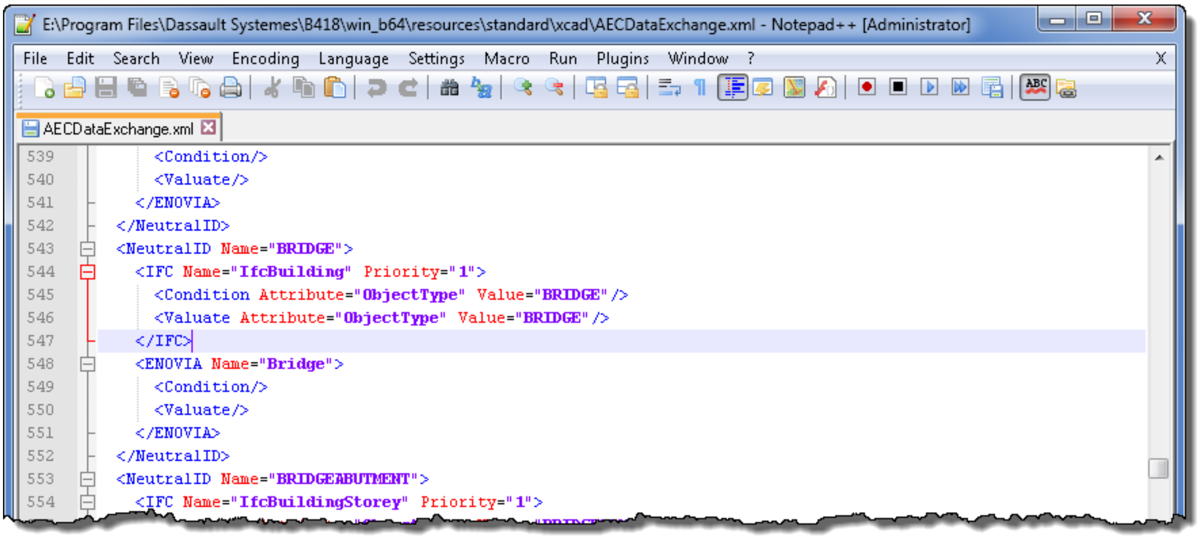


C.2.7 Export to IFC

Unfortunately if we use Infrastructure types that don't exist yet in the IFC standard, when we export to IFC we have to do a mapping between "our" types and the standard ones.

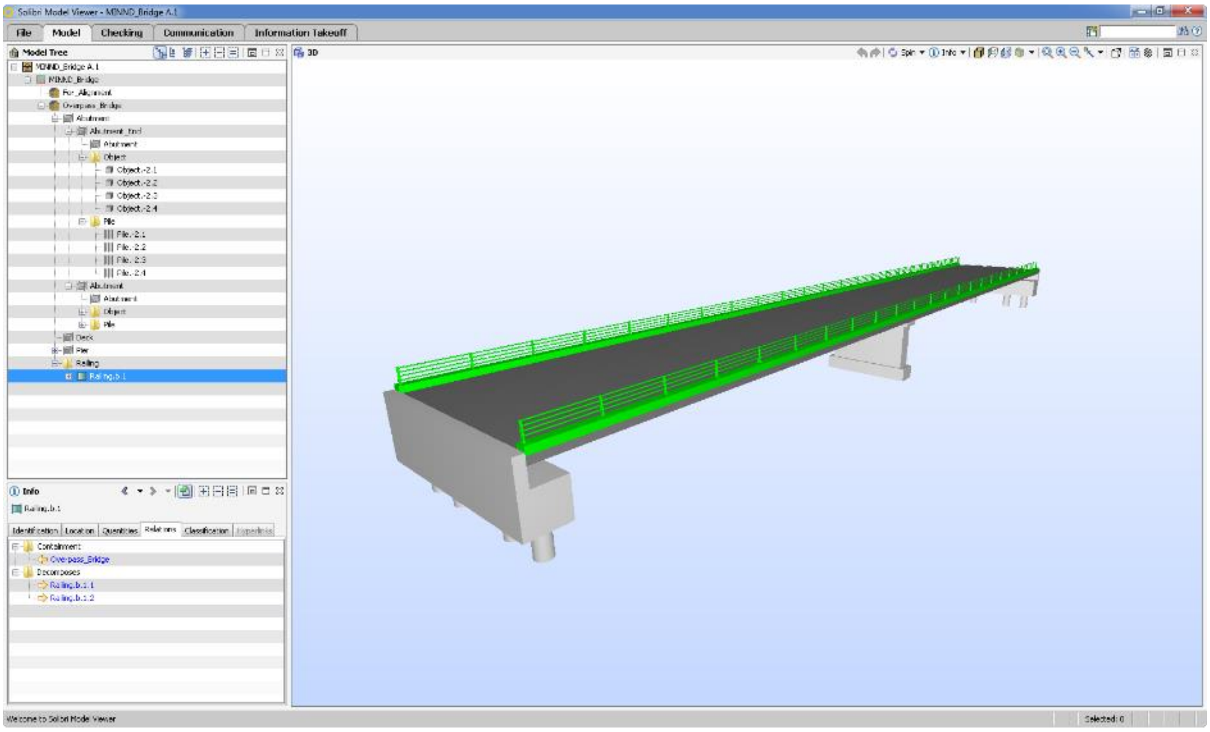
We provide this mapping capability using an proprietary XML file that is managed on the Collaborative space so on the project level. Hence, end user does not have to worry about this. The setting is handled by the BIM Administrator.

For example in our case we said that a Bridge (our AEC Bridge type) will be exported to an IfcBuilding type. We are also manage such mapping if we re-import the IFC file.



We do that for all non-IFC standard types.

Example of the model opened in Solibri



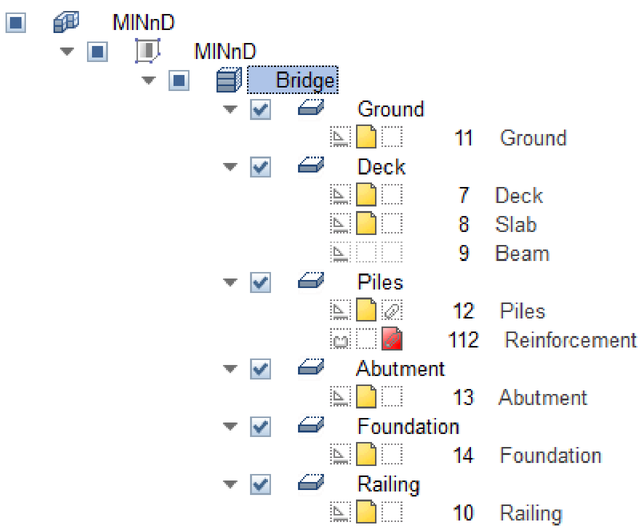
Annex D: Civil engineering structure modeling with ALLPLAN

D.1 Product Used

For establishing the state of art of the IFC the modeling of the bridge started on the version 2015-1-8 of Allplan and finished on the last version at this day which is 2016-0-4.

D.2 Project organization

ALLPLAN is a BIM software which a project oriented organization. This means that unlike traditional CAD tools a project isn't broken down into multiple files, each containing a plan, but it includes all the model and plans. The various components of the model are grouped together in what is called the "project structure":



It is simply a tree diagram, where you can create as many folders and subfolders as necessary. These folders contain numbered files called "working document". And it is in these files, by changing their status (active, passive, frozen, hidden) that we are going to draw 3D objects. And in those documents, the elements are filtered by layers.

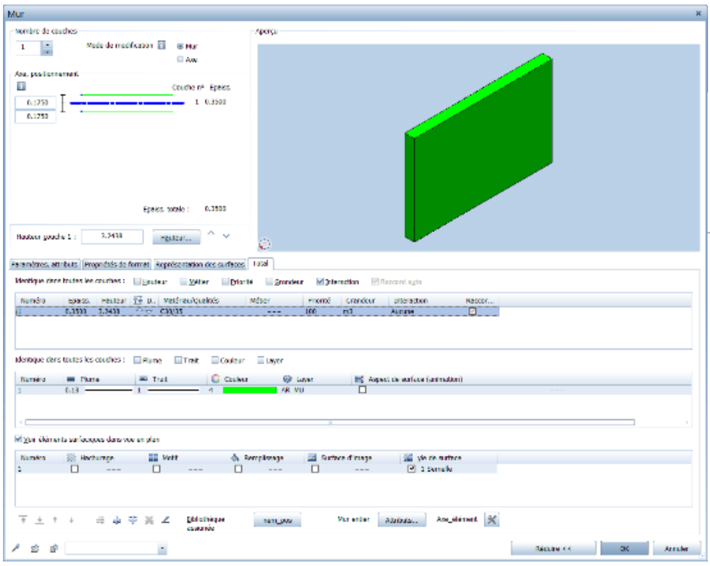
It's important to create a clear project structure because the organization is kept when the model is exported in the IFC format.

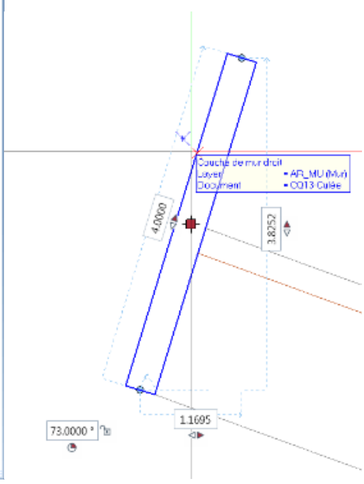
In this case we have created a project called “MINnD” with a subfolder for the civil engineering structures called “Bridge”, which is separated in different folders, one for the ground, one for the deck, one for the pier, one for the abutment, one for the foundation and one for the railing.

D.3 Formwork modeling

There are different ways to model objects in ALLPLAN, there are « BIM » functions which are dedicated object such as walls, beams or columns functions. We can use those functions to create some of the element like the walls of the abutments, the foundation or the piles.

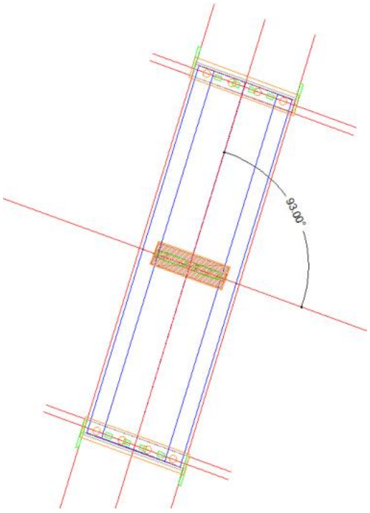
With those functions the volume created already has number of characteristics, of course the dimensions of the element, the sort of element, the type of concrete used… The fact that we used BIM function implies that most of the characteristic will be already set for an IFC export.





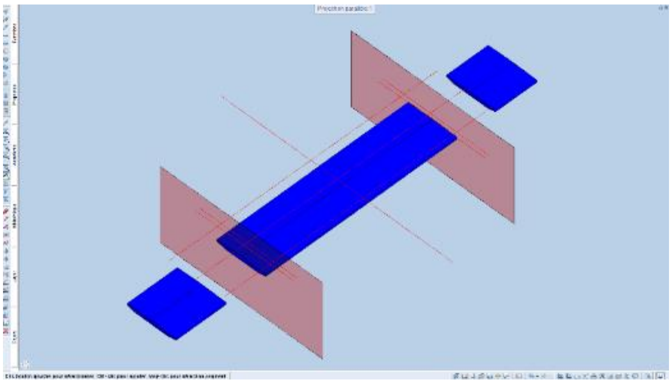
But the use of these functions will not be the most suitable for the creation of complex geometries, furthermore it doesn't exist IFC object class dedicated to all Civil engineering elements. For those geometries we use the 3D modeler, this modeler allows through complex modeling functions and Boolean operations to create those geometries.

In the case studied the difficulty comes from the angles between the different elements. The axis of the structure is not perpendicular to the axes of the abutments and piers.



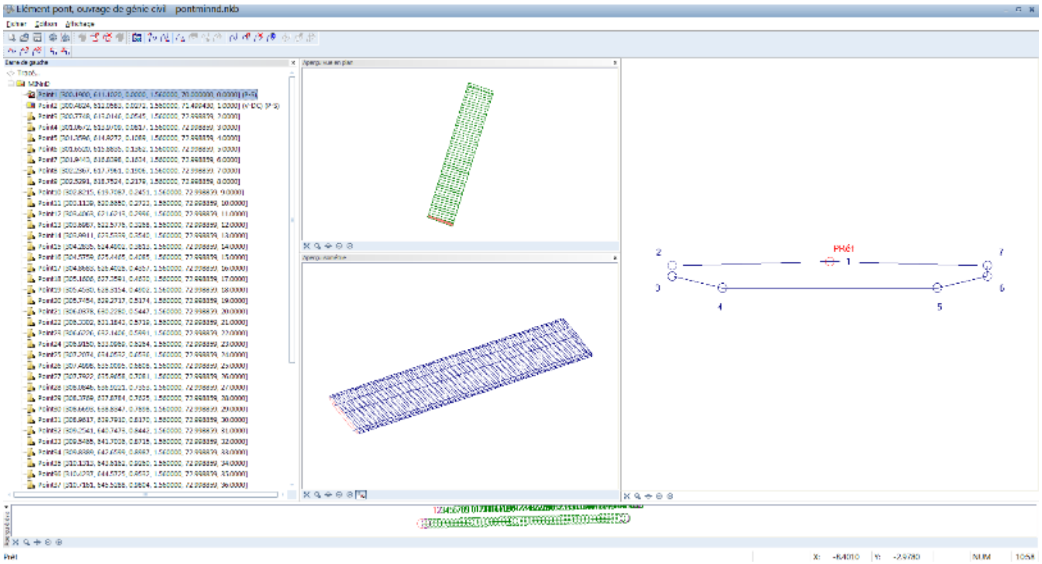
For the modeling of the deck, there are three methods.

The first consists in extrude the bridge section along the axis and cut the ends along a plane, so that the edges of the bridge are parallel to the axes of the abutments.



A second method is to draw the two sections of each end of the deck and connect them according to the selected curve to create volume.

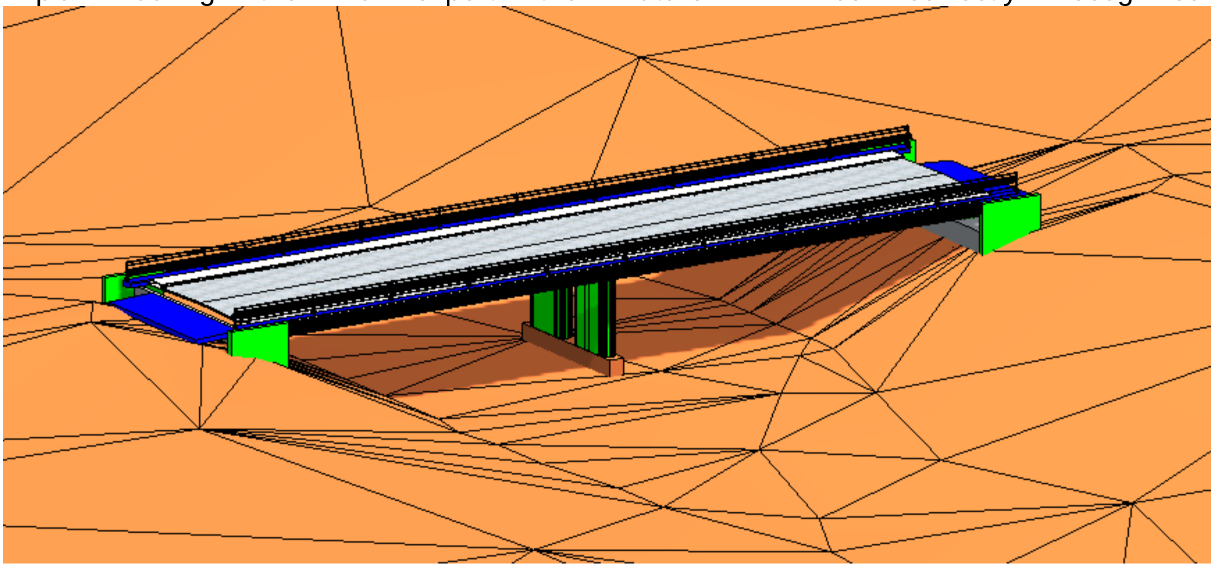
These first two methods are based on the use of free 3D ALLPLAN modeler. For the third method we will use the engineering structure modeler.



With this modeler we start by saving the axis as a point file, each point will be used as a marker for the bridge. Then it will be possible to load a section, for each marker we can choose the geometry of the section and the reference point of the axis. After we can set for each marker the characteristics of the bridge (high, pitch, crossfall ...). The modeler will linearly interpolate the geometry for each unspecified marker. This method is longer than the first one but more accurate.

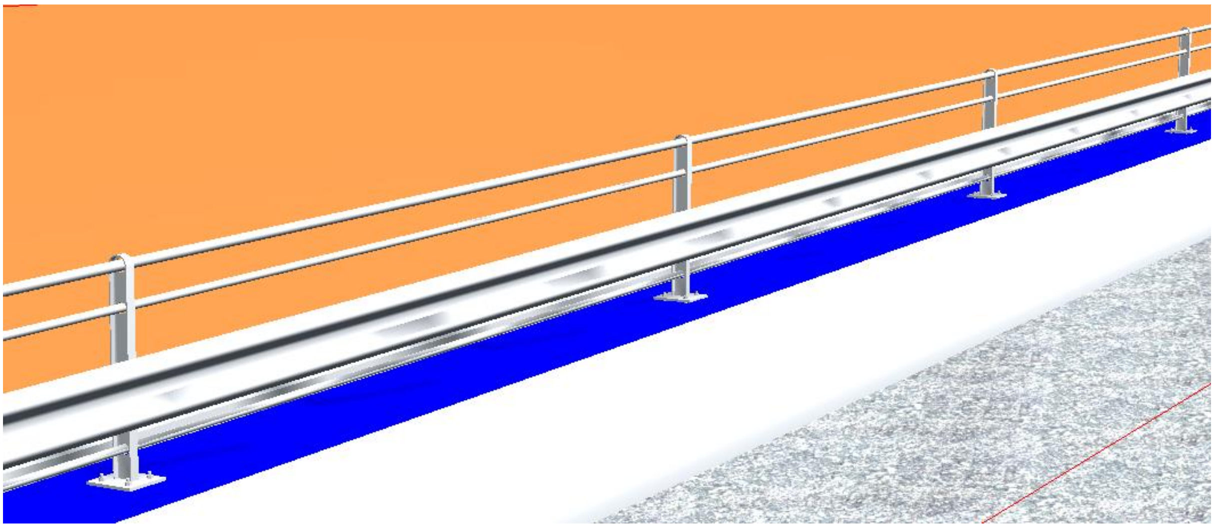
D.4 Ground modeling

In Allplan there is a ground modeler, to create the ground we need to import the points of the model, as a text file like asci or a drawing file like dxf or dwg. In this case the ground has been imported as a 3D surface and we convert it in a 3D ground. Once it's real ground in Allplan during the ifc export the nature will be correctly recognized.



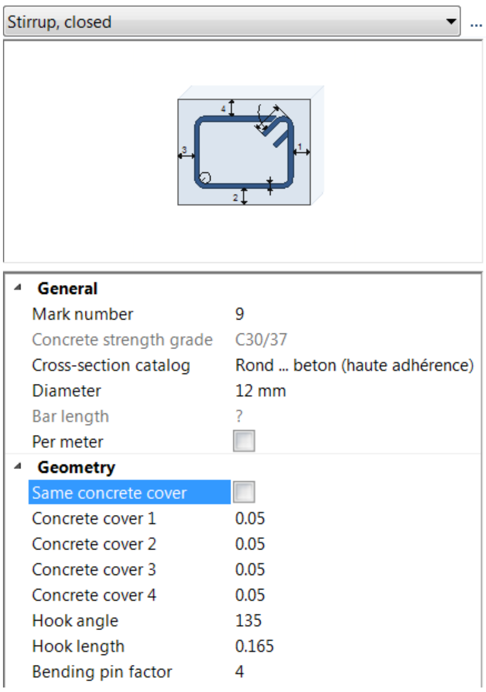
D.5 Railing modeling

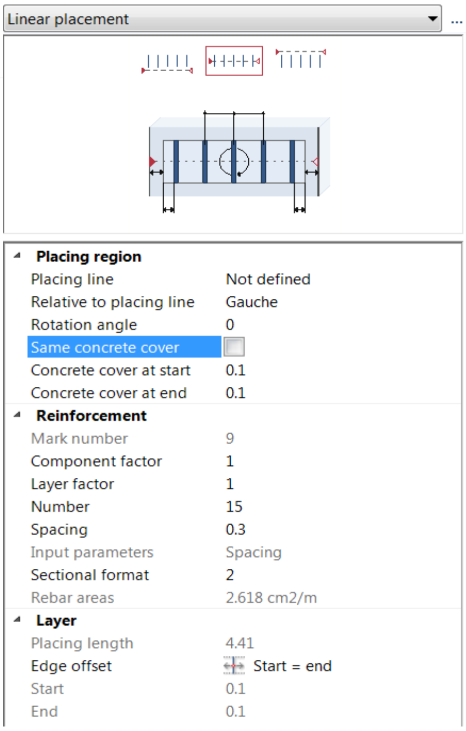
For the railing we used the railing function in Allplan, in this case we used one of the favorite of the library.



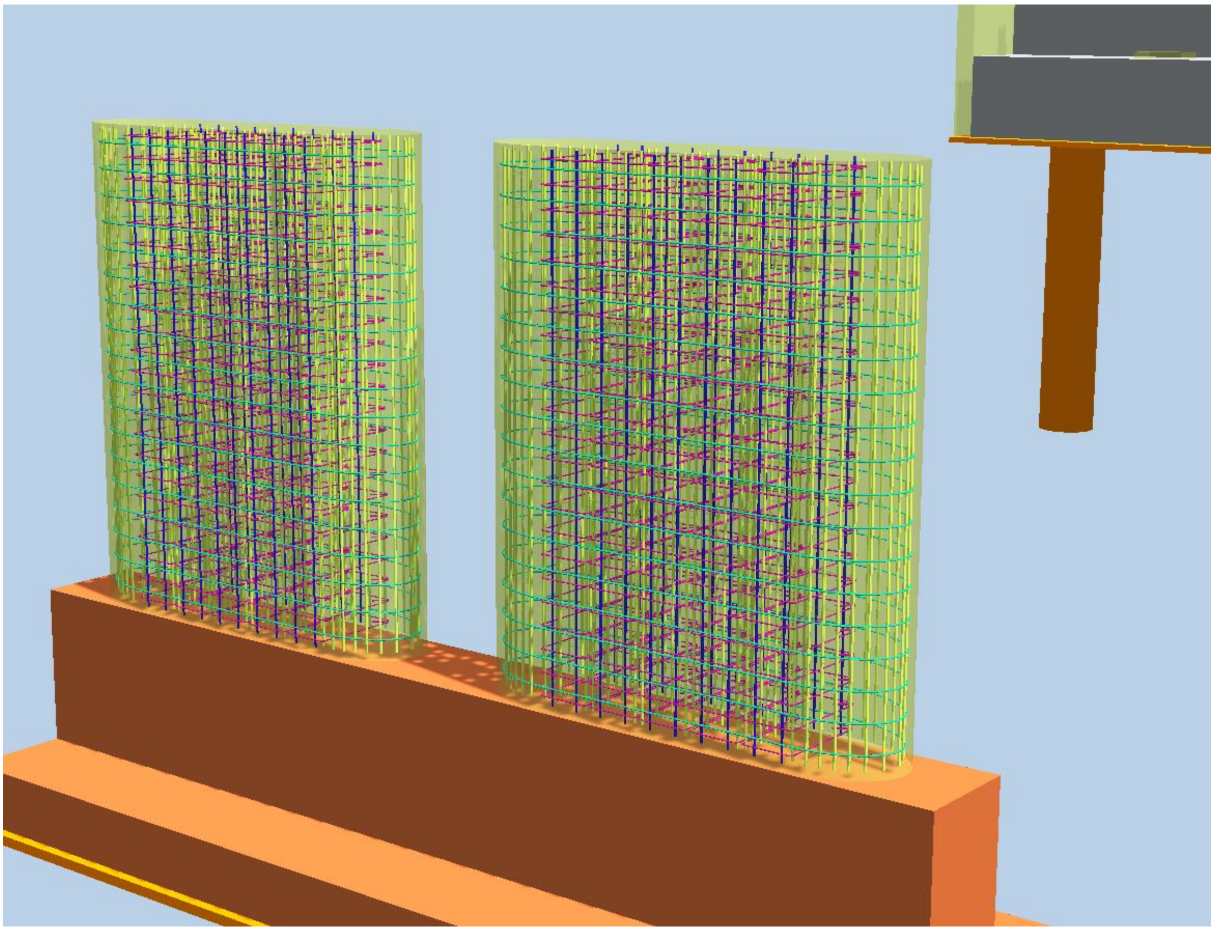
D.6 Reinforcement modeling

In Allplan it's possible to create 3D reinforcement drawing, there are dedicated tools to make those drawings. For bridges and in general for civil engineering we have to use "free" reinforcement because there isn't parametrical reinforcement. To make this reinforcement we need different views of the model then we create the bars and place them.





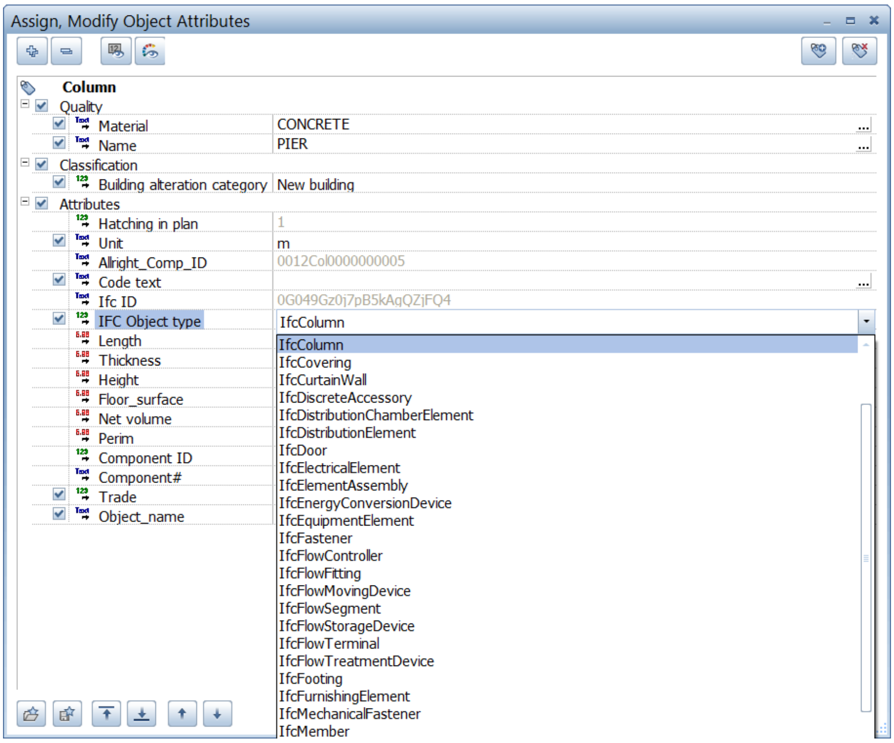
Of course the bars created with those function already have the required parameters for IFC export. But we can create new attribute if necessary, this will be detailed in the next chapter.



Even if in this case Meshes weren't used it's also possible to create and export in IFC that reinforcement.

D.7 IFC object

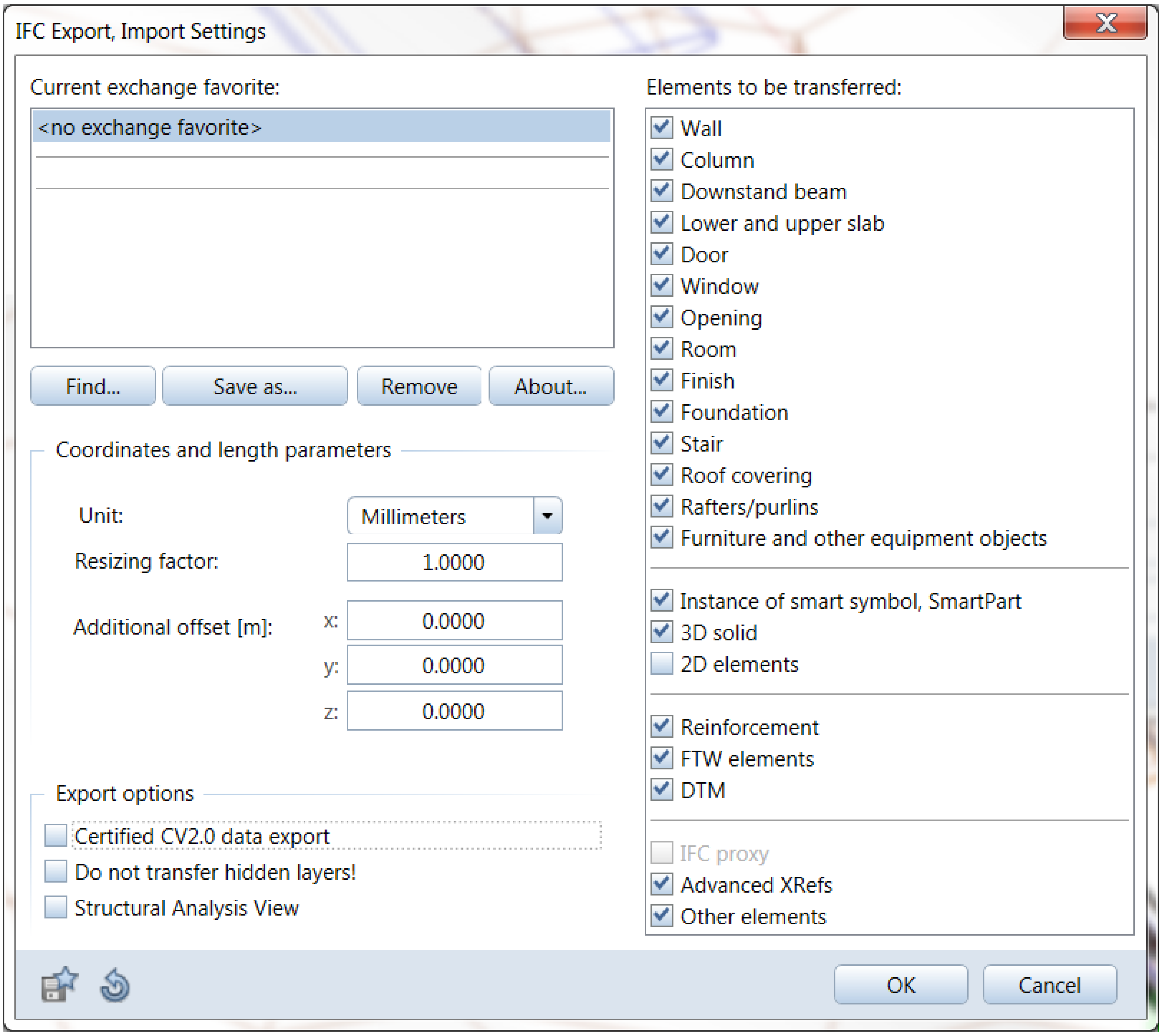
Before exporting the model it is interesting to properly inform objects in order to recover the maximum information during transfer. With ALLPLAN attributes are managed using a right mouse click on an object, it will be possible to create as many attributes as you want like material used or fire resistance. In this case what is interesting us is the ability to assign an IFC class to the elements that constituted the bridge. The allocation is automatic when using the “BIM” functions but when we models with 3D volumes we must specify the type of object.



If there are mistake in the nature or in the name of the object it’s in this window where we can correct it.

Export the model

Once the elements set correctly, just export the model. At the time of export we can still filter the elements to export (choose the types of elements, do not export hidden items ...)



The IFC export is based on IFC 2x3 model schema and CoordinationView_V2.0.

D.8 Conclusion

Here is the conclusion made by C. Dumoulin from Bouygues Travaux Publics after the first export of the model.

The spatial breakdown is good. It has to be noted that an additional well-documented breakdown is based on the *IfcPresentationLayerAssignment* entity. Unfortunately, such a use is not machine readable.

The semantic based on entities is good. There are some translation mistakes between French and English. To go further, the exchange needs have to be detailed by the end-users, through a detailed Exchange Requirements document.

Quite all the shape representations are boundary representations, with no semantics. Some shape representations based on extrusions for instance regarding the footing of the central pier which is a parallelogram.

After the correction of the model we are able to supress the translation mistake using the method described in the IFC object parts. But to go further we need to wait for the implementation of the IFC 2x4 which should be in the next version of ALLPLAN.

Annex E: Vianova Use Case Application

E.1 Préambule

L'objet du présent document est d'expliciter le processus par lequel la modélisation et l'export IFC de l'ouvrage d'art OA645 ont été réalisés via la mise en œuvre des solutions Vianova de conception et de synthèse/contrôle de projets d'infrastructure.

Ce rapport constitue un REX de cette opération.

E.2 Résumé

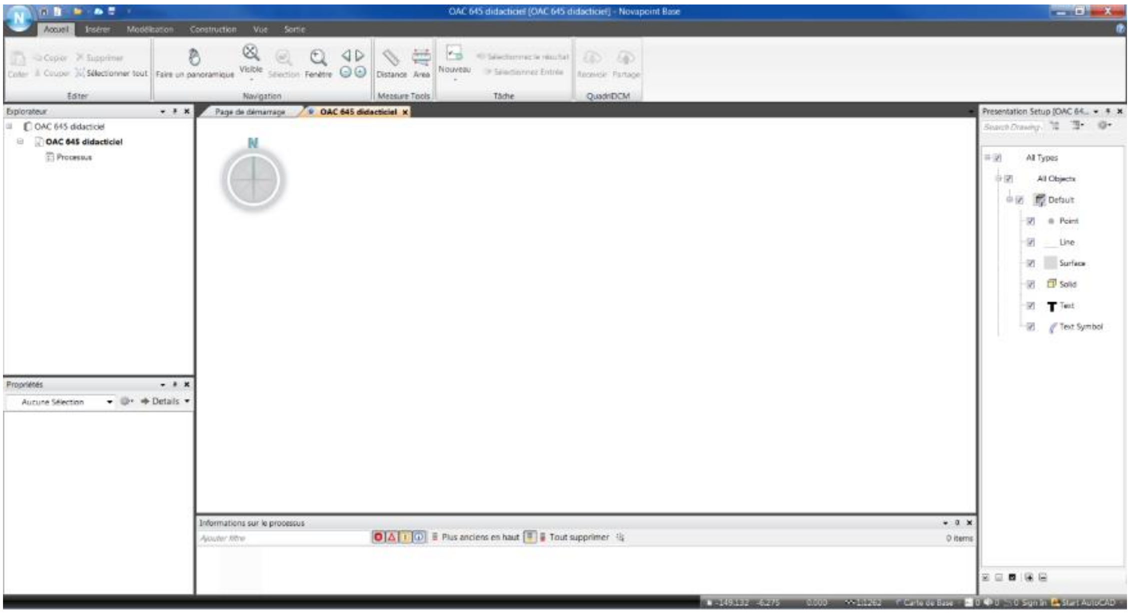
La démarche suivie a comporté les grandes lignes suivantes :

1. Du fait de l'absence de TN : création d'un TN virtuel + entrées en terre ;
2. Du fait de l'absence de fil rouge (axe 3D) : création de 2 fils rouges 3D virtuels ;
3. Du fait de l'absence de coupe type de la chaussée portée (comme de la chaussée enjambée) : création de profils types chaussée virtuels ;
4. Sur la base de la VeP et de la coupe type du tablier : conception paramétrique du tablier (énergie constante / caisson à hauteur constante à âmes constantes), relativement aux segments du profil de la chaussée portée, conception de la développée du tablier relative au profil en long et VeP du fil rouge 3D.
5. Export/import IFC : du fait de l'absence d'IDM, export IFC2x3 selon catalogue & familles d'objets puis contrôle par ré-import dans Viewer IFC (+ export sous modèle 3D/4D autonome).

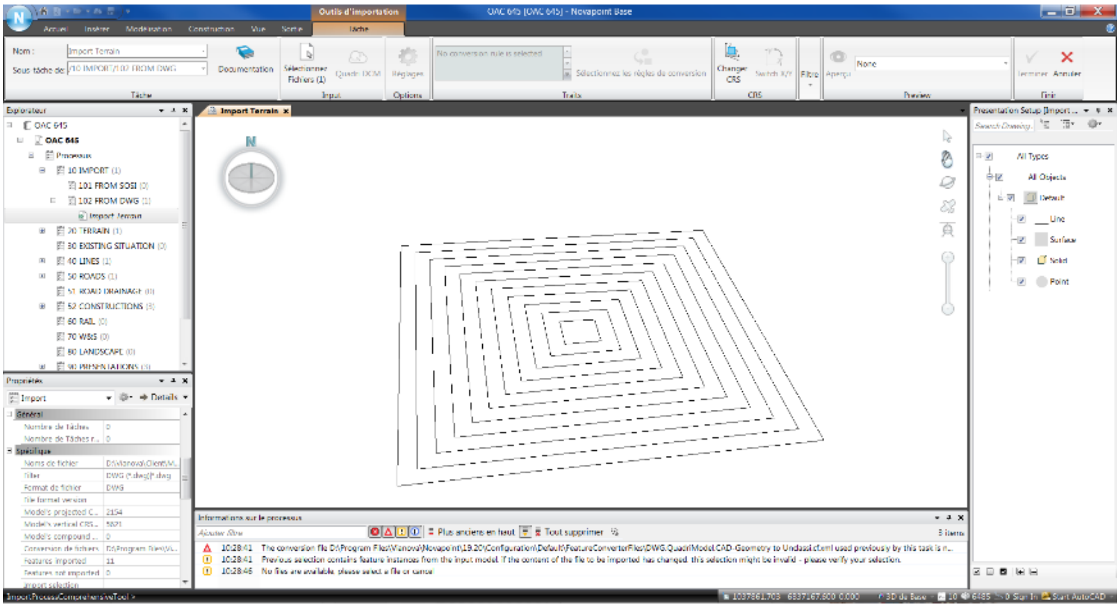
Elle a été assurée à l'aide des outils Vianova : Novapoint Base / Roads / Bridge & VDC ;

E.3 Création projet & TN

- Création d'un nouveau projet :

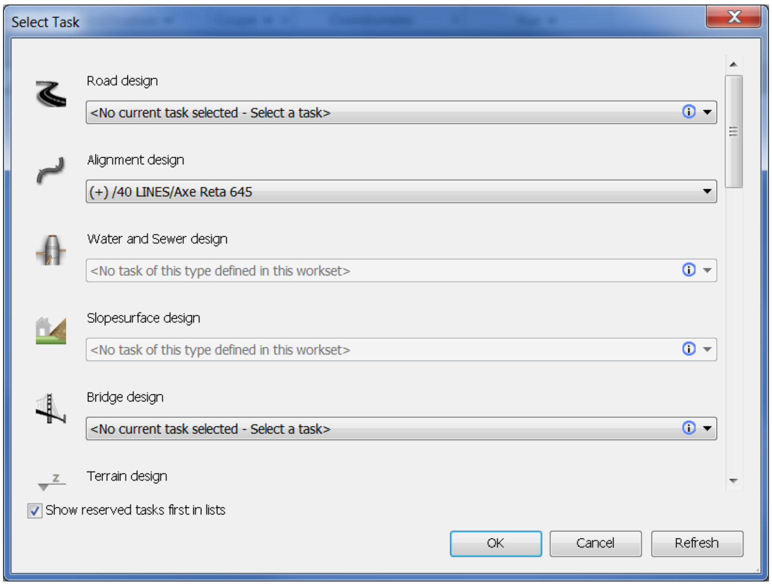


- Import d'un modèle de terrain fictif (MNT) et triangulation :

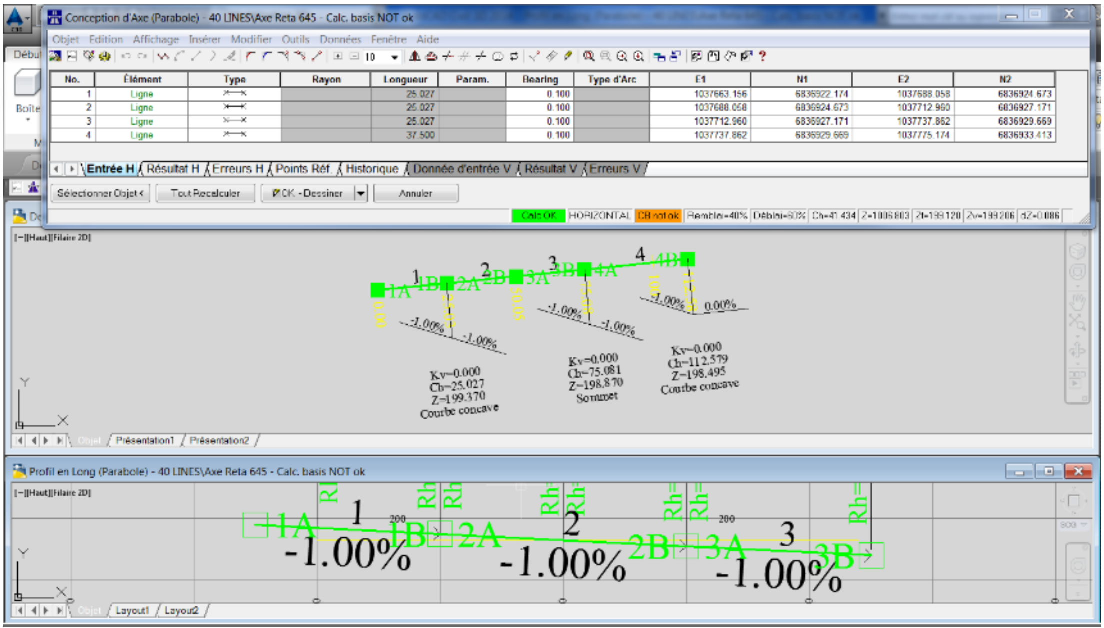


E.4 Création fil rouge (axe 3D)

- Création de l'axe du rétablissement routier :

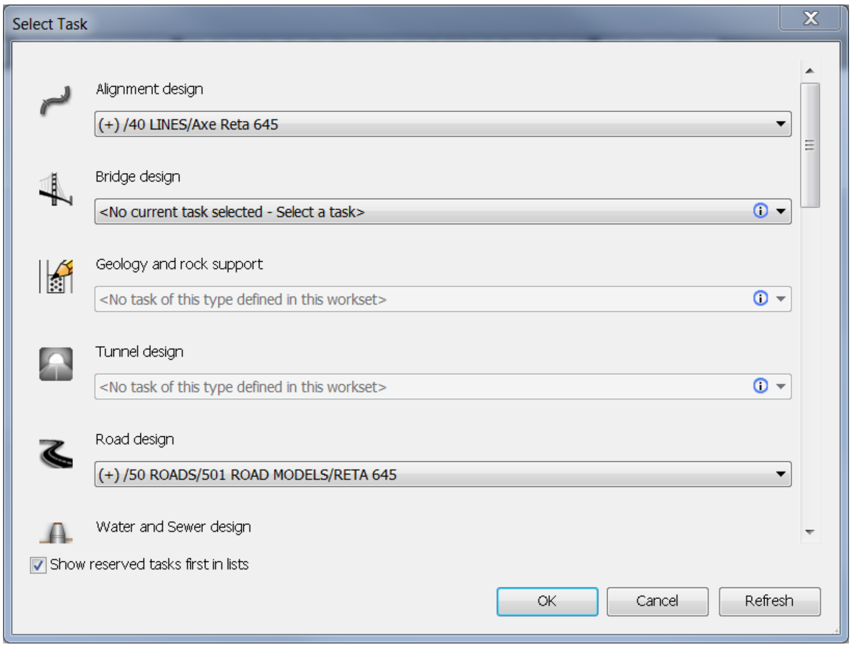


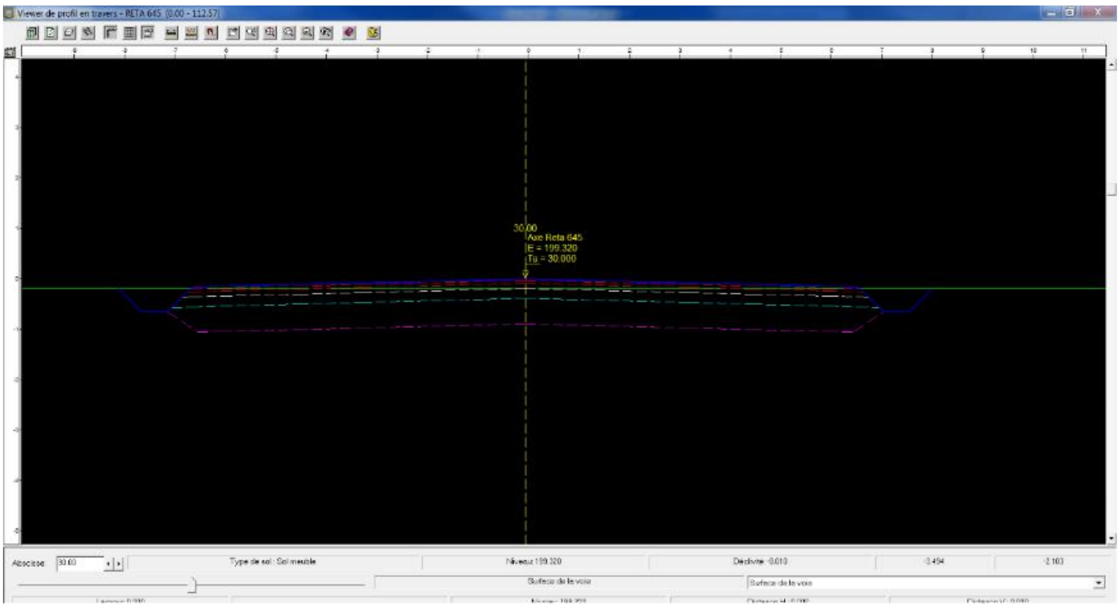
- Reprise des informations fournies (pdf) de géométrie de l'ouvrage :

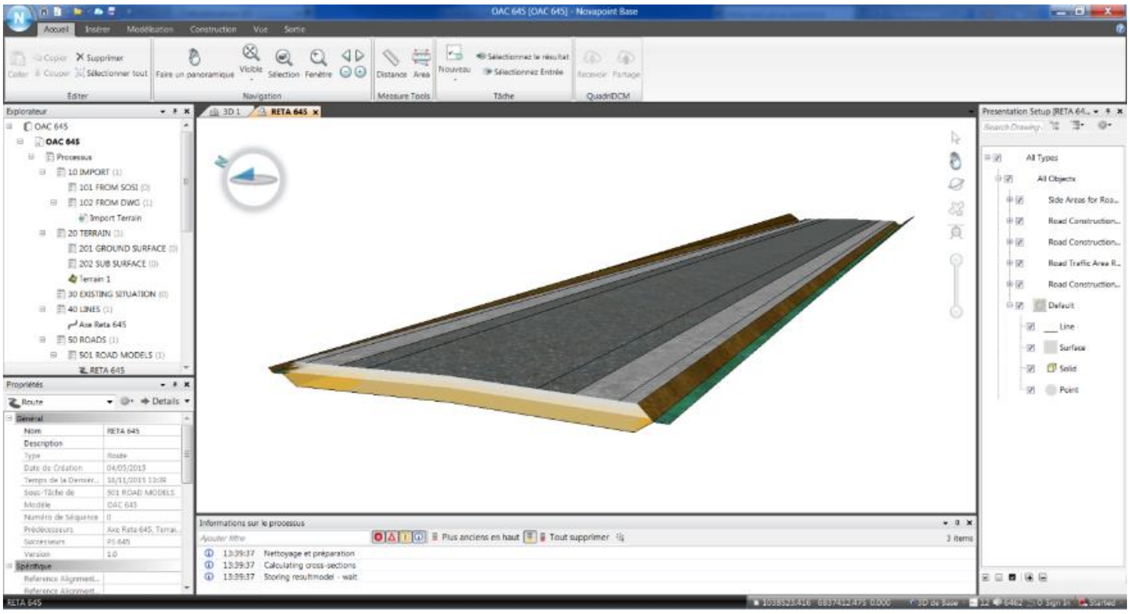


E.5 Création profils type chaussée portée

- Construction du rétablissement
- Utilisation de la géométrie de l'ouvrage pour définir la chaussée portée.



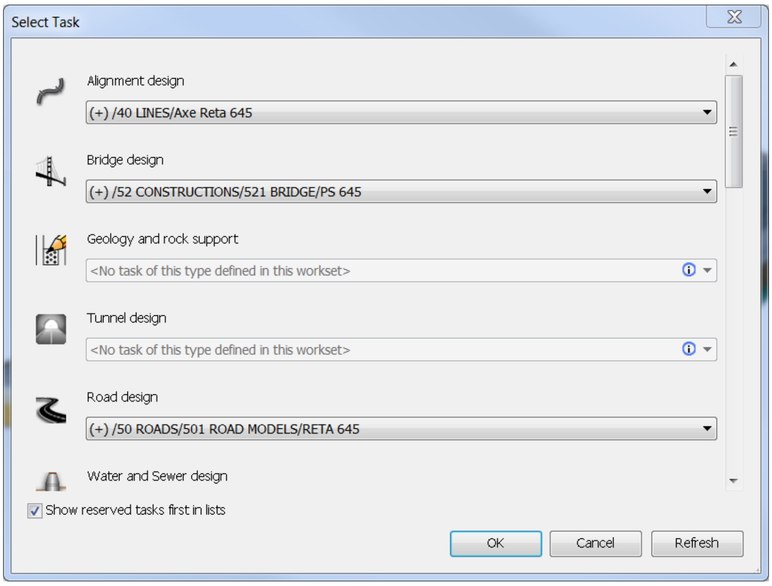




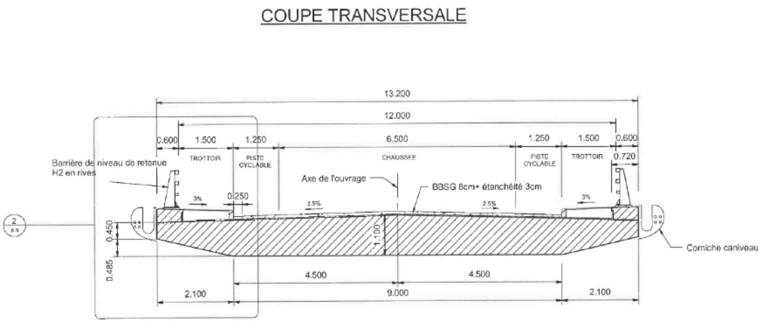
E.6 Conception paramétrique du tablier

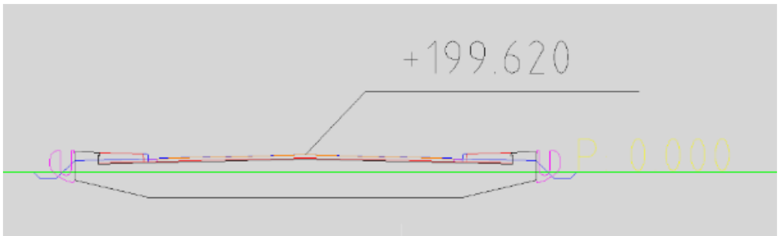
- Définition paramétrique de la section du tablier relativement aux éléments composant la section de la chaussée portée ;

  NB : si celle-ci subit des modifications, elles sont répercutées sur l'ouvrage.

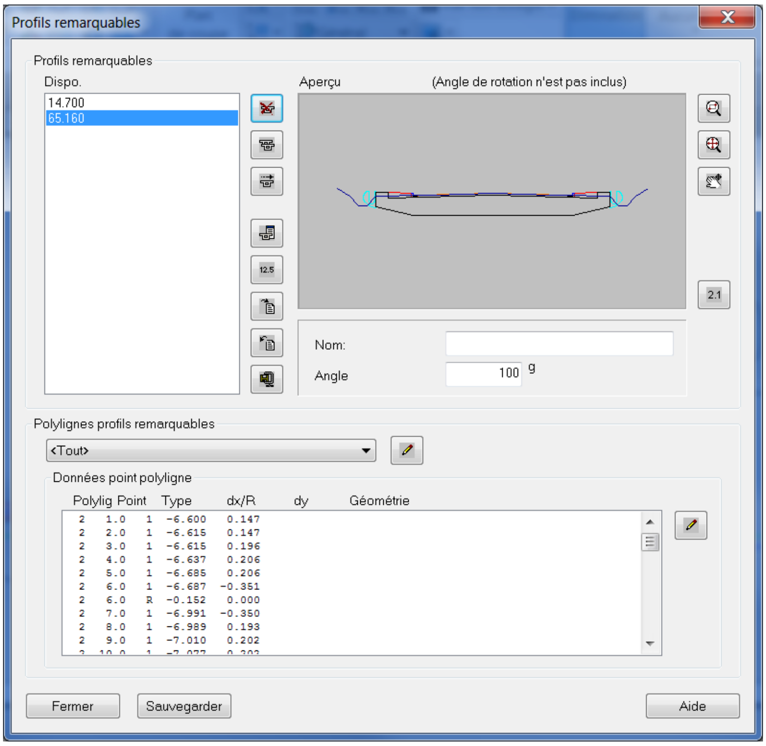


- Modélisation de la géométrie de la coupe sur la base du pdf fourni.

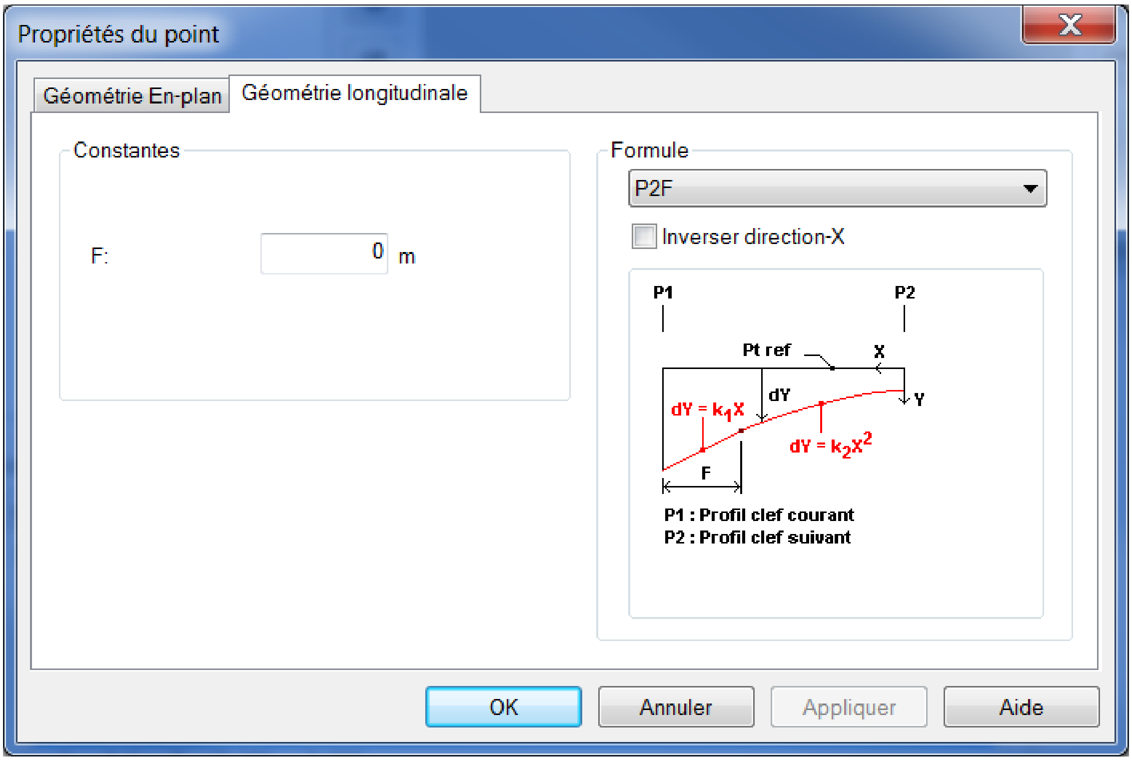




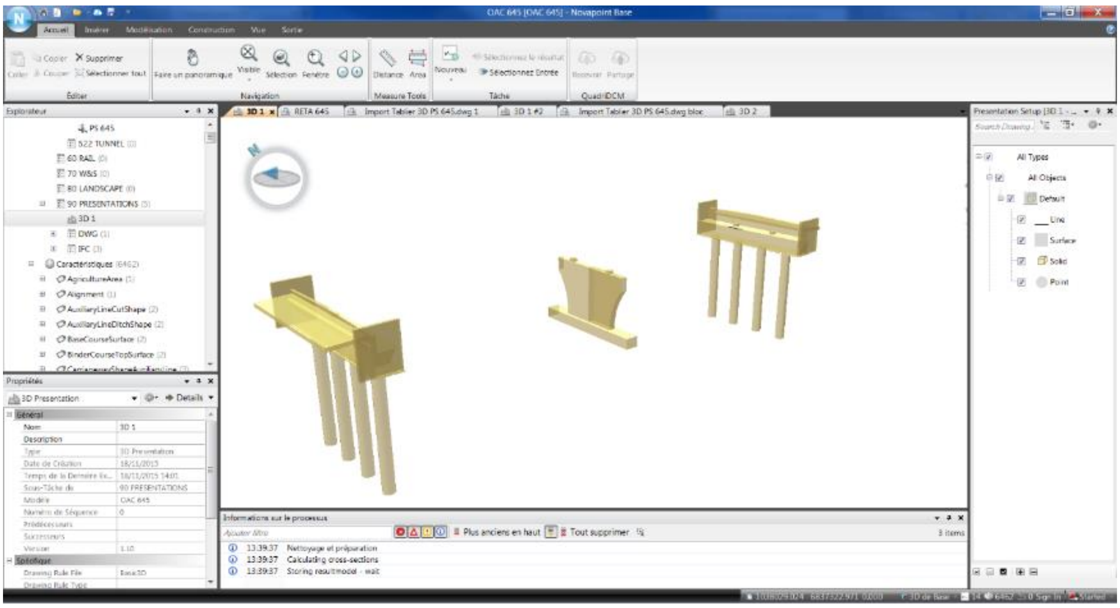
- Enregistrement des différents profils de l'ouvrage (aux PK particuliers),



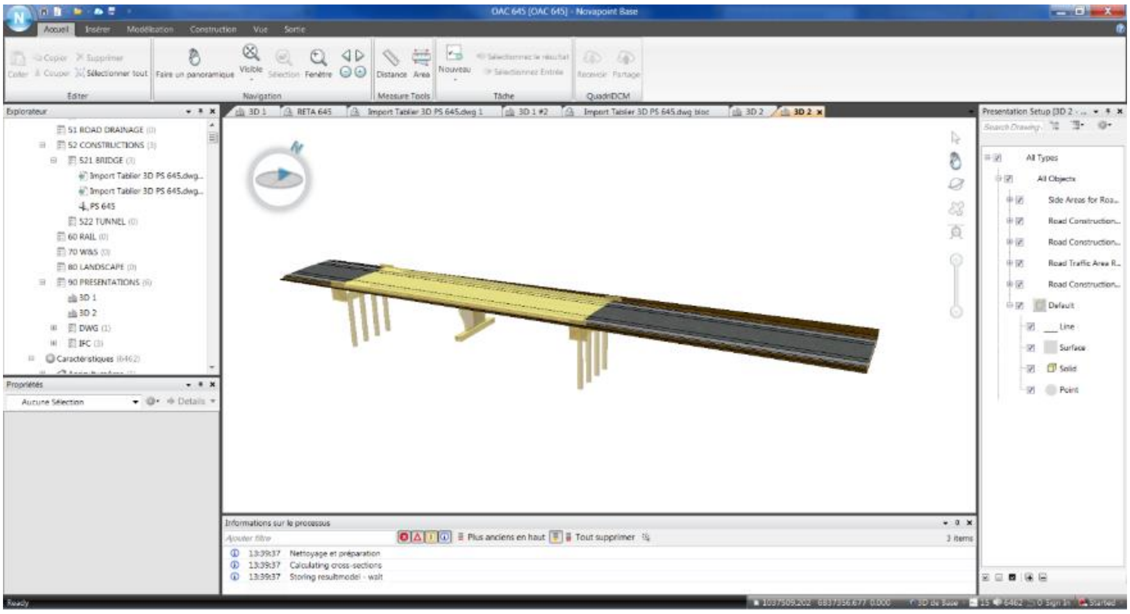
- Définition des variations d’inertie.



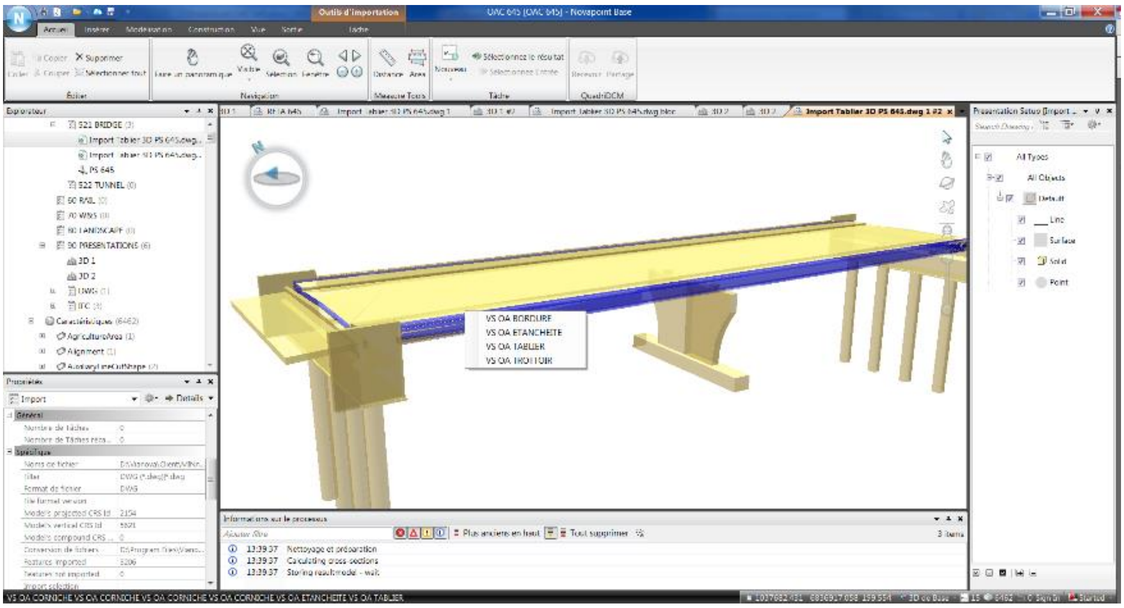
- Modélisation des piles et culées : import des piles depuis modeleurs, puis stockage en base de données.

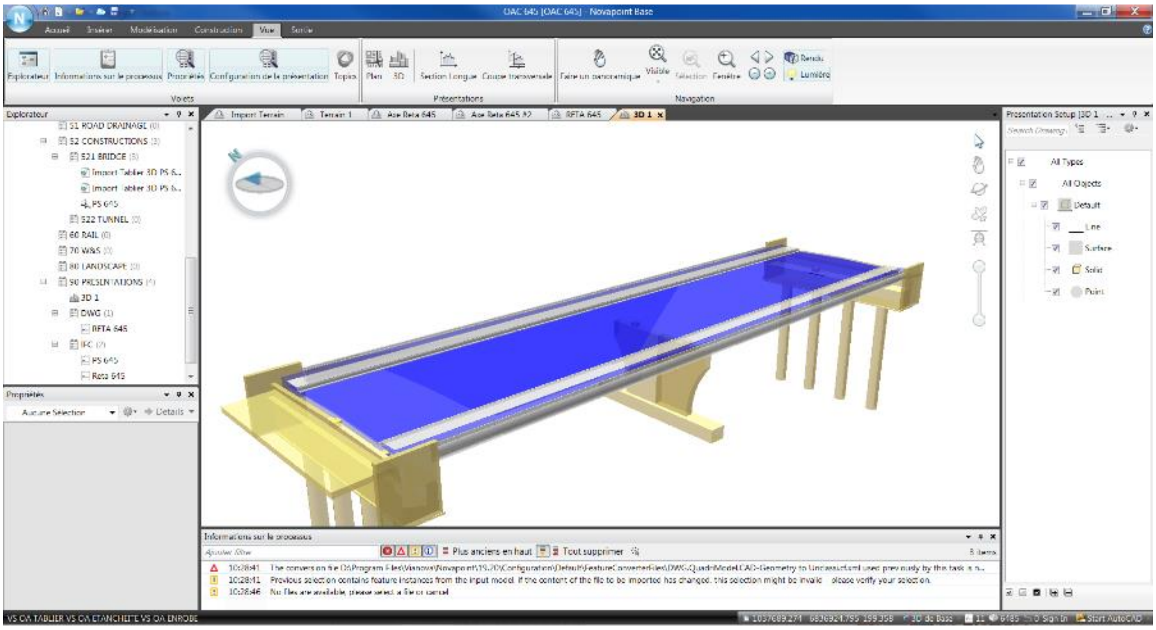


- Alimentation de la base de données : TN, chaussée portée, tablier, piles et culées :



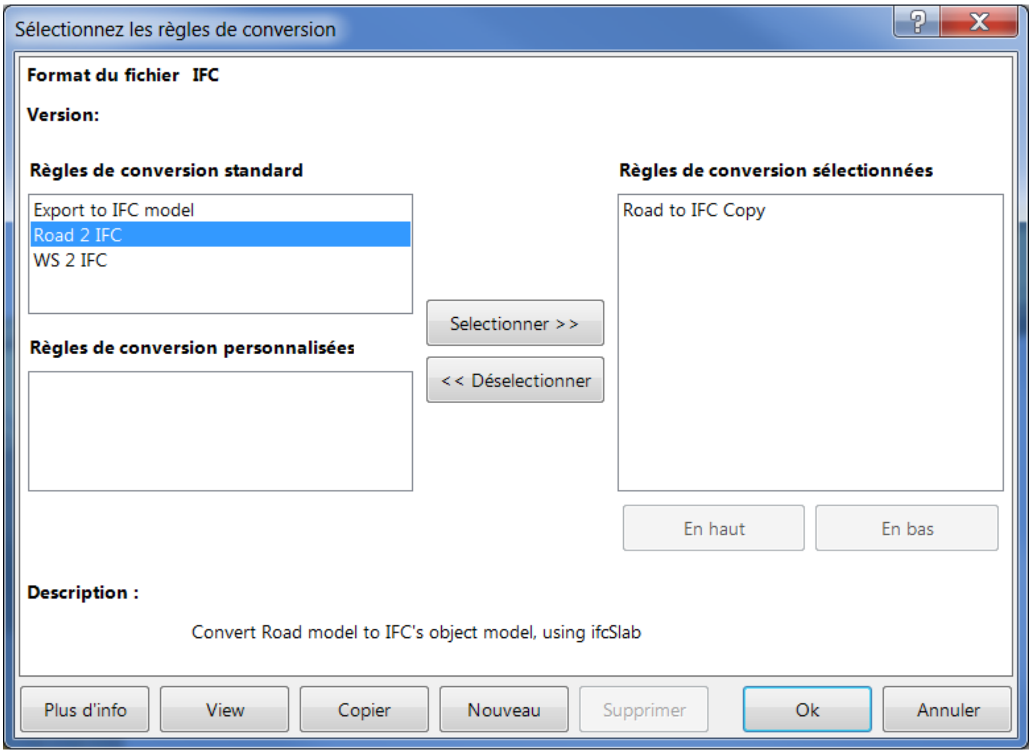
- Organisation hiérarchisée des parties d'ouvrage et du retablissement :

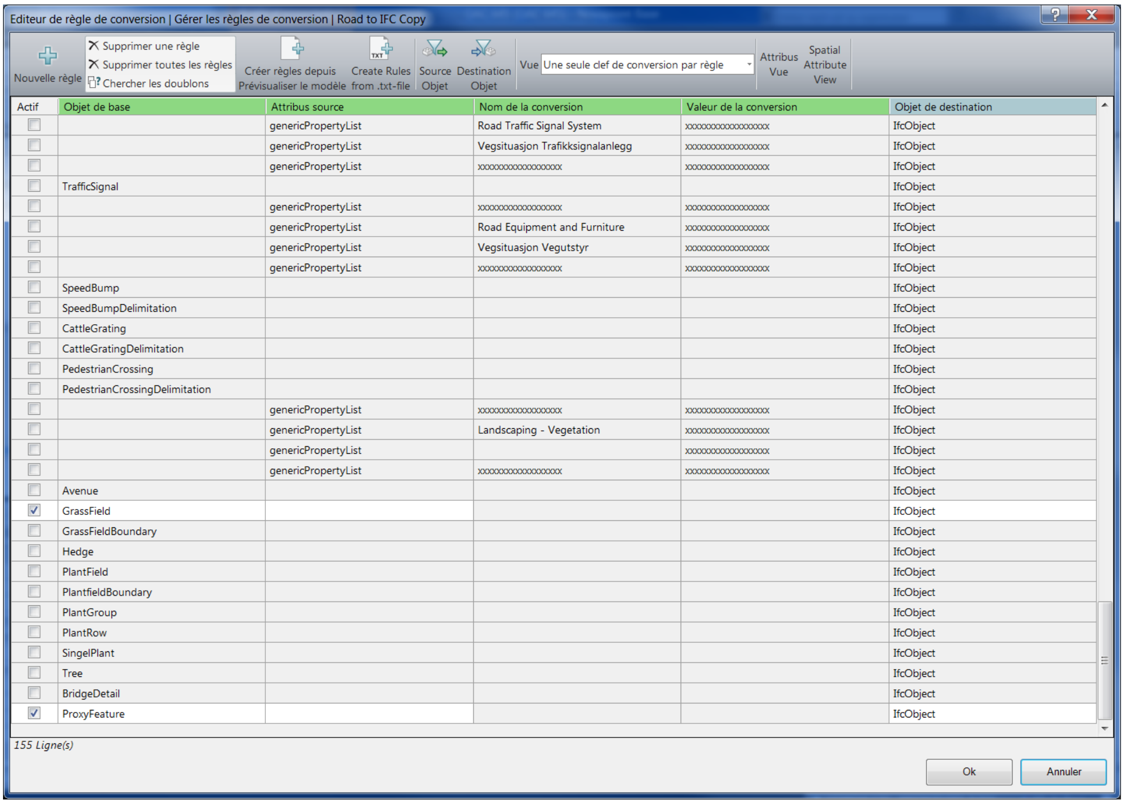




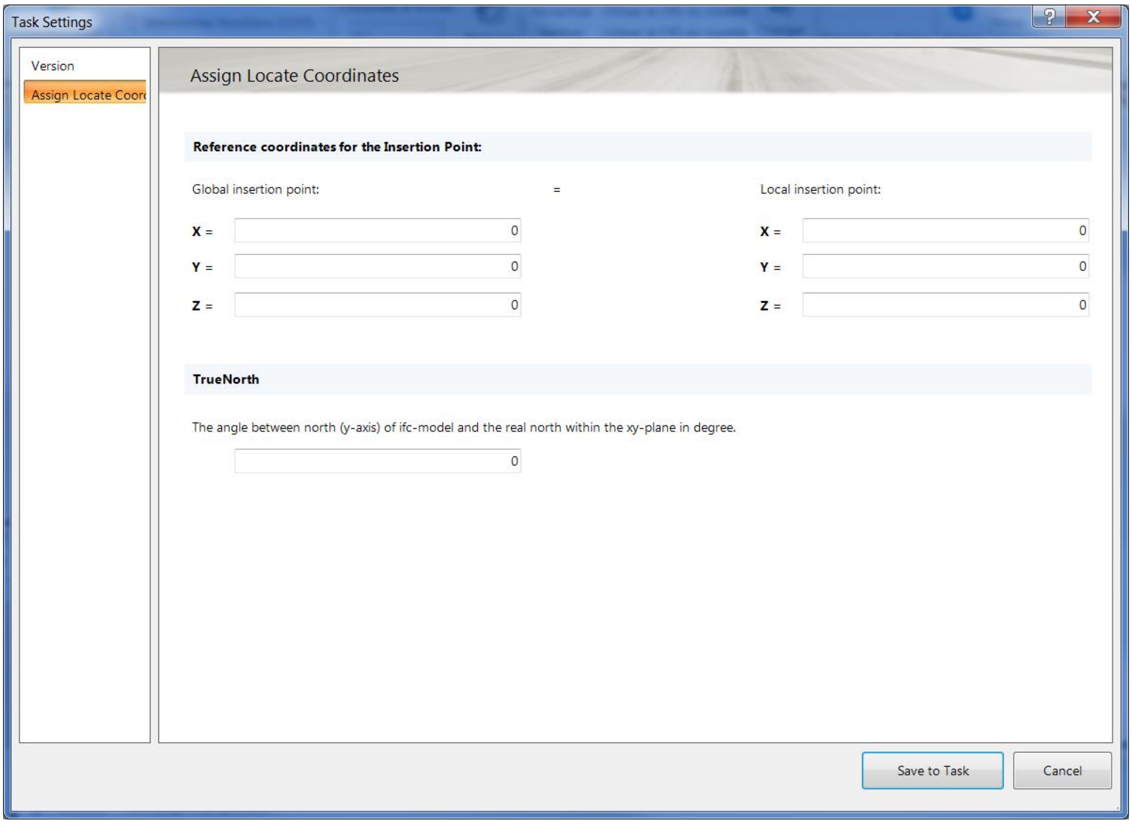
E.7 Export IFC / Contrôle via Viewer IFC

- Export IFC sur la base de règles de conversion:





- Géo-référencement : au besoin, relocalisation du modèle de l'ouvrage :



Modélisation des INformations INteropérables pour les INfrastructures Durables

Projet National MINnD

RAPPORT DE RECHERCHE / LIVRABLE

IFC Bridge
Data Dictionary

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Table of contents

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1 Abstract

Résumé

Le but de ce groupe de travail est de créer un dictionnaire de données multilingue dans le domaine des ponts. Un dictionnaire de données est constitué d'une bibliothèque d'objets et de leurs attributs qui décrivent les relations entre les objets ainsi que leurs propriétés. Il permet ainsi de partager avec plus de facilité et d'échanger des informations sur les produits manipulés.

Dans notre étude, ce dictionnaire est relatif aux concepts utilisés dans le secteur des ouvrages d'art. Ce dictionnaire de données rassemble donc les éléments constitutifs des ponts avec leur traduction en anglais et en français, leurs descriptions, leurs liens hiérarchiques et leurs caractéristiques. Le but de ce dictionnaire de données est de définir les éléments constitutifs des ponts pour décrire tous les types de pont. Son exhaustivité sera validée sur un projet de pont, pour chaque phase d'étude d'un projet. Ce dictionnaire sera finalement intégré dans le Dictionnaire de données de buildingSMART (bsDD).

Ce groupe de travail a utilisé plusieurs documents pour établir ce dictionnaire de données.

Abstract

The aim of that working group is to create a multilingual data dictionary in the field of bridge. A data dictionary is a library of objects and their attributes which maps relationships between objects as well as their property definitions. It enables to easily share and exchange product information.

In our case, this is a document related to the Bridge concept definition. This data dictionary gathers bridge elements with their English and French translation, their descriptions, their hierarchical link and their characteristics. The aim of that Data Dictionary is to define bridge elements to describe all kind of bridge. Its comprehensiveness will be validated on a bridge project, for each study phase. This dictionary will be integrated in the Data Dictionary of Building Smart (bsDD).

This working group used several documents to provide the Data Dictionary.

2 Reference documents

2.1 Dr. Stuart Chen's Data Dictionary

Dr. Stuart Chen is an experienced researcher and instructor in applications of emerging information technologies to bridge engineering. He is a professor at Buffalo University in the state of New York. He provided us his work on the data dictionary of bridge elements. His dictionary gathers different elements of bridges, from the study phase to the construction of a bridge. Each attribute belongs to a group and the links between the different attributes clearly appears. This document contains exclusively English terms with no properties.

	A	B	C	D	E
1	**Information Groups**	**Information Items**	**Attribute Sets**	**Attributes**	1.1 bridge concept design
441				Station at wall pier location	
442			Location	Skew angle at wall pier location	
443		Wall pier		Elevation at the upper left corner	
444	Bridge substructure			Elevation at the upper right corner	
445				Wall pier thickness	
446			Dimensions	Wall pier depth	
447				Wall pier width	
448				Fillet radius	
449			Material	Wall pier material designation	
450				Drilled shaft name	
451			Properties	Drilled shaft description	
452				Drilled shaft type	
453				GUID	
454				Station at drilled shaft location	
455			Location	Skew angle at drilled shaft location	
456				Elevation at the top of drilled shaft	
457				Elevation at the bottom of drilled shaft	
458				Drilled shaft section	
459				Drilled shaft diameter	
460		Drilled shaft	Dimensions	Drilled shaft width	

Figure 1 : Extract from Dr. Stuart Chen's Data Dictionary

That document is a good starting point because it already presents more than 1200 objects with their hierarchical links.

2.2 AFNOR's XP P07-150 standard

« Propriétés des produits et systèmes utilisés en construction – Définition des propriétés, méthodologie de création et de gestion des propriétés dans un référentiel harmonisé. », AFNOR, décembre 2014

AFNOR association makes up, with its subsidiaries an international group which aim to serve the general interest and economic development of organizations. This association provides standardizations and certifications.

The XP P07-150 standard is an experimental French standardization. As there is no other document of that kind in an international or European level, this document is the reference used for that data dictionary. However, this standard aims to become European and international. It describes a standardization method of properties related to products and methods used in construction industry. This document defines and manages properties related to each object of a data dictionary, and a list of attributes for each property, such as its mandatory nature, a list of values and some example.

Thus, each object of the data dictionary of bridge terms has the following properties:

- Unique identifier: a character related to a single object, which is convenient to identify it.
- English name
- Description in English

- French name
- Description in French
- Visual representation
- Status: active or not
- Creation date
- Country where the object is used
- Nature of the group: domain, class or group of properties depending on the hierarchy level of the object.
- Group of properties: the name of the group in which the object is, for an object at the bottom of the hierarchy level.
- Relationship between groups: the name of the group in which the object is and the names of the groups included in it, for an object which is not at the bottom of the hierarchy level.
- Type: kind of value (integer, real, character…)
- Cardinality: number of values to describe the object. For example, three values are required for coordinates.
- Physical values: length, speed…
- Unit
- Threshold values

Besides, in order to easily distinguish the hierarchy between them, the terms representing groups have been colored in grey, the other one stayed colored in white.

2.3 English-French lexicon of bridge terms

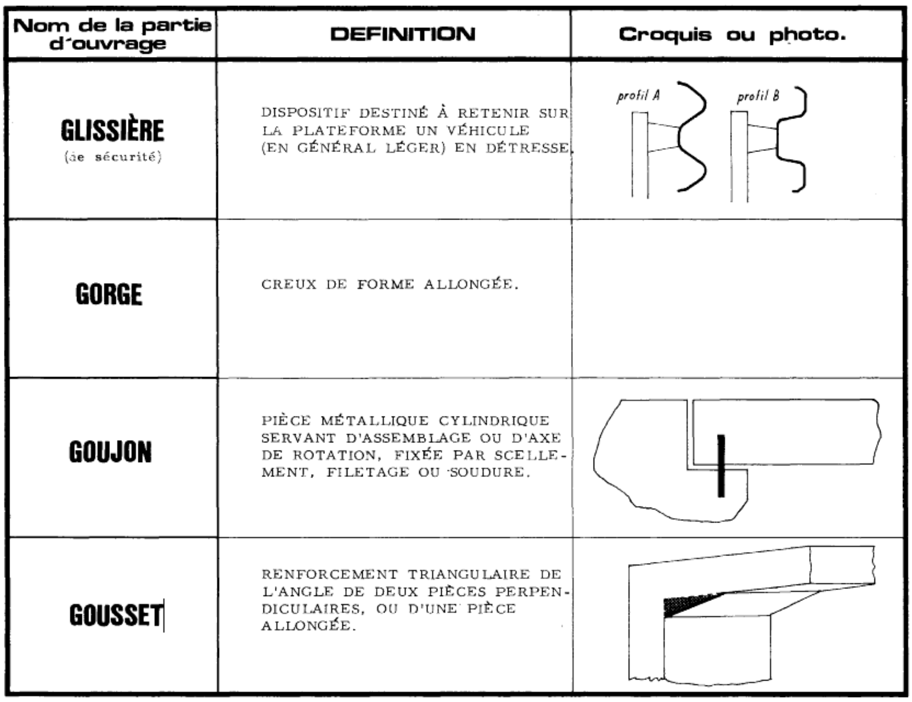
H. Oudin, R. Tardy, « Lexique relatif à la construction des ouvrages d'art », SETRA – CTOA/DGO, août 1997

The English-French lexicon of bridge terms is a reference document written by the DTecITM of the CEREMA (previously SETRA). It is a technical lexicon of bridge terms, and provides an English-French translation.

2.4 Nomenclatures of parts of bridge

"Nomenclature des parties d'ouvrages d'art métalliques", LCPC-SETRA, 1986
"Nomenclature des parties d'ouvrages d'art en béton armé et précontraint et en maçonnerie", LCPC-SETRA, 1976

The nomenclatures of parts of bridge consist in two documents. One is related to reinforced concrete bridges, prestressed concrete bridges and stone bridges. The other one is related to metal bridges. It is a document written by the LCPC and the DTecITM. These nomenclatures gather the kind of bridges and their parts.



Nom de la partie d'ouvrage	DEFINITION	Croquis ou photo.
GLISSIÈRE (de sécurité)	DISPOSITIF DESTINÉ À RETENIR SUR LA PLATEFORME UN VÉHICULE (EN GÉNÉRAL LÉGER) EN DÉTRESSE	profil A profil B
GORGE	CREUX DE FORME ALLONGÉE.	
GOUJON	PIÈCE MÉTALLIQUE CYLINDRIQUE SERVANT D'ASSEMBLAGE OU D'AXE DE ROTATION, FIXÉE PAR SCELLEMENT, FILETAGE OU SOUDURE.	
GOUSSET	RENFORCEMENT TRIANGULAIRE DE L'ANGLE DE DEUX PIÈCES PERPENDICULAIRES, OU D'UNE PIÈCE ALLONGÉE.	

Figure 2 : Extract from the nomenclature related to reinforced concrete bridges, prestressed concrete bridges and stone bridges.

At the beginning, these documents had been written to use a common vocabulary to structural monitoring, because it also provides structural defects. However, they represent an effort to unify, simplify and organize technical vocabulary. Indeed, for each item, the nomenclatures provide its definition and a visual representation in order to avoid ambiguities.

3 Approach

All the previous documents are the fundamental documents from which the data dictionary has been created. The work was to combine information to fill each properties of each bridge item of the Data Dictionary.

3.1 Participants

The work has been distributed among different participants of the working group UC3. Once each participant had sent his part, all the contributions has been gathered and unified to make a coherent Data Dictionary, and all the duplicates have been highlighted. This Data Dictionary is provided in the annex.

3.2 Results

The first results are in the joined file: MINnD-UC3-3_DataDictionnary.xlsm

Some words or expressions have to be translated with more accuracy.

4 Next steps

First, our mission is to check the relevance of the objects registered in the Data Dictionary, as well as the comprehensiveness of that dictionary. Indeed, it has to cover the whole field of Bridges. The lacks identified by the working group UC3-2 will be integrated. Besides, the dictionary will compared expected entities for bridges with the existing IFC entities (IFCx4).

Then, the next step will be to make the buildingSMART Data Dictionary with bridge elements from the previous Data Dictionary. BuildingSMART is an international organization which aims to improve the exchange of information between software applications used in the construction industry. It has developed Industry Foundation Classes (IFCs) as a neutral and open specification for Building Information Models (BIM). Thanks to their working platform bsdd.buildingsmart.org, our working group will be able to create a library of objects with their attributes in a formal way. The interest of that tool is its open and international aspect. Besides, its automatic rule checking prevents miscommunication and data duplication.

In order to initiate this work, our working group will manually create a few objects in order to understand the creation process. This step will be executed on the test platform http://test.bsdd.buildingsmart.org. Then, when this process will be clearly understood, the object will be created on the official website http://bsdd.buildingsmart.org. The objects already created on the test platform will be imported, and the other ones will be automatically imported from the Data Dictionary Excel sheet.

5 Used Documents

Muthiah Kasi and Robert E. Chapman, 2011, Proposed UNIFORMAT II Classification of Bridge Elements, NIST (U.S. Department of Commerce National Institute of Standards and Technology) Special Publication 1122

Observatoire nationale de la route (ONR), Dictionnaire de l'entretien routier, VOLUME 5 : Ouvrages d'art, 154p.

BRIME – Bridge Management in Europe, 2001, Appendix III : Glossary of terms used in bridge engineering, 99p.

Modélisation des INformations INteropérables pour les INfrastructures Durables

Projet National MINnD

RAPPORT DE RECHERCHE / LIVRABLE

IFC Bridge
Lifecycle view
IDM - Information Delivery Manual

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Table of contents

1 Abstract

Résumé

Ce document présente le travail effectué durant la première phase du projet de recherche MINnD pour arriver à la publication d'un Manuel de Livraison des Informations (Information Delivery Manual ou IDM) dans le contexte de l'extension des IFC au domaine des ponts, IDM qui doit couvrir pleinement ce domaine de façon holistique selon les usages des professionnels les plus avancés.

Ses objectifs sont d'expliciter pleinement les processus suivis pour une telle publication et d'en justifier la pertinence en traitant l'exemple d'un type de pont suffisamment générique et fréquent.

L'approche suivie a consisté à prendre tout d'abord une axe de désintégration-intégration, intuitif pour les professionnels qui détaille les composants d'un pont selon trois vues : la vue opérationnelle (question POURQUOI le pont est-il nécessaire – c'est là l'espace du problème posé), puis la vue fonctionnelle (question QUOI ou que doit faire le pont) et enfin la vue organique (question COMMENT ou de quoi le pont est-il composé, ces deux dernières questions constituant l'espace de la solution). Ce sujet est traité dans un premier tableau Excel puis il est projeté dans un second tableau sur l'axe du cycle de vie qui détaille tous les états des composants du pont depuis la genèse jusqu'au démantèlement. Au cours de ce dernier travail, il est possible de renseigner les échanges d'informations (acteurs, contenu, étape) en utilisant par exemple le formalisme BPMN.

Faute de temps, le travail fourni durant la phase 1 n'a permis de ne renseigner que partiellement l'IDM. Cependant, il a permis de valider la justesse du processus et de l'approche suivie et d'identifier toutes les questions majeures que l'extension des IFC et l'IDM devront s'attacher à résoudre pour couvrir pleinement le domaine.

Ainsi :

- Les IFC sont bien adaptées à la description organique des structures, mais doivent être complétées pour une couverture satisfaisante des besoins des professionnels (citons en particulier les éléments descriptifs de l'environnement physique dans lequel la structure doit s'intégrer, et les éléments relatifs à la géométrie procédurale des solides générés qui sont indispensables pour la modélisation ou pour la construction desdits éléments) ;
- Les IFC sont capables de décrire aussi les fonctions des structures, mais sont encore trop pauvres ou trop peu souvent renseignés pour couvrir complètement le domaine et en particulier toutes les modélisations fonctionnelles des ponts (trafic, résistance mécanique, fondations, …) ;
- Les IFC ne sont pas appropriées et doivent être complémentées par d'autres catégories pour couvrir les vues opérationnelles et pour gérer les besoins et exigences attachés aux éléments depuis la vision opérationnelle jusqu'à la vision organique, gestion indispensable à un processus complet et exhaustif de vérification et de validation d'un pont. Pour autant, ce contexte complémentaire doit être explicité de façon à développer un IDM vraiment adapté aux besoins et pratiques de la profession.

Abstract

This document details the work performed in the research project MINnD phase 1 in order to derive an Information Delivery Manual (IDM) to support the necessary extension of the IFC features to cover correctly, in an holistic manner, the design and construction of bridges as currently practiced by leaders in their fields.

Its objectives are to explicit the process to be used for publishing such an IDM and to exemplify it by the partial treatment of the example of a generic and frequent bridge structure.

The approach has been to take first a disintegration-integration axis, intuitive to bridge practitioners for detailing the descriptive content of bridge components successively into the operational view (question WHY is the bridge needed – problem space), and then the functional (question WHAT should do the bridge) and organic view (question HOW is the bridge made of, these two questions being the solution space). This is detailed in a first Excel sheet and then expanded in a second Excel sheet into the lifecycle axis detailing all states of the bridge components of any view from cradle to grave. In this later step of the work preparing the IDM, one can fully document the exchanges of information (actors, content, step) using for example BPMN.

At this point the approach is partially exemplified. However, the practical works performed so far validate the approach and enables identifying all questions to be solved by IFC and IDM, and also by points that must be eventually addressed to fully document the process of information and modelling when engineering a bridge from cradle to grave.

For instance:

- IFC are mainly dedicated to deal with organic description of structures, and ought to be completed to cover satisfactorily the requirements of bridge practitioners whether design or contractor (in particular description of the environment into which a bridge must be integrated, integration of components of bridges used really by practitioners according to their well-established discipline, constructive solid geometry parameters);
- IFC are appropriate to deal with functional descriptions of structures, but need to be significantly expanded and used to cover fully the various models needed (traffic, mechanical resistance, foundations, …);
- IFC are not appropriate and must be complemented by other concepts and categories to cover the operational views and to support fully managing the needs and requirements from operational view down to the organic view enabling the satisfaction of verifying and validating the design and construction of a bridge. However this background is key to develop an IDM for IFC consistent with overall engineering needs and practice.

2 Introduction

In the process of complementing the IFC elements of the IFC4 ISO standard[1] to cover in a comprehensive manner the bridge domain, it is necessary to arrive at not only filling the gaps which are listed in the deliverable UC3-2[2], but also at specifying what should be described in an IDM in order to trigger the specialized modelling works and to use scenarios.

The Information Delivery Manual[3] (IDM) aims to provide the integrated reference for process and data required by BIM by identifying the discrete processes undertaken within construction, the information required for their execution and the results of that activity. It will specify:

- where a process fits and why it is relevant
- who are the actors creating, consuming and benefitting from the information
- what is the information created and consumed
- how the information should be supported by software solutions

In that perspective it is important to project the design process into its various phases and steps and to spell out the various design and simulation processes. The design process will also be included into the more general and global life cycle of the considered bridge infrastructure from cradle to grave, meaning spelling out all states in which the bridge may be or evolve.

This IDM is paramount to identified missing IFC concepts and IFC entities, based on existing exhaustive list of objects describing bridges, their environment and their construction methods (UC3-3[4]).

Moreover, IDM is an essential part of any IFC development approach: Model View Definitions (MVDs) follow from IDM, and software packages IFC-compliance must be agreed in relevance with IDM, more than just with geometry compliance.

This work is further in line with the general reference framework under development in MINnD UC1 working group, dealing with the engineering holistic process describing the complete life-cycle of an infrastructure project.

3 Objectives and extent of deliverable

In consideration that this document must be published by late 2015 the objectives of the deliverable have been formulated as follows:

1. describe the complete process that must be performed in order to elaborate completely an IDM specifying document for a new IFC bridge set covering all the bridge domain and satisfying the needs of end users and bridge Owners,
2. exemplify the approach by partial implementation and, in so doing, validate the proposed methodology,

[1] IFC4 (Industry Foundation Classes) is ISO 16739 standard.
[2] MINnD UC3-2 IFC-Bridge / State of the Art & Missing Concepts
[3] IDM (Information Delivery Manual) is ISO 29481 standard
[4] MINnD UC3-3 Data Dictionary

3. identify in the partial results which of them are correctly covered by existing IFC features and those that must be created or modified.

4 Approach and methodology

Generally the approach described hereafter is in line with:

- the engineering and construction practice being currently implemented by engineers and contractors bearing international recognition,
- the overall engineering reference framework that is proposed by the working group UC 1, itself formulated in as a synthesis of COMMUNIC, systems engineering (please refer also to the deliverable of 3-6 which show examples of this approach in the fields of infrastructures) and other practices like PLM and requirements management,
- the working methodology of Building Smart when drafting IFC extensions,
- the previous works of UNIFORMAT[5] and the US FHWA working group on Bridge Model deliverable of October 2015[6],
- the results of the European project BRIME[7] and the Bridge Glossary of the French Ministry of Roads[8]

UNIFORMAT describes elemental classifications, and in particular the one referenced here above addresses bridge elements. Elemental classifications differ from the traditional “product-related” classifications because their core concept is an “element” that performs a given function, regardless of the design specification, construction method, or materials used. Thus, elemental classifications support a structured approach for developing budget estimates during the planning and conceptual design stages where quantity takeoffs and other product-related information are still under development. IFC is an entity relationship model which claims to be “machine-readable”, and therefore needs semantics to describe the entities. Elemental classifications are therefore very useful to address semantics. In addition, the different levels developed through elemental classification are an appropriate way to address the level of development of the data model and a tool to ease the development of appropriate IDMs.

BrIM 2015 focuses on new IFC entities needed to address IFC Bridge modelling. It explores the same domain as UC3-2 and the results are complementary. But as UC3-2, the concern is the model and not the information exchange between actors at a specific stage of the bridge life-cycle. Results are valuable and should be compared with the work carried out in UC3-2.

BRIME delivered a glossary, which is the beginning of a classification. But elemental classification was not developed. Therefore it is more difficult to manage the level of development which is a prerequisite for detailing the information exchange between actors at a specific stage of the life cycle.

The French glossary is also a one-level classification, as BRIME’s Glossary.

[5] Proposed UNIFORMAT II Classification of Bridge Elements, NIST Special Publication 1122, May 2011
[6] Bridge Information Model Standardization, US Federal Highway Administration, Volume B Schemas, October 2015
[7] BRIME project, Glossary of terms used in bridge engineering.
[8] Dictionnaire de l’entretien routier, Ouvrages d’Art, MEDDE

4.1 Integration steps spreadsheet

See Annex 1: MINnD_UC3-4_IDM_Annexe1_PaliersIntegration_V2.xlsx

In order to follow closely the design process which – jumping from the problem space to the solution space – proceed with iterative disintegration – integration cycles ("from a global deck to support a given load on a given span as a simple slab on beams to slabs and beams forming the required deck") we propose to structure the bridge information into its components and sub-systems in a logical way of combining elements into assemblies of a greater structural or traffic function that we call integration steps. In so doing we structure also the information into the logical processes of checking, verifying and validating a bridge.

Each of the following three views are detailed in a specific sheet bearing the view name.

4.1.1 Operational view or question WHY?

This view, which has so far never been covered by IFC elements, although essential to the design process as it fully records all needs of all stakeholders and actors, has not been yet detailed. It will be done at the next stage before issuing to IDM drafting task in view of its said importance.

4.1.2 Functional view or question WHAT?

This view has just been started. The functions examined so far are only the traffic comfort, the traffic capacity, the traffic support and the geometrical compatibility with the physical environment.

In the first case, this is the extended domain of the IFC alignment. It triggers all the grids and geometrical references and reference axes that the designer and the constructor needs to design and build the complete bridge with all its lanes and network services.

In the second case, the function enables the model of the number (vehicles of a given type per day) and of the size capacity of the traffic. This will help validating the number of lanes planned and checking that the clearances are sufficient to let the traffic of a given gauges to pass.

In the third case we find the structural or mechanical modelling of the bridge. This is the description of the mechanical bridge model into volume, surface, linear components (exhibiting mechanical characteristics like physical modules and coefficients – materials – and geometrical modules – inertia, surface) able to resist to mechanical imposed forces (axial loads, shear loads, torsion and bending moments) and connectors (fixed, enabling displacements, enabling rotations) linking them together into a complete model structure of the bridge.

The fourth case consists into allocating rules and gauges to all elements of the physical environment included into the organic layer (see further down) when in the close vicinity of the bridge.

In this view the attributes needed are the ones of definition, the relations they are in within the other elements of this view and the relations they have with the organic view elements of which they are modelling the mechanical behaviour.

Satisfying the first function is mostly obtained through following the reference lines in the organic view when positioning any organic components. 4

Satisfying the fourth and the second will most likely be done by using simple geometrical routines of clash detection within the organic view.

Satisfying the third function is a much more elaborated problem as it requires:

- checking the consistency between mechanical characteristics of the functional view and of the dimension and materials indicated in the organic view,
- export the model into mechanical simulation tools for complete computation of the bridge structure.

4.1.3 Organic view or question HOW?

This view is the most advanced view as it is the preferential field for IFC elements and for CAD or CADM tools.

In the case we have considered, the infrastructure being described is a simple rail or road bridge with multiple spans crossing an obstacle that can either be a valley, a river, another road or railway line. It covers the cases of truss-bridges, over- and under-crossings. It does not cover the cable bridges (be they cable guy or suspension) and the arch-bridges and sloping legs bridges.

The columns on the left indicate the various disintegration (from left to right) or integration (from right to left) steps and these steps have all a meaning in the process of designing and constructing a bridge. It is important that these steps are always documented in any BIM of a bridge. This fact must be reflected in the future IDM specification.

Another principle that has been followed has been to maximize the use at the components level of the more generic existing IFC features.

It is necessary that the IDM enables on all IFC features the Boolean operations of splitting, concatenation, recursive definition. For instance a deck may be split in deck segments, a pile into concrete lifts, and a road in curvilinear segments of small lengths. In these cases the column relations is referred with Ant/Poster meaning that it is connected to previous elements and successive elements of the same type. In the same manner aggregating together a cap beam, piles and a wing beam will trigger the constitution of a complete pile or support be it intermediary or abutment.

For each feature so defined, two columns are introduced at the right of the component column. One indicate the type of the attributes of the component and the second the value these attributes may take.

TYPE	VALUES
Ident	type/GUI/Upper class/Project groups
Geometry	
Material	
Relations	possible components/using which intermediates
Functional relations	connected model features
Catalogue reference	envelope geometry/detail drawing ref/characteristics
Lifecycle state	state/time schedule
Routines	design rules/construction rules/tolerances

attached	

In the cells VALUES, the separators are / for sub types of the attributes grouped in the same type; and – for possible different values in the same sub-types of attributes.

For example, the attributes Ident of Road/Rail are Ducts-Cable-Pipes/GUID/Network/xxx (xx means attribute not used in this case, but that may be used by specific projects for a – to be defined by project - use).

The geometry definitions are already well covered in IFC and call for placement in a project reference and to define already local natural axes for any given considered features. IFC also enables using Boolean operations. It has therefore been elected to simply describe in usual language the constructive solid geometry CSG being used routinely for bridge design and construction that must be systematically used in bridge projects. The use of faceting tools and of the sole resulting BREP should be severely restricted to cases where there is no other method available, for example in the representation of existing ground surface and layers. It is indeed only in the procedures followed by the CSG that the information critical to any simulation and manufacturing process exists.

The coding of materials is the following:

BA	reinforced concrete
BO	pre-stressed concrete
GB	lean concrete
GT	granite
GR	vitrified clay
PE	polyethylene
PV	polyvinylchloride
CA	electric cable
AC	steel
AL	aluminium
MX	steel-concrete composite structure
CP	composite
SL	soil in layers
TT	treated soil, or aggregate or quarry material
VD	void
EN	bituminous material

For the functional relation, the paving is linked to the SupportedLane, the curb to none, the ditch, the duct, the cable or the pipe with the network_i (the "I" denominated network). It will have to be checked at the end of the process that the compatibility with the functional sheet is really met.

When putting something into (), it means that the information is optional.

In the lines “routines attached”, “sloping” means that the vertical extension of the volume of the layer crossed will be determined using a specific slope depending upon the soil characteristics using a given set of rules. When backfilling, the width is the one of the finished layer, when excavating, the width is the one at the excavation bottom. Boolean operations existing in IFC to limit linear, surface or volumetric extensions can be used for that purpose but they will have to be supplemented by disciplines’ routines (geotechnics in this instance).

A last column of remarks identifies the IFC feature that is the closest model to the considered element, or if it is missing completely and shall be developed.

At this stage of the works, one can see that the introduction of some elements like piles, prestressing cables and reinforcement is yet to be detailed and requires following a specific process of a void creation in a solid followed by inserting a new element taking part or fully of the void created. For instance:

- A rebar is taking the place of concrete in any volume of o solid in concrete (beam, slab, column, …) but two rebars cannot be at the same location;
- A hammered steel pile is driven into the ground compressing the ground outwards (but one can approximate simply by a void creation) and then the pipe forming the mile presents a void inside which can be subsequently filled with concrete;
- A prestressing duct is taking the place of concrete similarly to rebar except that it is flexible so that it takes a free fall (catenary curve according to deadweight) between a few given supporting points; the prestressing cable is subsequently inserted into the void inside the duct and finally the void left by the cable inside the duct is filled with a special cement grout.

4.2 Lifecycle axis spreadsheet

See Annex 2: MINnD_UC3-4_IDM_Annexe2_CycleConception_V2.xlsx

The horizontal axis describes the various steps or states of the lifecycle.

The left part of the spreadsheet should arrive eventually at the column just before the column programming which initiate the lifecycle with listing in as many lines as needed all the attributes of the components and sub-systems of the bridge full information (please refer to the discussion in the preceding chapter).

This part is structured with the following splits:

- The sub-systems of:
    - The bridge itself,
    - The bridge maintenance,
    - The organization of the actors and resources to design and build the bridge;
    - The external systems
- The architectural views: operational, functional and organic.

The stakeholders are so far differentiated into:

- P bridge owner,
- E bridge operating organization,
- CC design organization,

- CS contractor organization,
- AC other design organization,
- SE external systems organization.

The lifecycle states are so far:

- Programming,
- Design, further split into
    - Design challenges,
    - Preliminary design
    - Advanced project
    - Construction bidding stage
    - Contract
- Construction (will have to be split further),
- Testing,
- Delivery,
- Operation (normal),
- Accident,
- Maintenance,
- Repair,
- Dismantling.

5 Lifecycle Exchanges of information

A process map is to be established summarizing graphically the lifecycle spreadsheet and the type of information exchanged according to BPMN process maps.

All these elements are of a descriptive nature and are not specifying anything in terms of modelling, simulating and verifying and validating procedures. They must of course be eventually linked to requirements that have to be satisfied and without the full satisfaction of all requirements any bridge project cannot be declared completed satisfactorily.

This calls for introducing as a background the process of managing needs and requirements for which the industry has already developed tools and methods and to transfer it to the fields of bridge design and construction. Such a process should at least arrive at a cross table referencing all requirements to all components of the bridge description so that the process of checking and validating is traced for each component from the smallest to the complete structure.

6 Annexes

6.1 Integration steps spreadsheet

The spreadsheet shall be completed for all three views. A tree structured output is envisaged as well.

See file: MINnD_UC3-4_IDM_Annexe1_PaliersIntegration_V2.xlsx

6.2 Lifecycle spreadsheet

The lines that exist at present in the said spreadsheet result from exploiting existing design and build guidance notes in force from the French administration. It must be extended and filled in to cover fully the final integration steps spreadsheet.

It has to be completed for a more detailed coverage of stakeholders and actors, and for a more complete identification of all bridge states along its lifecycle.

See file: MINnD_UC3-4_IDM_Annexe2_CycleConception_V2.xlsx

7 A short glossary

Words and Acronyms:

- COMMUNIC

  The collaborative research project COMMUNIC, for COllaboration par la Maquette Multi-Usages Numérique et l'Ingénierie Concourante (Collaboration using the Multi-Purpose Digital Model and concurrent engineering) was selected by ANR (Agence Nationale de la Recherche) following a call for proposals in 2006. Completed in 2010, its main objective was to foster the development of collaborative work in infrastructure projects through the use of an information model (IM).

- IFC4 (as a standard)

  IFC4 is a full ISO standard 16739 and is the latest issue in 2013 of the IFC (industry foundation classes) exchange standards for data sharing in the construction and facility management industries.

- IFC-Bridge

  IFC-Bridge is a project of the Building Smart International organization for extending the IFC application fields into the domain of bridge design and construction.

- IFC-Alignment

  IFC-Alignment is a project of the Building Smart International organization for extending the IFC application fields into the specificities of linear civil infrastructures defined using abscises along a reference axis.

- PLM

  Product Lifecycle Management (PLM) is the process of managing the entire lifecycle of each component of a bridge from inception, through engineering design and manufacture, to service and disposal of manufactured products. In particular it tracks the modifications of the attributes (by whom, when, what, why). PLM integrates people, data, processes and business systems and provides a product information backbone for companies and their extended enterprise.

- Uniformat

UniFormat is a standard for classifying building specifications, cost estimating, and cost analysis in the U.S. and Canada. The elements are major components common to most buildings. The system can be used to provide consistency in the economic evaluation of building projects. It was developed through an industry and government consensus and has been widely accepted as an ASTM standard.

- US FHWA

US FHWA designates the US Federal Highway Administration.

- GUI

In computer science, a graphical user interface or GUI is a type of interface that allows users to interact with electronic devices through graphical icons and visual indicators such as secondary notation, as opposed to text-based interfaces, typed command labels or text navigation.

- BPMN – Process map

Business Process Model and Notation (BPMN) is a standard for business process modelling that provides a graphical notation for specifying business processes in a Business Process Diagram (BPD), based on a flowcharting technique very similar to activity diagrams from Unified Modeling Language (UML). The objective of BPMN is to support business process management, for both technical users and business users, by providing a notation that is intuitive to business users, yet able to represent complex process semantics. The BPMN specification also provides a mapping between the graphics of the notation and the underlying constructs of execution languages, particularly Business Process Execution Language (BPEL).

- BREP and constructive solid geometry

In solid modeling and computer-aided design, boundary representation - often abbreviated as B-rep or BREP - is a method for representing shapes using the limits. A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid. BREP may be exported in IFC as the sole resulting faceting of the surfaces of the boundaries, thereby losing the procedures followed to derive the solid, which in turn are the indispensable basis of all simulations and of all manufacturing processes.

Constructive solid geometry (CSG) is a technique used in solid modeling. Constructive solid geometry allows a modeler to create a complex surface or object by using Boolean operators to combine objects. Often CSG presents a model or surface that appears visually complex, but is actually little more than cleverly combined or decombined objects. In 3D computer graphics and CAD CSG is often used in procedural modeling. CSG can also be performed on polygonal meshes, and may or may not be procedural and/or parametric. This information is the basis of simulations and manufacturing.

8 Bibliography

8.1 Bridge design

A good source of bridge design and theory that has been used for this work is the academic course that is currently taught by one of the team member considering both theoretical and practical questions that must be raised and solved by the bridge designer. It is annexed to this deliverable although in French.

8.2 French directives

In the French national context, the realisation of bridges is subject to Ministerial directives 84/87 of 1984 and 94/55 /56 of 1994. These distinguish three main steps:

- EPOA (for Etudes préliminaires d'ouvrages d'art – Preliminary design of bridges);
- APOA (for avant-projet d'ouvrages d'art – Basic design of bridges).

These two steps trigger the call for tenders to contractors, and subsequently the detailed design phase.

8.2.1 EPOA

During EPOA phase, the consulting engineer, contracted by the Employer or the Owner, performs the following tasks:

- A detailed inventory of all data and requirements;
- Exploration of the possible technical solutions with corresponding budget evaluations;
- Proposal of one or two of those for the next phase of APOA.

Prior to launching such a phase, the Employer or the Owner is supposed to have defined its basic needs in terms of programming: the service expected from the bridge, its approximate location, its integration into its environment, its scheduling and budgeting constraints, the lifecycle expectations.

The project must be sufficiently defined so that it may trigger the public consultation campaign following which a Ministerial decree may be taken declaring the public utility of the bridge.

The exhaustive collection of data and requirements is critical to the success of this phase and it must cover all fields: administration, functionalities of the bridge, natural and environmental data (geology, hydrology, climate, biodiversity etc.), architecture and landscape, exploitation.

8.2.2 APOA

This phase differs from the preceding in that extensive simulations (particularly in terms of mechanical resistance) are carried out in order to size out precisely all main bridge components, when during the preceding phase only quick calculations were performed relying extensively on expert judgments and experience.

The resulting bill of quantities, estimates and scheduling are therefore much more accurate and reliable. The construction constraints are supposed to have been explored in detail.

8.3 Classification and Glossary

UNIFORMAT describes elemental classifications, and in particular the one referenced here above addresses bridge elements. Elemental classifications differ from the traditional "product-related" classifications because their core concept is an "element" that performs a given function, regardless of the design specification, construction method, or materials used. Thus, elemental classifications support a structured approach for developing budget estimates during the planning and conceptual design stages where quantity takeoffs and other product-related information are still under development.

UNIFORMAT describes elements that perform a given function, and associates quantities to them in order to develop budget estimates. As far as the design progresses, the initial elements are subdivided (from level i to level i+1) in order to detail more and more the budget estimates. This kind of approach can be obtained with IFC through the so-called Building Breakdown Structure based on a hierarchy of spatial elements containing physical elements nesting components and so on… Of course, an IFC model can do more. In particular it can contain the structural analysis model (belonging in fact to the functional view) with structural elements connected to the so-called architectural model (more or less similar to the organic view). It can contain tasks organized in schedule, each task being associated to architectural elements…

The UNIFORMAT approach exhibits elements that have been forgotten in the existing IFC-Bridge. Up to now, the focus has been put on the resulting bridge, and principally the structure designed by the engineers. What is related to foundations, to ground, to earthworks, to environmental surrounding aspects, to traffic safety and operation has been neglected. Nevertheless, UNIFORMAT points out that these topics are mandatory.

A glossary describes the elements of a bridge, and clarifies the definition with pictures. "*A picture is worth than a thousand words*". It a first step to elemental classification.

In addition, what is very useful in UNIFORMAT is that to each element are associated attributes, such as primary function, secondary function, tertiary function, description, includes, excludes, and unit of measure.

IFC is an entity relationship model which claims to be "machine-readable", and therefore useful to address semantics. In addition, the different levels developed through elemental classification are an appropriate way to address the level of development of the data model and a tool to ease the development of appropriate IDMs.

8.4 Bridge Model

The objective of BIM is to replace the information exchange between actors today based on documents (drawings, notes, requests…) by a digital bridge model. Today, understanding documents requires human brains; but bridge model will be machine-readable.

To achieve this ambition, IFC offers an entity relationship model to allow consistency control and semantics to allow machine-interpretability. In information exchange, there are two actors: the client who requires a proposal and the provider who delivers an answer. Today in the IFC-model only the answer is described. Neither the client requirement, nor the way that lead to the proposal are described. Consequently the implicit constraints are not stored in the model. Therefore the consistency control of the model looks risky. Regarding clash detection based on geometry conflict, a beam which does not sit on its supporting column is not identified as an error because there is no clash. To the contrary, a human being identifies this, when he sees the beam “flying” and not supported. A relationship between the beam and the column is necessary to define the link between the two elements. IFC allows this capability to day, but if it is not often used. More generally, **the requirement and the answer have to be stored in the model.** In addition the level of development or detail should be defined in the requirement. Today, in the same model too rich information could be found leading to large model with no interest, in parallel with too poor information.

Defining the level of development or detail is the purpose of the IDM. What are the questions? What kind of answers are expected?

Regarding buildings (IFC-Bridge being not yet a standard), the information is mainly focused on architectural and MEP geometries of the building. Nothing about the ground, the foundations, the surroundings, the structural analysis, the tasks and the schedules… Regarding bridges, we have shown that the architecture of the bridge is a small part of the whole information needed. Information about the location where the bridge will be located is paramount. Information about the construction method is paramount. Information about the traffic crossing the bridge is mandatory. Information about operation, safety, security are critical. Here again, IDM is a way to exhibit the tremendous need of this kind of information and therefore the need to include them in the IFC-bridge model.

8.5 Other documents

8.5.1 Maintenance and operation of bridges

The guide "Surveillance et entretien courant des ouvrages d’art routiers" (Surveillance and ordinary maintenance of structures for road traffic), published by the SETRA (National French Service for studies and maintenance of roads and motorways), is presenting all aspects concerning bridge design and construction from the perspective of exploitation and maintenance. It is therefore an interesting piece of work to envisage infrastructures in a lifecycle perspective.

Modélisation des INformations INteropérables pour les INfrastructures Durables

Projet National MINnD

DELIVERABLE / RAPPORT DE RECHERCHE

IFC-Bridge Development Methodology Application to other Infrastructure Domains

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Table of contents

1 Abstract

1.1 Abstract in English

The initial goal set for the sub-use case UC3.6 was to serve as a base guideline to those in charge of developing future IFC specifications for other infrastructure-specific objects than bridges, though leveraging the return of experience gathered over the past 18 months through the development of the IFC Bridge specifications led by the use case UC3 of the project MINnD.

To that end, it appeared of value to:

1. investigate worldwide current infrastructure-related IFC initiatives ;
2. summarize the experience gathered in UC3.2, UC3.3, UC3.4 & UC3.5;
3. stress the importance of addressing key concepts like IDM (not that developed), MVD (reasonably well implemented), procedural geometries (rarely considered), relationships (rarely implemented) and glossaries (many versions of which even exist for a specific domain);
4. remind people concerned of IFC concepts/classes existing today which new infrastructure-specific IFC classes could be (easily) derived from;
5. establish a list of infrastructure-specific objects (components) types grouped per common characteristics which could benefit for one particular new IFC concept/class;
6. propose a ranking of those infrastructure-specific objects which appear to be the most legitimate to be considered for future IFC concepts/classes given their economic interest to our industry.

1.2 Résumé en français

L'objectif alloué au sous-cas d'usage UC3-6 était d'établir un canevas que pourraient suivre les personnes en charge de développer de futures normes IFC pour des ouvrages appartenant au champ des infrastructures de génie civil en s'appuyant sur le retour d'expérience des 18 mois passés par les participants au cas d'usage IFC Bridge UC3.

Pour ce faire, il est apparu intéressant de :

1. recenser les diverses initiatives à l'échelle mondiale dans le domaine des infrastructures ;
2. compiler les expériences et enseignements des groupes UC3-2, 3-3, 3-4 & 3-5 ;
3. souligner l'importance de quelques concepts clefs comme l'IDM (Manuel de Livraison des Informations – encore assez peu développés), MVD (Définition des Vues de Modélisation – plutôt bien mis en pratiques), des géométries procédurales (rarement mises en œuvre dans les formats d'export) et des glossaires (dont il existe souvent de nombreuses versions pour un seul domaine) ;
4. rappeler l'existence de classes IFC existantes dont de nouvelles classes pourraient utilement dériver ;

5. proposer une liste de composants d'infrastructures ou d'infrastructures types groupés par grandes caractéristiques qui pourraient utilement faire l'objet de nouveaux développements IFC ;

6. hiérarchiser lesdits composants ou types selon leur intérêt économique et leurs difficultés à priori pour les utilisateurs finaux.

2 Current infrastructure-related IFC initiatives

An investigation made on a worldwide basis of efforts conducted recently in order to develop IFC concepts able to serve the multiple domains involved in the development of an infrastructure project shows interesting progress around:

- Specifying IFC mechanisms for alignment exchange:
    - IFC Alignments 1.0, led by BS Int'l;
    - IFC Alignments 1.1, led by BS Int'l;
- Specifying IFC mechanisms for roadways exchange, led by BS Korea;
- Specifying IFC mechanisms for railways exchange, led by BS China;
- Specifying IFC mechanisms for tunnels exchange, led by BS Japan & BS Germany;
- Specifying IFC mechanisms for bridges exchange, led by BS France, Germany & US;

That being said, the levels of maturity of the above mentioned initiatives vary a lot, and questions remain as to their convergence. If the MINnD UC3's deliverables clearly aim at enriching today's available IFC Bridge, it is believed that its development methodology could be applied to the development of other infrastructure domains IFC, not limited to the sole ones listed.

3 Return of Experience from MIN^{n}D UC3's sub-cases

The development of the specifications of the mechanisms to support the exchange of bridges information, being geometries and semantics, was split into 4 sub-cases (UC3.2 to UC3.5) each of which provide an interesting return of experience (RoE) potentially reusable for other domains IFC initiatives. It appears of value to summarize it.

3.1 State of the Art & Missing concepts (UC3.2)

The sub-use case UC3-2 deals mainly with two major aspects of engineering structures:

- Gaps of standardized IFC classes, both in their semantics and in their poor implementation or misunderstanding by software editors (extrusion, Boolean operations...).
- Deficiencies, that is to say the object classes used in the field of civil engineering structures, which have not been developed yet.

This analysis highlights several aspects:

- The need to first identify the needs of end users, which must be translated into technology solutions and finally by a development of classes (and not the opposite, which - it seems - was the development methodology used for existing IFC classes). This methodology gives constraints to be implemented in software packages, beyond aspects of certifications.
- The need to describe and preserve the procedural geometry in IFC exports, in order to change the geometry of an object after export-import into another application, different from the native software that created it. Descriptive geometry is insufficient: the embedded semantic geometry is paramount.

3.2 Bridge concept definition / Data dictionary (UC3.3)

In order to describe a given infrastructure, and that in all countries, it is essential to speak the same language and to agree on the vocabulary used by specialists. This is, above all, to agree on concepts hidden behind the words, but also to describe the links between these concepts.

Many dictionaries are available today, but no compilation was ever drafted, and above all, there are few documents describing the relationship between objects manipulated in the area of structures (e.g. a bridge deck is always in connection with the piers that support it).

The experimental AFNOR / XP PPBIM 07-150 standard describes a methodology to describe an object catalogue. In the UC3-3, it was used to describe the objects of structures. The set list has been entered in bSDD, the platform implemented by buildingSMART to describe construction objects.

3.3 Information Delivery Manual (UC3.4)

This sub-use case UC3-4 describes the needs of end users, as designers, builders or operators. These needs are different depending on the development phase of a project, and thus resulting in notions of LOD ("Level Of Detail" or "Level Of Development"). The work describes the exchanges between different actors at each development phase, taking into account the expected needs by some and others. It is a work of experts, which helped to describe the semantics of objects, that is to say, the list of attributes for each object with their persons in charge and users.

This is a lot of work we will have to finalize because it was directed mainly at the object level, whereas it should have been first focused on the operational and functional aspects, before focusing on manipulated objects (in agreement with the analysis of UC3-2)

3.4 Memory of Understanding (UC3.5)

The development work cannot be officially delivered without the prior consent of a representative group of international experts.

In addition, developments of missing IFC entities or improvements of the existing IFC classes' semantics can only be achieved through international procedures, under the aegis of buildingSMART International. Furthermore, these actions are expensive and can only be financed by organizations convinced of their reliability and their added value. It is therefore essential to include this work in a contractual framework with buildingSMART, which endorses the relevance of the initiative and the seriousness of the experts who developed the necessary deliverables for the expected developments.

A Memory Of Understanding (named "Project Proposal" by buildingSMART) must be developed and validated by the infraROOM steering committee, responsible for initiatives dealing with IFC objects for infrastructure.

4 Key IFC concepts to tackle

Whilst developing specifications of the mechanisms to support the exchange of a specific infrastructure domain's objects, one needs to tackle 3 main concepts:

- The definition of the needs, through IDM;
- The definition of the means, through MVD;
- The use of normalized naming and methods through glossaries and relationships.

In addition, the goal should be stressed to exchange machine-readable geometries through procedural geometries as the IFC concepts offer.

4.1 Needs definition through IDM

The search for needs definitions through IDM for IFC Bridge has proven a difficult exercise and very few construction related examples have been identified. Given the structuring aspect that the definition of needs obviously carries, it has been proposed to implement an approach used in the industrial world that helps specify systems and sub-systems through 3 points of view: operational objectives (the "what-for"), functional abilities (the "what to do") and organic composition (the "how to do")[1].

This approach was applied, as examples, on 4 types of objects, different in nature and importance: bridge, tunnel, water and sewer network and signalling equipment. These 4 use cases are presented in appendices 10.1 to 10.4, in French for the time being. These examples are not presented in an exhaustive manner but only in a few aspects that these examples highlighted.

[1] IDM can be seen as the operational view of the information system of an infrastructure (what information want the users to be IT embedded and when), the MVD being the functional view (what are the views that the information system should procure to the users in the language of the software developer), the software coding being the organic view.

4.2 Means definition through MVD

Means definitions through MVD for IFC Bridge exist in a variety of richness and concrete examples can been found. Equally important but less structuring than IDM, the definition of means obviously requires advanced knowledge of IFC internal mechanisms.

The recommendation at this level is not to go into too many details at this level unless the base step of IDM is properly documented and understood by IT specialists.

A few remarks and recommendations can be given already before proceeding with the works with BSI experts:

1. for instance, and even though IFC existing features might be good approximates for a new feature for reasons that their models may be similar, it is important to privilege the creation of new elements even in the form of aliases of existing elements in order to follow the skills and habits of the structure engineer: although a header acts as a beam, it is important to differentiate it from normal beams as it is a special piece of structure linking several columns to support the bridge deck and as it behaves in a certain manner and exhibits several other details which the man of the art will know to explicit further;
2. although bridge components may be viewed differently by different skills, it is important to use by default the description using the highest semantic-bearing approach that may be common to several view points and not the different descriptions sufficient in terms of results: for an architect a circular beam has a certain shape (that can be defined by facets), for a structural engineer the circular concrete column is a cylinder with a certain radius (of which derive the modulus of inertia), for a construction engineer the column is to be poured in concrete inside a cylindrical shutter, but for all of them concrete – radius – height and cylinder geometry are sufficient and common characteristics for all their respective works. For all these reasons, the MVD for each of them should refer to exactly the same generic model onto which each of the users may complement their needed descriptions by a few additional characteristics. The more often one can arrive at these common models, the more efficient the description will be in the exchanges that will happen in the collaborative design process and the interoperability almost natively met.

One should refer to the UC3-5 deliverables for more details.

4.3 Glossaries & relationships

In addition to IDM (for needs definition) and MVD (for technical means definition), glossaries are key to make sure that parties exchanging a project through an IFC approach share a common understanding of the project' elements definition and abilities. The issue resides in the fact that such glossaries exist in a variety of richness and granularity, and different versions may even exist for a specific domain or sub-domain.

To our knowledge, no compilation (dictionary of glossaries) was ever done; industry-specific normalization associations/national organisms are probably the most reliable starting point for investigating. Worthwhile noticing, the experimental AFNOR / XP PPBIM 07-150 standard describes a methodology to describe glossaries.

Likewise, the concept of relationships, supported today by the IFC toolbox in a building design/construction context, offers ways to enrich the objects exchanged through an IFC package by describing the functional connections and physical dependencies that exist between objects of different natures implemented/constructed in a real-world project, being building or infrastructure. Although barely used, such relationships add significant value (design-related / constructability-related / maintenance-related) to the geometrical and attributive definition of the objects concerned.

One should get an overall understanding of the major IFC concepts that deal with using glossaries and relationships by referring to the sub-use case UC3.2's deliverable "MINnD_UC3-2_SOTA&MissingConcepts_final" chapter 4.2, which in addition describes the concepts missing today in the current IFC toolbox in order to properly deal with such aspects for infrastructure projects.

4.4 Procedural geometries

In solid modelling and computer-aided design, boundary representation - often abbreviated as B-rep or BREP - is a method for representing shapes using the limiting surfaces of the solid. A solid is represented as a collection of connected surface elements, the boundary between solid and non-solid. BREP may be exported in IFC as the sole resulting faceting of the surfaces of the boundaries, thereby losing the procedures followed to derive the solid, although they are the indispensable basis of all simulations and of all manufacturing processes.

In opposition to the above concept, constructive solid geometry (CSG) allows a modeller to create a complex surface or object by using Boolean operators to combine objects. Often CSG presents a model or surface that appears visually complex, but is actually little more than cleverly combined or de-combined objects. In 3D computer graphics and CAD CSG is often used in procedural modelling. CSG can also be performed on polygonal meshes, and may or may not be procedural and/or parametric.

One should refer to the deliverable "' MINnD_UC3-4_IDM_Deliverable' for more details.

5 Existing IFC concepts

When evaluating the development of IFC for a specific infrastructure domain it is obviously important to understand which IFC mechanisms exist that could be used or derived from, in order to match the functions expected, as well as which methodological guides exist which can act as check-lists or safeguard.

Therefore the idea to summarize the major IFC classes according to the type of functions they aim at serving; e.g.: when looking at mechanisms that could support describing/exchanging the sequencing of operations: objects and tasks can be described through the ifcProduct classes and their link through the ifcTiming class.

Likewise, different guides have been developed by MediaConstruct, some of which providing interesting recommendations on additional matters not to be ignored.

5.1 Major IFC classes

One should get an overall understanding of the major IFC concepts and classes by referring to the sub-use case UC3.2's deliverable "MINnD_UC3-2_SOTA&MissingConcepts_final" chapter 4.2, which in addition describes the concepts missing today in the current IFC toolbox in order to properly deal with the requirements of infrastructure projects.

5.2 MediaConstruct's BIM

The guideline "Convention BIM" produced by MediaConstruct provides interesting recommendations on additional matters not to be ignored when contemplating developing a BIM implementation plan, like:

- Program planning;
- Site constrains;
- Analytical studies;
- Inconsistencies analysis;
- Construction methods.

Such critical matters apply to buildings design & construction projects as well as to infrastructures design & construction projects; even if addressed today through IFC classes and mechanisms dedicated to buildings, an investigation of these abilities is therefore worthwhile doing when considering extending the IFC Bridge classes and mechanisms given that the future necessary features can be derived from them.

6 Infrastructure domains objects types

Objects composing an infrastructure project are of different kinds but some common characteristics can be found that lead to the possibility to classify these in homogeneous groups, when put in the perspective of developing IFC mechanisms that could serve several objects of the same kind.

To that end, infrastructure-specific domain objects could be grouped as follows:

1. In relation to the existing environment in which the civil infrastructure must be integrated :

1a. Georeferencing grid;
1b. Topography and data acquisition;
1c. Geology and geotechnics;
1d. Cadastral mapping, soil usages, ownership; existing buildings and structures in the vicinity;
1e. Existing networks;
1f. Hydrographic system ;
1g. Biosphere and generally environment;

2. In relation to the description of the geometry of the project (covered by *IfcAlignment*):
2a. Alignment of the infrastructure and its connection to existing networks;
2b. Alignments of the networks and reinstated networks;

3. In relation to the main infrastructure itself:
3a. Permanent earthworks such as dykes, embankments, cut and fill, dams;
3b. Roads and carriage ways, subgrades, subbases, pavements, platforms, ballast, sidewalk, shoulder

(covered by *IfcRoads*);
3c. Rails and guided transport systems and structures (covered by *IfcRail*)
3d. Cut and cover, tunnels;
3e. Sewers;
3f. Dry (buried cables, …) and wet networks (pipes, …), culverts, storm sewers;
3g. Foundations;

4. In relation to <u>ancillary infrastructures</u> or necessary utilities, incidental construction:
4a. Longitudinal drainage, ditches;
4b. Special structures connecting ground and abutments;
4c. Special structures enabling the transition between infrastructures such as ramps,
4d. (Soil) Retaining structures;
4e. Noise protection devices and walls;
4f. Passive safety system and equipment (railing, …);

5. In relation to safety, traffic and energy related <u>utilities</u>:
5a. Information and signing, marking;
5b. ITS (traffic control, traffic management, tolling, …);
5c. Energy supply and lighting;
5d. Ventilating;
5e. Structural Health Monitoring system;

6. In relation to <u>reinstatements</u> (disturbed networks to be reinstated):
6a. Hydrographic network reinstatement;
6b. Networks reinstatement structures (bridges, …);
6c. Biosphere reinstatement structures (bridges, animal-ducts…).

7 Future infrastructure-specific IFC priorization

It appeared important too to try ranking the future domain specific IFC initiatives that can be envisioned through 2 main criteria: economic interest x easiness of development. Each criterion is evaluated from 0 to 5. The figure 5 is for the most interesting or for the easiest development: in so doing a natural hierarchy comes from the sum of both figures (called method 1[2] here below) and the orthogonal projection of the points along the first bisector gives the ranking.

Such a ranking exercise was conducted by 4 individuals not knowing each other's opinion, on the basis of the grouping matrix presented above, leading a consolidated ranking presented in appendix 10.5, summarized below, with its deviation ratios, which could be used as a recommendation for future infrastructure-specific IFC classes/objects development:

[2] One can use also the mathematical operation product: hence the method n°2 which has for effect to rank lower the points the more distant from the first bisector than when using method n°1.

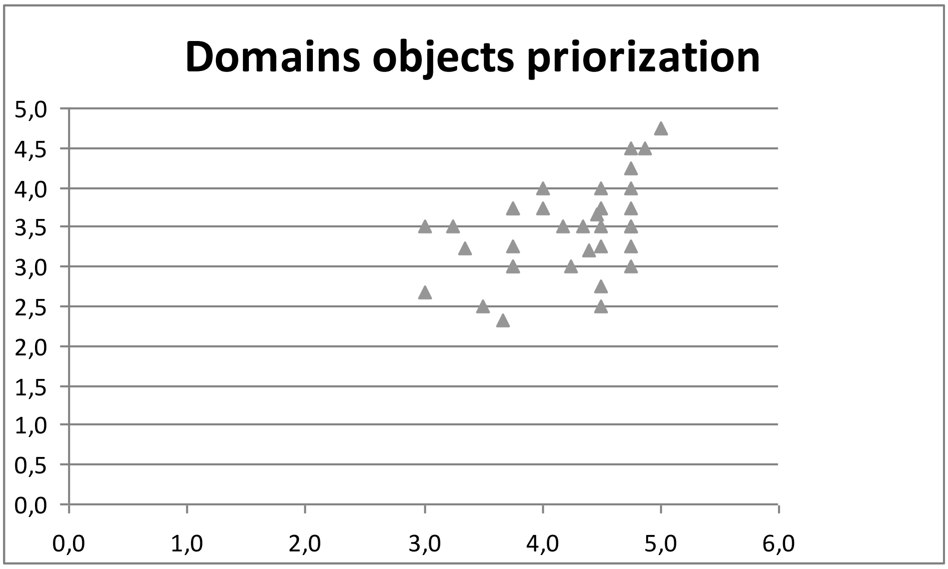
	Interest (1 to 5)	Easiness (1 to 5)	Variance Interest	Variance Easiness	Rate Method 1	Rank Method 1	Rate Method 2	Rank Method 2
1	4,3	3,5						
1a	**5,0**	**4,8**	0,00	0,25	9,8	1	23,8	1
1b	**4,8**	**4,5**	0,25	0,33	9,3	2	21,4	2
1c	**4,5**	**2,8**	0,33	0,92	7,3	10	12,4	17
1d	**4,0**	**3,8**	1,33	0,25	7,8	8	15,0	12
1e	**4,8**	**3,5**	0,25	1,00	8,3	6	16,6	8
1f	**3,8**	**3,0**	0,92	0,67	6,8	12	11,3	20
1g	**3,7**	**2,3**	0,33	2,33	6,0	14	8,6	23
2	4,9	4,5						
2a	**5,0**	**4,8**	0,00	0,25	9,8	1	23,8	1
2b	**4,8**	**4,3**	0,25	0,92	9,0	3	20,2	3
3	4,4	3,2						
3a	**4,8**	**3,3**	0,25	0,92	8,0	7	15,4	11
3b	**4,8**	**4,0**	0,25	1,33	8,8	4	19,0	4
3c	**4,8**	**3,0**	0,25	1,33	7,8	8	14,3	14
3d	**4,5**	**2,5**	1,00	0,33	7,0	11	11,3	20
3e	**3,8**	**3,0**	0,92	0,67	6,8	12	11,3	20
3f	**3,8**	**3,3**	0,25	0,92	7,0	11	12,2	18
3g	**4,5**	**3,5**	0,33	0,33	8,0	7	15,8	10
4	4,5	3,7						
4a	**4,5**	**3,8**	1,00	0,25	8,3	6	16,9	7
4b	**4,8**	**3,8**	0,25	0,92	8,5	5	17,8	6
4c	**4,8**	**3,5**	0,25	0,33	8,3	6	16,6	8
4d	**4,5**	**3,3**	0,33	0,25	7,8	8	14,6	13
4e	**3,8**	**3,8**	0,92	0,25	7,5	9	14,1	15
4f	**4,5**	**4,0**	0,33	0,67	8,5	5	18,0	5
5	3,4	3,2						
5a	**4,0**	**4,0**	0,00	0,00	8,0	7	16,0	9
5b	**3,5**	**2,5**	1,00	0,33	6,0	14	8,8	22
5c	**3,3**	**3,5**	1,58	0,33	6,8	12	11,4	19
5d	**3,0**	**3,5**	0,67	0,33	6,5	13	10,5	21
5e	**3,0**	**2,7**	1,00	0,33	5,7	15	8,0	24
6	4,2	3,5						
6a	**4,3**	**3,0**	0,92	0,67	7,3	10	12,8	16
6b	**4,5**	**3,8**	1,00	0,92	8,3	6	16,9	7
6c	**3,8**	**3,8**	0,92	0,92	7,5	9	14,1	15

The figures highlighted in rose mark domains where the experts were in stronger disagreements as to the characteristics of the domain.

1g (2.33 for easiness variance) refers to Biosphere environment and the disagreement might come from the fact that the biosphere field is not very well known from all experts of the panel.

5c (1.58 for interest variance) refers to Energy and lighting and is believed to be linked to the particular experience of each of them in civil works depending upon their own exposure to designing and constructing civil structures with important electromechanical components and systems (a road tunnel with heavy ventilation and signalling as opposed to simple bridges for example).

The variance values being in general low, it is believed that the main directions of hierarchical organisation are already a good signal and that the method used is sound: it is just a question to expand the panel for reaching a robust decision.



8 buildingSMART formal process

An important aspect not to be underestimated whilst completing the development of IFC for a specific infrastructure domain is the consideration of the formal buildingSMART (bS) process for eligible initiatives.

Every candidate project must be approved by BS steering committee in charge of the considered domain (e.g., the “infraROOM” for the IFC-Bridge project).

The project proposal must at least match the following criteria:

- An international representation (not a single project leader's country)

- A project execution plan explaining the context and other related initiatives

- The objectives and if considered use case

- The expected deliverables

- The project governance

- The work plan with details of its sub work packages (tasks, deliverables, milestones…)

- The work effort and the cost breakdown

- The work breakdown

- The appropriate funding

For more information concerning a new bSi project, one shall follow the guidelines available at www.buildingsmart.org/standards/standards-process/#charters

9 References

[1] https://en.wikipedia.org/wiki/Industry_Foundation_Classes

[2] https://en.wikipedia.org/wiki/Bridge

[3] https://en.wikipedia.org/wiki/Tunnel

[4] https://en.wikipedia.org/wiki/Earthworks_(engineering)

[5] IFC 2x Edition 2, Model Implementation Guide, Th. Liebich, version 2.0, May 18, 2009

[6] http://nff.no/wp-content/uploads/2014/05/16223-Bok-Fjellsprengningsdagen-2012_del6.pdf, Nordenga Bridge – Challenging foundation across the railway lines at Oslo Central Railway Station

10 Annexes

[1] Cas d'étude IDM rétablissement de réseau d'adduction d'eau / Case study for the reinstatement of a water network

[2] Cas d'étude IDM ouvrage de franchissement / Case study for the major bridge crossing

[3] Cas d'étude IDM tunnel / Case study for a tunnel

[4] Cas d'étude IDM portique de signalisation / Case study for a signalling gantry

[5] Priorisation de futurs IFC par types d'ouvrages/sous-ouvrages / Hierarchical organization of future IFC by domain types

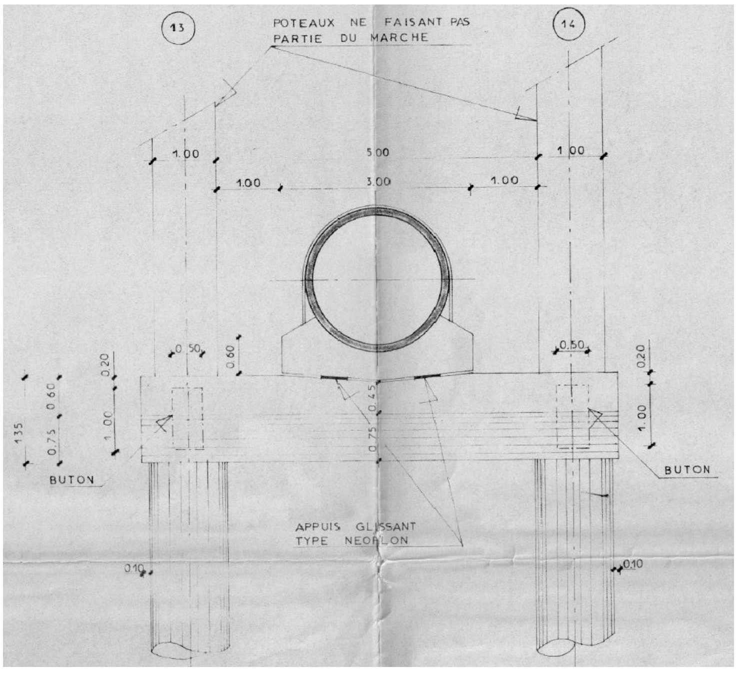
MINnD – UC3.6

Description d'un rétablissement de réseau selon
les visions opérationnelle, fonctionnelle & organique.

10.1 Cas d'étude : maintien d'une adduction d'eau potable au-dessus d'une autoroute urbaine

10.1.1 Contexte

Dans le cadre du projet d'autoroute urbaine à 2x3 voies + BAU contournant Marseille, le projet initial prévoit une tranchée ouverte (profondeur 10m environ) à un endroit où traverse le réseau d'adduction eau potable Marseille (1 des 3 réseaux adduction eau potable opérés par la SEM [Syndicat des Eaux de Marseille] depuis 40 ans). La canalisation en acier est, à cet endroit, de diamètre 2.0m, et repose sur des piles tubées à une dizaine de mètres d'altitude. Au centre de la tranchée, la canalisation repose sur un chevêtre et 2 piles de diamètre 1.20m (sens perpendiculaire à la conduite eau). Il n'y a pas de massif de fondation et les piles tubées ne peuvent pas être modifiées. Le terre-plein central (TPC) est étroit (1.5m) et ne permet pas d'implanter les GBA supplémentaires nécessaires. Ce sont là des structures de support de la canalisation qui ont été réalisées par la SEM en prévision du futur passage de l'autoroute urbaine.



L'incohérence a été identifiée après intégration dans la maquette.

Une fiche de non-conformité (explication + résolution) a alors été émise.

- ➔ Demande d'élargissement TPC à 2.50m dans la zone des piles non déplaçables
- ➔ Axe référence du projet non modifié
- ➔ Déplacement chaussée extérieure

➔ Incidence sur mur extérieur : Béton projeté fibré remplacé par mur cloué (modélisation 3d des positions des clous pour éviter interférences avec fondations ext)

➔ Incidence sur Pied droit de la Tranchée Couverte « Olivier » (recalage sur 15m environ)

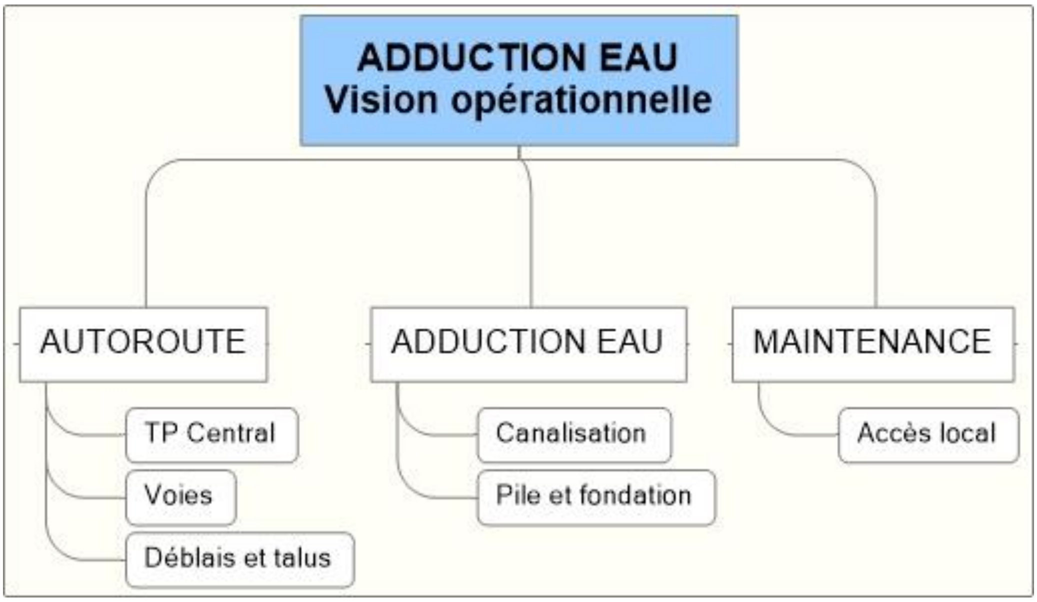
10.1.2 Vision opérationnelle

10.1.2.1 Parties prenantes

Sont importantes pour la bonne solution de cette problématique les parties prenantes suivantes :

- La SEM qui opère les adductions d’eau potable pour Marseille,
- Le MO ou le concessionnaire qui devra assurer l’accessibilité à l’ouvrage de la SEM,
- Les réglementations applicables,
- Le constructeur qui devra travailler sans interférer avec l’opération de la conduite.

10.1.2.2 Architecture



En ce cas, l'architecture opérationnelle se réduit en l'ouvrage lui-même et l'adduction d'eau ainsi que dans le système de maintenance :

1. Adduction d'eau potable de Marseille.
2. Autoroute urbaine sous l'adduction d'eau
3. Maintenance

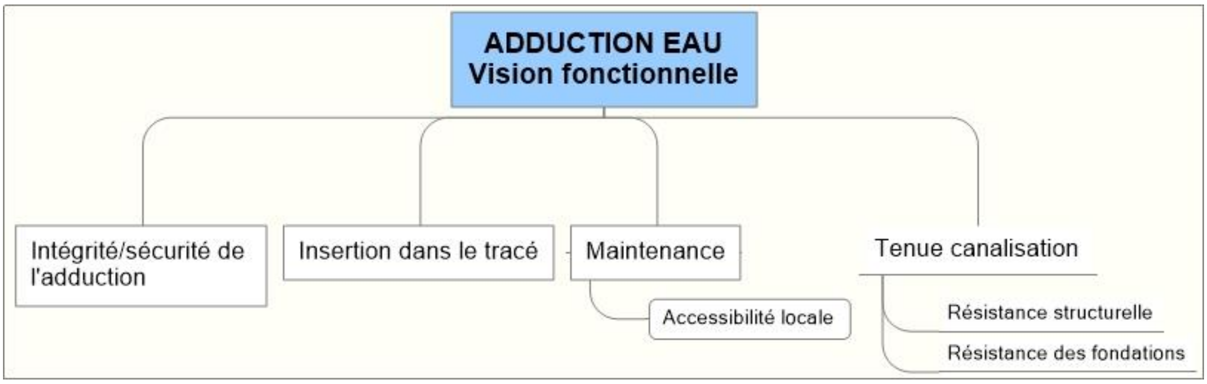
10.1.2.3 Besoins :

- La SEM demande que les appuis sur le sol de la canalisation[3], une fois la tranchée ouverte excavée, soient distants d'une portée inférieure à une certaine distance et que l'appui intermédiaire soit maintenu intact,
- La SEM ne peut tolérer aucune interruption du service d'eau potable assurée par cette canalisation,
- La SEM doit avoir accès en toutes circonstances à la canalisation aérienne pour inspection et réparation éventuelle ou entretien routinier.
- Nouvelles normes « autoroute urbaine » : 2x3 voies + BAU (ceci est un besoin hérité du projet général).

10.1.3 Vision fonctionnelle

10.1.3.1 Architecture

[3] Il est supposé que cette condition est suffisante pour assurer la tenue mécanique de la canalisation préalablement vérifiée par la SEM.



Il y a tout d'abord une fonction de résistance (au sens résistance des matériaux) pour assurer la tenue de la canalisation. Pourtant, celle-ci n'appartient pas à proprement parler à l'ouvrage à construire et elle est supposée ici avoir été résolue par la SEM antérieurement (d'où une symbolique différente utilisée). La SEM en a simplement conclu un besoin opérationnel exprimé ci-avant. Selon les schémas des responsabilités contractuelles, il pourrait être décidé que cet ouvrage fasse partie des travaux de conception et de construction. Dans un tel cas, il y aurait lieu d'inclure une telle fonction.

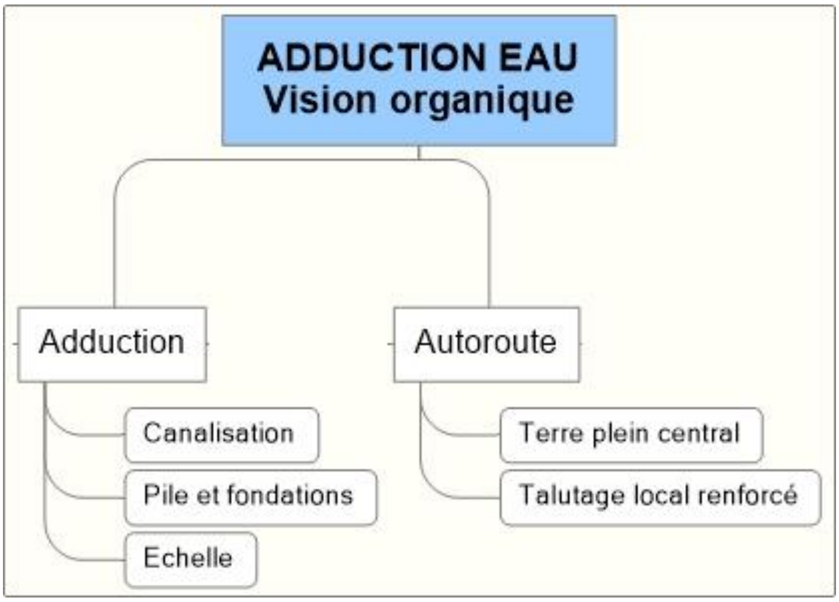
Et il y a la fonction générale liée au tracé des voies et des profils en travers qui se trouve héritée de l'ouvrage général, et celle de maintenance.

1. Sécurité de l'ouvrage existant (piles existantes + fondations latérales)
2. Insertion dans le tracé global de la rocade L2
   a. reprofilage nécessaire de l'axe des chaussées
   b. Elargissement du tracé actuel pour autoroute urbaine
3. Maintenance

10.1.3.2 Exigences :

- Aucune intervention sur piles de l'adduction d'eau
- Aucune modification de l'axe de référence du tracé global de la L2
- Permettre un accès sur la canalisation pour maintenance au personnel de la SEM

10.1.4 Vision organique



C'est à ce niveau que peut se détecter le conflit géométrique entre les structures, et que peuvent être trouvées les solutions du COMMENT ?

- Relevé précis de l'ouvrage existant
- Mise en place de Glissières en Béton armé (GBA) de protection (élargissement Terre-Plein Central à 2.50m)
- Déplacement de la chaussée extérieure
- Remplacement des murs en béton projeté (selon profil taluté) par murs cloués (attention interférences clous avec fondations latérales) permettant un profil plus vertical
- Incidence reprofilage sur la Tranchée Couverte (TC) des Oliviers (élargissement en sortie TC).

MINnD – UC3.6

Description d'ouvrage de franchissement selon
les visions opérationnelle, fonctionnelle & organique.

10.2 Cas d'étude : le Pont de la Confédération ou de l'Ile du Prince Edwards

Nota bene : même si les photos sont bien réelles les indications apportées ci-après n'ont pas l'objectif de donner une image fidèle du projet en question mais simplement d'illustrer un processus d'ingénierie partiel mais vraisemblable et en aucun cas de reproduire ce qui s'est réellement passé.

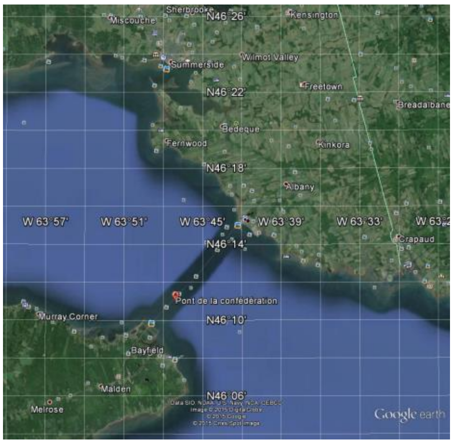
10.2.1 Contexte :

Pont de 13 km environ destiné à procurer un lien fixe entre le continent nord-américain (rive sud de l'embouchure du Saint-Laurent) et l'Ile du Prince Edward. La contrainte essentielle de ce projet était celle des contraintes climatiques puisque le détroit à traverser est bloqué par la banquise pour une longue durée annuelle de l'ordre de 3 à 4 mois.

10.2.2 Vision opérationnelle

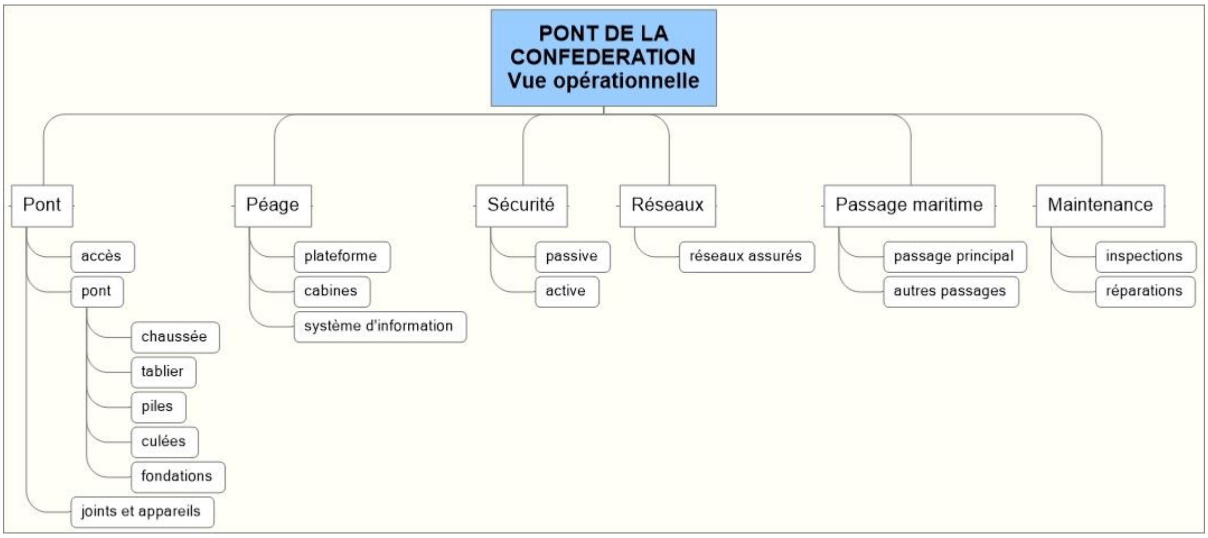
10.2.2.1 Parties prenantes (liste incomplète) :

client/exploitant ; mainteneur ; conditions climatiques ; règlements ; navigation maritime ; constructeur



10.2.2.2 Architecture

On décrit ici la structure de l'ouvrage vue par les yeux d'un exploitant ou d'un maître d'ouvrage qui demande un lien fixe entre le continent et l'ile sans préjuger de la solution technique.



Même si le langage peut paraître très « organique » il reste du langage commun et fait référence aux préoccupations de l'exploitant.

Celui-ci sait bien qu'il aura à faire à un pont, lequel aura des accès, un pont proprement dit et des appareils de jonction mis en avant dans son esprit car ils seront forcément des nids à problèmes.

Comme c'est un ouvrage en concession il lui faudra un péage, des organes de sécurité, des réseaux à assurer (ou réinstaller), un œil opérationnel également tourné vers le trafic maritime (ou la pêche) et un échelon de maintenance pour maintenir l'ouvrage en condition.

C'est là une description qui ne préjuge pas des solutions définitives qui seront adoptées mais l'exploitant sait qu'il aura au moins besoin d'une telle structuration pour pouvoir opérer.

La description est ici montrée à un niveau de plus en matière de « désintégration » de cette vision et il est fort possible qu'il ne soit, de ce point de vue là, pas très nécessaire pour la compréhension de devoir descendre bien plus dans ce même sens. Pour le besoin de cet exemple ce n'est en tous les cas pas nécessaire.

10.2.2.3 Besoins associés (exigences au sens ISO)

Sémantique : Le <système externe> doit être capable ou non de <faire qqch> grâce au <système> ou <composant> avec un certain <niveau de performance> dans un <certain contexte>.

A cette description opérationnelle doit être attachée un certain nombre de besoins exprimés selon la sémantique ci-avant. Celle-ci est à dériver en considérant tour à tour tous les systèmes externes impactés ou tous leurs représentants, d'où l'importance du caractère exhaustif à dresser des parties prenantes (cf. supra).

Ainsi :

1. Le réseau viaire de l'Ile doit être capable, grâce au pont, de faire passer 10 000 véhicules/jour 360 jours/an sur 24h, pour les deux sens confondus.

2. Le trafic maritime doit pouvoir passer par le détroit, en un endroit du détroit, tous les jours libres de banquise avec des bateaux (trafic non significatif) de tirants d'air de

60m et un encombrement latéral de 50 m libre de pile mesuré perpendiculairement aux courants de marée dans le détroit.

- En cas de détresse un bateau de 10 000 t dérivant à 5 nœuds ne doit pas pouvoir endommager une pile de rive du passage principal

3. La banquise ne devra pas pouvoir endommager l'ouvrage sauf pour des éventuelles usures à réparer selon un cycle d'au moins 20 années.
4. Les méthodes constructives devront être adaptées aux conditions climatiques et en particulier s'adapter à ne pas pouvoir intervenir pendant tous les mois de banquise.
5. La maintenance ne doit pas avoir à intervenir pour des réparations majeures sur l'ouvrage pour une durée de vie de 100 ans.

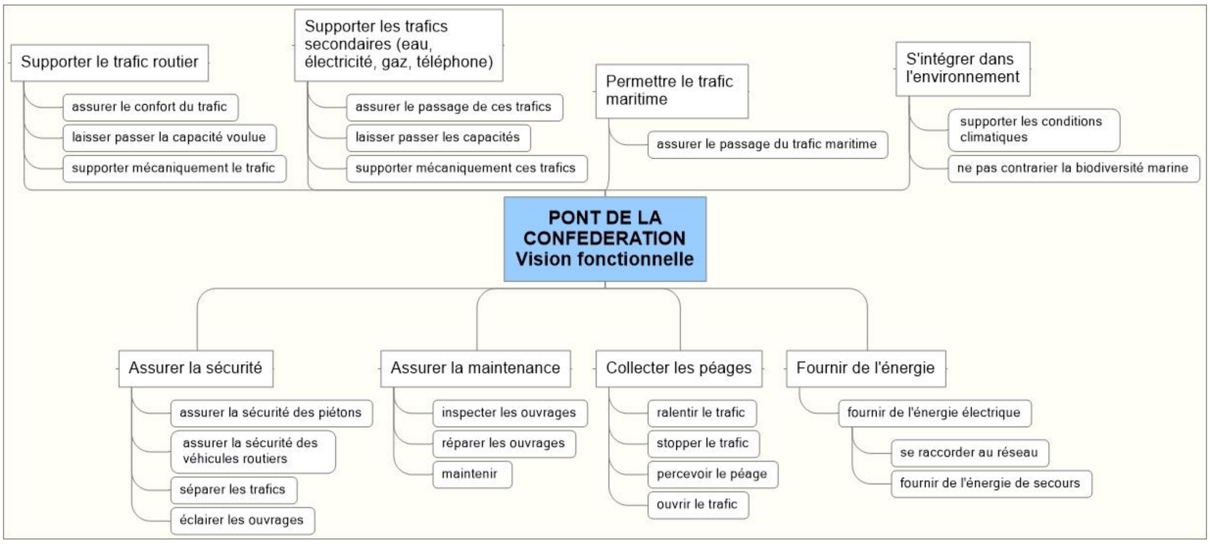
Ce sont là 5 des besoins détectés dès le niveau opérationnel lors de la phase consistant à bien poser le problème. Ces besoins, formulés selon la syntaxe indiquée, ne préjugent pas des solutions, ils résultent tous d'un « système externe » (le réseau viaire représenté par les autorités de l'Ile ; le trafic maritime par le service de navigation ; la banquise par les règlements environnementaux et par l'hydrographie maritime du lieu ; les méthodes constructives qui seront plus tard incarnées par le constructeur mais qui sont à exprimer dès le niveau opérationnel consistant à poser le problème (à tous les niveaux de « désintégration » et selon une vision de l'ouvrage à tous ses instants du cycle de vie : en exploitation mais aussi en construction). Ils sont attachés soit au pont dans son ensemble soit à un composant :

1. S'applique au pont dans son ensemble, au pont bien sûr, au péage, à la maintenance
2. S'applique au passage principal du passage maritime
3. S'applique au pont et particulièrement aux piles qui sont les seules parties de la vision opérationnelle impactées par la banquise
4. S'applique au pont dans son ensemble (et en fait à tous ses composants). C'est là un besoin de nature universelle.
5. Idem 4.

10.2.3 Vision fonctionnelle

10.2.3.1 Architecture

En comparaison de la vision précédente, le point de vue est celui de l'ouvrage lui-même que le concepteur « voit » ou organise en fonctions abstraites qu'il sait que le pont devra assurer pour répondre aux besoins détectés lors de l'élaboration de la vision opérationnelle. A nouveau, celles-ci sont déstructurées en autant de niveaux hiérarchiques que de besoin.



La fonction première et évidente pour un pont est celle de permettre le passage du trafic. Ici, celle-ci a été décomposée en une fonction de tracé ou de confort (le trafic routier ne peut se faire selon des rayons trop serrés ou un dévers trop fort etc.), une autre de capacité et une dernière de support mécanique. On peut remarquer que l'on aurait pu aussi exprimer la fonction de support mécanique au niveau de l'intégration dans l'environnement. Ces choix relèvent du savoir-faire de tel ou tel ingénieur (société ou individu). Avec cette triple fonction, on peut raisonnablement espérer satisfaire au besoin 1 de la vision opérationnelle ci-avant.

Le pont doit assurer aussi d'autres trafics par lui-même, c'est la seconde fonction montrée, et doit aussi laisser le passage au trafic maritime (c'était le besoin 2 ci-avant). Il s'agit toujours des mêmes notions de trafic. Cependant les modèles et paramètres de tracé et de capacités sont différents dans le cas du trafic routier et de ceux des réseaux supportés. Pour ces deux réseaux, il est bien sûr évident que la vérification mécanique se fera – entre éléments de supportages – dans les réseaux, mais qu'elle ne se fera qu'au niveau du pont pour tous les poids propres et sollicitations et surcharges. Pour ce qui est du trafic maritime il s'agit de vérifier le passage d'un certain gabarit[4] dans une certaine direction pour le passage principal.

Les autres fonctions sont également décomposées comme indiqué. La fonction de l'énergie n'était pas apparue au niveau opérationnel mais la nécessité d'opérer en permanence sauf 5 jours par an impose bien d'avoir une fonction de fourniture autonome d'énergie. Si la solution pouvait en rester à une connexion réseau, il aurait sans doute pu être possible de se passer de la création d'une nouvelle fonction. A nouveau, ce sont là des choix de savoir-faire propre aux intervenants.

Il est à remarquer que la description complète de la fonction de support mécanique suppose de la modéliser en des « barreaux structuraux » qui sont des éléments abstraits permettant de résister à une certaine sollicitation (compression-traction/moment fléchissant/moment de

[4] Il est supposé que le croisement est interdit lors de ces passages.

torsion). L'ensemble de ces barreaux modélise le pont dans sa fonction mécanique. Cette décomposition n'est pas faite ici.

10.2.3.2 Exigences associées

Sémantique : le <composant ou système> doit <faire qqch> avec un <niveau de performance> dans un <contexte donné>.

Ainsi et pour continuer dans les besoins précédemment identifiés pour les transformer en exigences fonctionnelles :

1. Le pont doit faire passer 10 000 véhicules/jour 360 jours/an sur 24h pour les deux sens confondus.
    - Le pont doit faire passer 5 000 véhicules/jour … par sens
    - Le pont doit suivre un profil adapté pour un trafic routier VL et PL tous temps avec pentes et dévers adaptés
    - Le pont doit supporter mécaniquement les surcharges de trafic, les autres sollicitations et les poids propres :
        - La chaussée doit supporter mécaniquement la surcharge routière
        - La structure d'ensemble doit supporter les surcharges routières et tous les poids propres
2. La travée centrale du pont doit laisser passer tous les jours libres de banquise des bateaux de tirants d'air de 40m et d'un encombrement latéral de 50 m libre de pile mesuré perpendiculairement aux courants de marée dans le détroit.
    - Les piles de rive de la travée centrale ne doivent pas pouvoir être endommagées sérieusement par le choc d'un navire de 10 000 t dérivant à 5 nœuds
    - La structure d'ensemble doit supporter le choc du navire…
3. Aucune des piles en mer ne devra être endommagée par la banquise en déplacements cycliques dans le détroit du fait des courants de marée sauf pour des éventuelles usures à réparer selon un cycle d'au moins 20 années[5].
    - Les piles devront pouvoir cisailler la banquise pour que celle-ci circule librement
    - Les piles ne devront pas subir d'usure préjudiciable pièces d'usure d'au moins 20 années avant remplacement) lors du passage de la banquise
    - La structure d'ensemble devra pouvoir supporter les efforts simultanés horizontaux transmis par la banquise
4. *L'exigence 4 opérationnelle portant sur la construction ne peut être résolue sans considérer la vision organique. En fait elle sautera directement de la vision opérationnelle à la vision organique. Aucune intermédiation théorique n'est réellement nécessaire.*

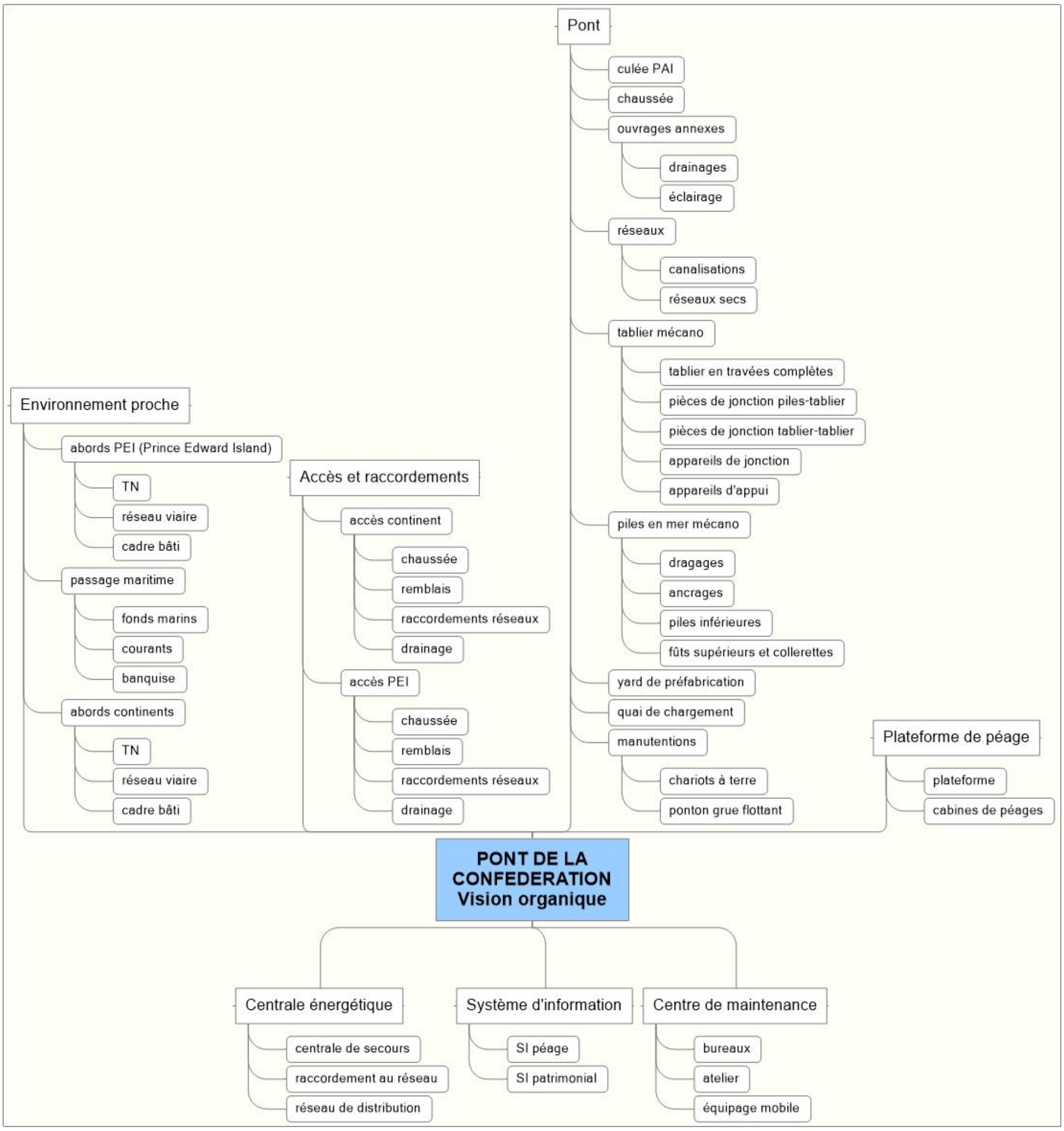
5. Le tablier du pont doit assurer l'étanchéité à l'eau (stagnante donc sur toutes les surfaces subhorizontales) en toutes circonstances pour 50 ans[6].

[5] Il ne s'agit pas d'une opération majeure contredisant la durée de vie de 100 ans mais de considérer la pièce comme une pièce d'usure.
[6] Idem note précédente.

10.2.4 Vision organique

10.2.4.1 Architecture

En complément de la vision précédente, le point de vue est celui des composants dont l'ouvrage lui-même est constitué et que le concepteur organise en solutions concrètes qu'il sait pour répondre aux fonctions identifiées lors de l'élaboration de la vision fonctionnelle (voire directement aux besoins opérationnels. A nouveau, celles-ci sont déstructurées en autant de niveaux hiérarchiques que de besoin, que l'on choisit naturellement selon une logique d'intégration constructive (ou de désintégration si l'on choisit le sens inverse).



La décomposition en paliers d'intégrations est assez intuitive pour un constructeur. Celle-ci est plus fouillée que les précédentes mais elle est très loin de la décomposition réelle. Cependant, elle oblige déjà – dès lors que l'on doit toujours considérer le pont dans tous ses états successifs et donc aussi durant la construction – à incorporer des structures temporaires ou des équipements majeurs de la construction ou d'autres éléments de décomposition tenant compte des choix constructifs.

10.2.4.2 Exigences associées

Sémantique : le <composant du système> doit <être constitué de qqch> qui satisfait à un <niveau de performance visé> dans un <contexte donné>.

1. [trafic]

   - Le pont doit présenter une chaussée de 8 m (4m par sens de circulation) satisfaisant à 5 000 véhicules par jour et par sens
   - La chaussée doit suivre le profil adapté
   - Le tablier du pont doit être constitué d'un caisson en béton précontraint de hauteur d'âme sur support[7] 10m qui résiste mécaniquement aux surcharges de trafic, aux autres sollicitations et aux poids propres

   - Les travées ne doivent pas dépasser 250m.
   - La chaussée doit être constituée d'un bicouche en béton bitumineux à très haut module et d'épaisseur 10 cm résistant à la surcharge routière

2. [passage maritime]

   - Les piles de rive de la travée centrale sont entourées d'un caisson poids de 5 000 t indépendant de la pile qui peut dévier un navire de 10 000 t dérivant à 5 nœuds et résister au choc résiduel
   - Les piles de rive sont espacées de 250m et d'une hauteur de 40m.

[7] Le voussoir sur pile est en fait une structure mixte béton précontraint et acier de façon à reprendre les efforts tranchants induits par une telle portée.

3. [déplacement banquise]

    - Les piles sont munies d'une collerette conique au niveau moyen de la mer capable de soulever la banquise en déplacement à tout moment de la marée et de la rompre sous l'effet du poids propre de ladite banquise

    - Les collerettes des piles sont revêtues de tôles d'acier Corten d'épaisseur 30mm capable de résister à l'usure de 20 années de déplacement de la banquise et d'être renouvelées alors

4. [conditions climatiques limitant la construction]

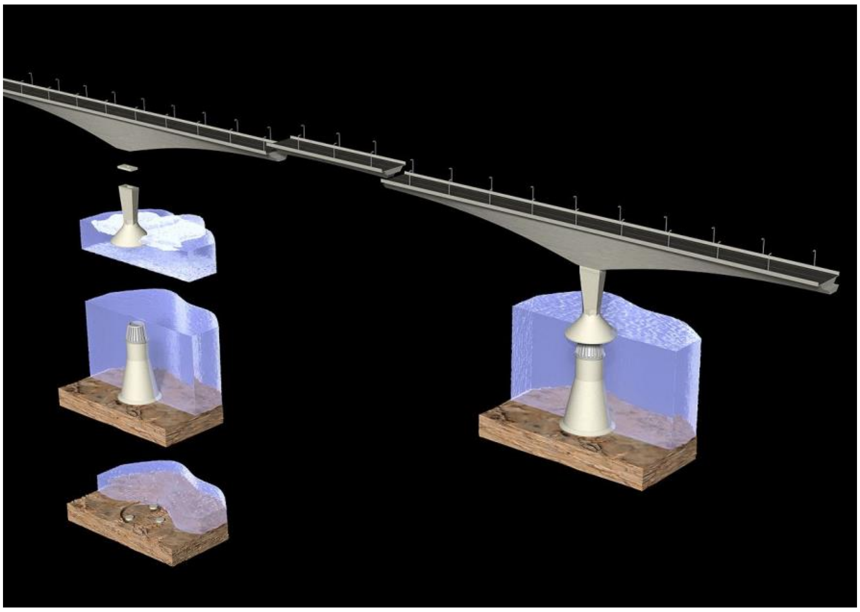
    - Les installations à terre seront capables de produire tous temps des pièces et voussoirs préfabriqués en béton 365j/an

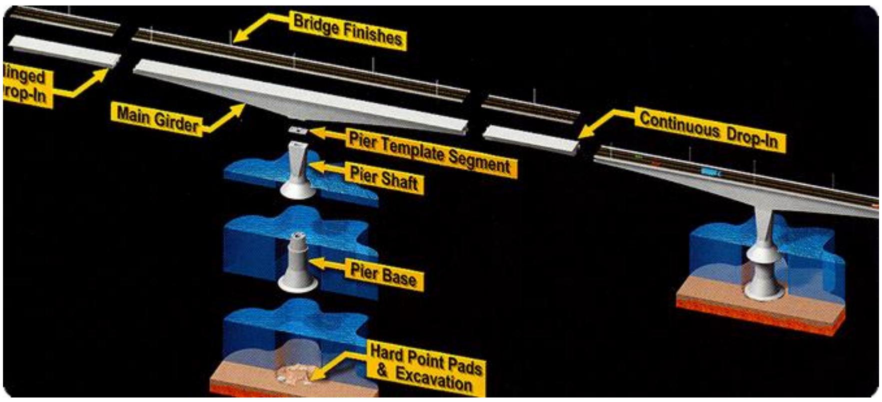
    - Le pont sera construit en préfabriquant au maximum toutes les structures en mer.

- Les piles seront décomposées en ancrages, piles basses de hauteur variable, collerettes et fûts de hauteur variable, pièces de jonction


- Le tablier sera constitué de fléaux de 240m à inertie variable

- Les fléaux de tablier une fois posés seront clavés entre eux par des travées uniformes de clavage de 10m de long





- Tous les éléments seront préfabriqués à terre 365j/an

- Les installations à terre seront munies d'un quai de chargement permettant l'emport des pièces préfabriquées
- Tous les éléments préfabriqués à terre seront acheminés par chariots au quai
- Tous les éléments préfabriqués seront pris à quai, transportés en mer et mis en place par un ponton-grue de 10 000 t le tout ne pouvant opérer que 8 mois par an.

- Les piles sont assemblées puis mises en tension par des câbles de précontrainte spéciaux. 

5. [étanchéité]

   - La face supérieure du tablier du pont sera constituée d’une membrane d’étanchéité avant application de la chaussée.

MINnD – UC3.6

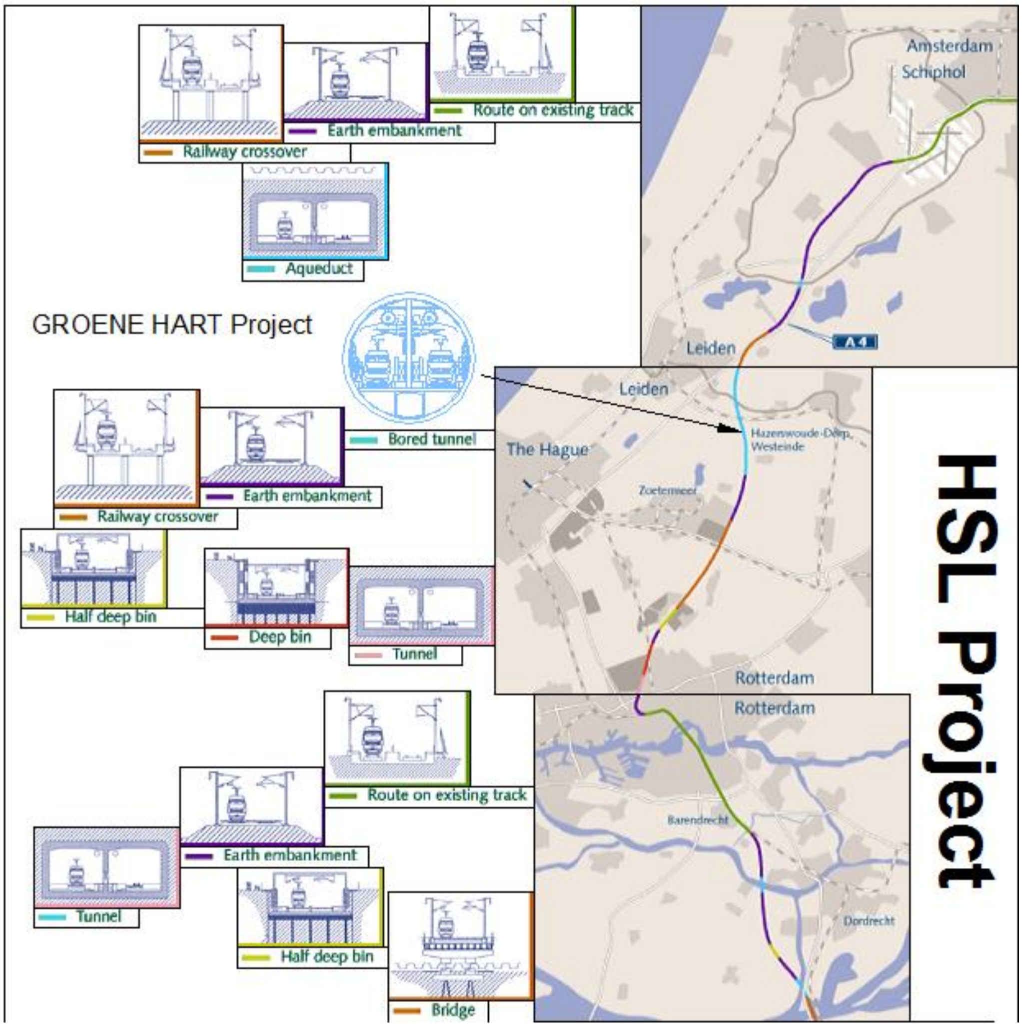
Description d'un tunnel ferroviaire selon
les visions opérationnelle, fonctionnelle & organique.

10.3 Cas d'étude : le tunnel ferroviaire du Groene Hart (NL)

Avertissement au lecteur : l'objectif n'est pas de donner une image fidèle du projet mais d'illustrer un processus d'ingénierie à partir d'un exemple concret plus parlant qu'une présentation académique.

10.3.1 Contexte :

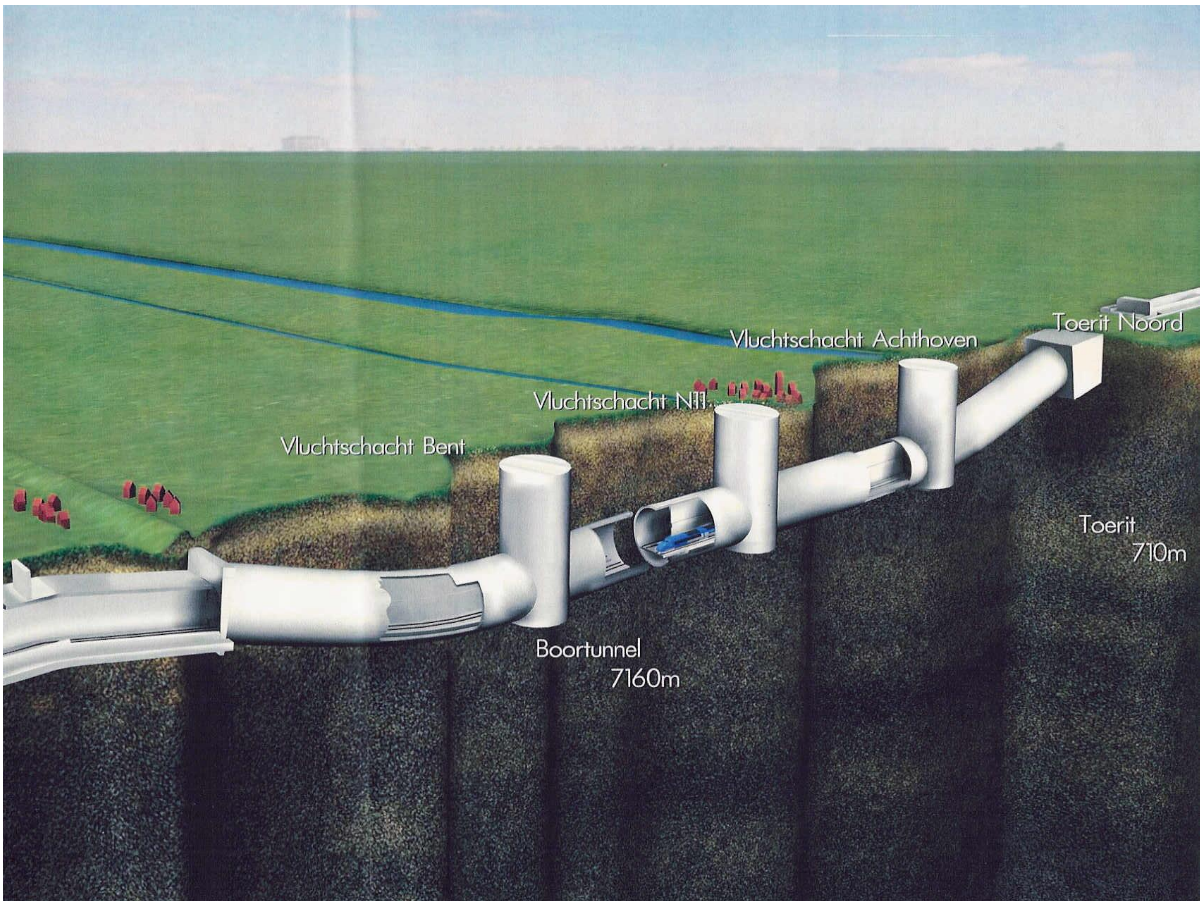
L'ouvrage est un tunnel ferroviaire situé aux Pays-Bas sur la ligne nouvelle à grande vitesse reliant Bruxelles à Amsterdam. Afin de minimiser l'impact environnemental de la voie sur le *Groene Hart*[8], une zone protégée contenant notamment une réserve ornithologique, une solution en tunnel a été retenue dès l'origine, afin de réduire la nuisance sonore et les dommages au paysage et à l'environnement.



[8] « Cœur Vert » en flamand

Le projet a une longueur totale de 8 600 m.

Il comprend un tunnel de 7 200 m auquel s'ajoutent des ouvrages d'accès, de secours et techniques.



La géologie du site est typiquement néerlandaise. C'est une épaisse couche de sable entrecoupée d'horizons ou de lentilles argileuses, et surmontée, notamment aux deux extrémités, par une couche de tourbe et d'argile d'une épaisseur maximale de 10 m. La nappe phréatique est maintenue au niveau du terrain naturel par un drainage associé à un pompage (les fameux polders).

10.3.2 Vision opérationnelle

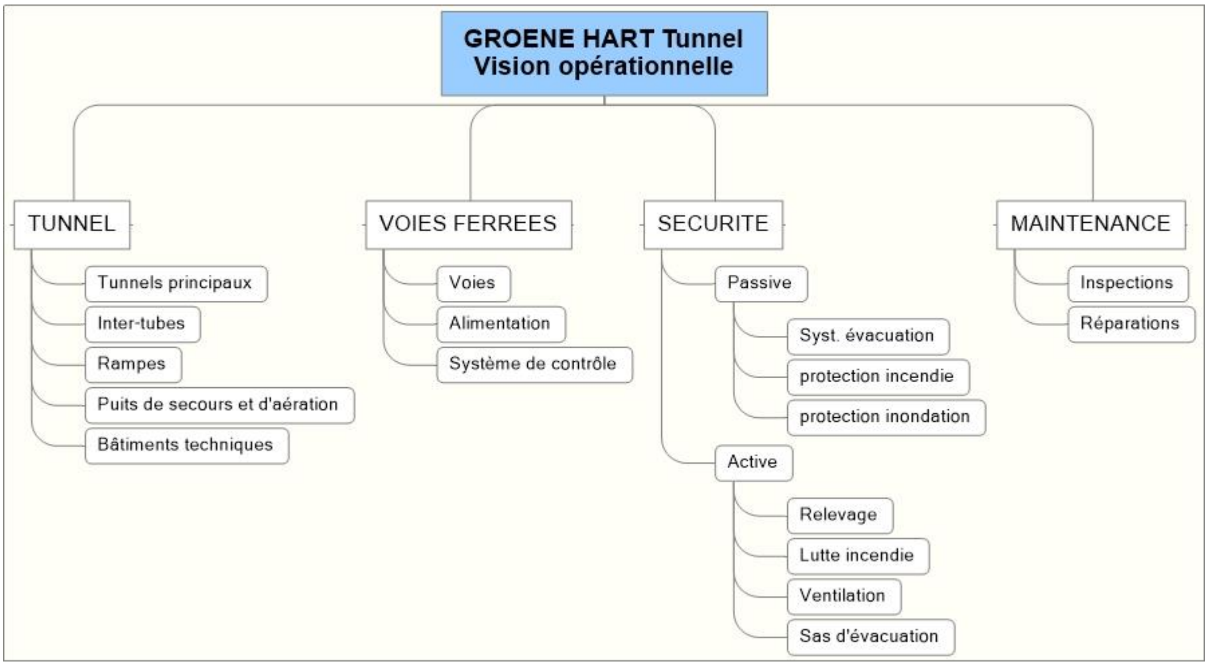
10.3.2.1 Parties prenantes (liste incomplète) :

- client ;
- exploitant ferroviaire ;
- mainteneur ;
- conditions environnementales ;
- géologie du site ;
- règlements, en particulier feu et sécurité en tunnel ;
- ingénierie ;

- constructeur ;
- industriels.

10.3.2.2 Architecture

On décrit ici la structure de l'ouvrage vue par les yeux d'un exploitant ou d'un maître d'ouvrage qui demande un lien ferroviaire enterré sous le *Groene Hart* sans préjuger de la solution technique.



- 1 Tunnel
  - Tunnels principaux (1 par voie)
  - Inter-tubes entre tunnels principaux
  - Rampes d'accès aux deux extrémités des tunnels principaux
  - Puits de secours et d'aération : 3 le long des tunnels, 1 à chaque entrée)
  - Bâtiments techniques à chaque entrée de tunnel
- 2 Voies ferrées
  - 1 voie dans chaque sens de circulation
  - Alimentation électrique des trains
  - Système de contrôle du trafic ferroviaire
- 3 Sécurité
  - Passive
    - Evacuation des piétons en tunnel

        - Protection incendie de la structure du tunnel
        - Protection contre l'inondation du tunnel
    - Active
        - Pompe de relevage des eaux de drainage
        - Système de lutte contre l'incendie
        - Ventilation du tunnel
        - Sas de sécurité sur les évacuations de secours
- 4 Maintenance
    - Inspections
    - réparations

Même si le langage peut paraître très « organique » il reste du langage commun et fait référence aux préoccupations (supposées bien sûr) de l'exploitant.

Celui-ci sait bien qu'il aura affaire à un tunnel, lequel aura des rampes d'accès, des tunnels proprement dits, des inter-tubes et des puits d'accès mis en avant dans son esprit car ils seront forcément des nids à problèmes, en particulier pour un ouvrage immergé.

Comme c'est un ouvrage ferroviaire d'une ligne à grande vitesse, il lui faudra un système de contrôle du trafic ferroviaire, des organes de sécurité, de ventilation, de drainage ainsi qu'un échelon de maintenance pour maintenir l'ouvrage en condition.

C'est là une description qui ne préjuge pas des solutions définitives qui seront adoptées mais l'exploitant sait qu'il aura au moins besoin d'une telle structuration pour pouvoir opérer.

La description est ici montrée à un niveau de plus en matière de « désintégration » de cette vision et il est fort possible qu'il ne soit, de ce point de vue là, pas très nécessaire pour la compréhension de devoir descendre bien plus dans ce même sens. Pour le besoin de cet exemple ce n'est en tous les cas pas nécessaire.

10.3.2.3 Besoins associés (exigences au sens ISO)

Sémantique : Le <système externe> doit être capable ou non de <faire qqch> grâce au <système> ou <composant> avec un certain <niveau de performance> dans un <certain contexte>.

A cette description opérationnelle doit être attachée un certain nombre de besoins exprimés selon la sémantique ci-avant. Celle-ci est à dériver en considérant tour à tour tous les systèmes externes impactés ou tous leurs représentants, d'où l'importance du caractère exhaustif à dresser des parties prenantes (cf. supra).

Ainsi :

1. 1.1 La ligne ferroviaire à grande vitesse empruntant le tunnel doit être capable de faire passer ***n*** trains/jour 360 jours/an sur 24h, dans les deux sens et à vitesse nominale.
    - Gabarit ligne à grande vitesse

- Voie sans ballast
- Géométrie des voies grande vitesse

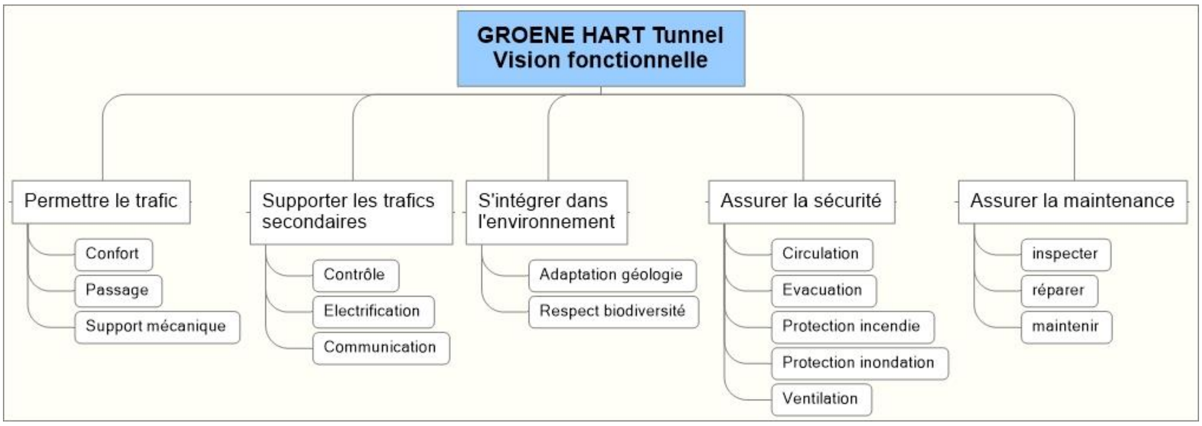
2. 3.1 En cas d'incendie d'un train dans le tunnel, arrêté pour permettre son évacuation, la structure ne doit pas être dégradée localement, pour ne pas conduire à une inondation complète du tunnel et une perte d'exploitation longue.
3. 3.2 En cas d'incident ou d'accident de train en tunnel, il faut pouvoir évacuer le train dans un délai ***d*** pour garantir la sécurité des personnes
4. 1.2 Un tunnel dans un sens de circulation ne doit pas empêcher l'exploitation dans l'autre tunnel.
5. 1.3 Les méthodes constructives doivent être adaptées à la géologie particulière du site et à la protection environnementale du *Groene Hart*.
6. 1.4 Ouvrage totalement immergé (poussée d'Archimède, étanchéité, drainage…)
7. 4.1 La maintenance ne doit pas avoir à intervenir pour des réparations majeures sur l'ouvrage dimensionné pour une durée de vie de 100 ans.

Ce sont là 7 des besoins détectés dès le niveau opérationnel lors de la phase consistant à bien poser le problème. Ces besoins, formulés selon la syntaxe indiquée, ne préjugent pas des solutions, ils résultent tous d'un « système externe » (l'exploitation d'un ligne ferroviaire à grande vitesse ; la sécurité des passagers ; les conditions environnementales du site ; la géologie locale ; les méthodes constructives qui seront plus tard incarnées par le constructeur mais qui sont à exprimer dès le niveau opérationnel consistant à poser le problème (à tous les niveaux de « désintégration » et selon une vision de l'ouvrage à tous ses instants du cycle de vie : en exploitation mais aussi en construction).

10.3.3 Vision fonctionnelle

10.3.3.1 Architecture

En comparaison de la vision précédente, le point de vue est celui de l'ouvrage lui-même que le concepteur « voit » ou organise en fonctions abstraites qu'il sait que le tunnel devra assurer pour répondre aux besoins détectés lors de l'élaboration de la vision opérationnelle. A nouveau, celles-ci sont déstructurées en autant de niveaux hiérarchiques que de besoin.



- Permettre le trafic ferroviaire à grande vitesse sous le *Groene Hart*
    - Assurer le confort du trafic (géométrie de la voie ; variation de pression dans le tunnel au passage du train…)
    - Laisser passer la capacité voulue
    - Supporter mécaniquement le trafic
- Supporter les trafics secondaires
    - Contrôler la circulation ferroviaire sur la voie
    - Electrification de la voie
    - Réseaux de communication du train et de la voie
- S'intégrer dans l'environnement
    - S'adapter à la géologie du site et le niveau de la nappe phréatique
    - Ne pas contrarier la biodiversité du *Groene Hart*
- Assurer la sécurité
    - Circulation des trains
    - Evacuation des passagers en cas d'urgence, par les tunnels, les inter-tubes, les puits de secours…
    - Protection des passagers, des trains, de la structure contre l'incendie
    - Protection de l'ouvrage contre l'inondation
    - Ventilation des tunnels et des ouvrages annexes, évacuation, traitement
- Assurer la maintenance
    - Inspecter les ouvrages
    - Réparer les ouvrages
    - Maintenir en exploitation y compris remplacement avant obsolescence

La fonction première et évidente pour un tunnel est celle de permettre le passage du trafic. Ici, celle-ci a été décomposée en une fonction de tracé ou de confort (le trafic ferroviaire à grande vitesse ne peut se faire selon des rayons trop serrés ou une pente trop forte), une autre de capacité et une dernière de support mécanique. On peut remarquer que l'on aurait pu aussi exprimer la fonction de support mécanique au niveau de l'intégration dans l'environnement. Ces choix relèvent du savoir-faire de tel ou tel ingénieur (société ou individu). Avec cette triple fonction, on peut raisonnablement espérer satisfaire au besoin 1 de la vision opérationnelle ci-avant.

Le tunnel doit assurer aussi d'autres trafics par lui-même, c'est la seconde fonction montrée.

Il est à remarquer que la description complète de la fonction de support mécanique suppose de la modéliser en des « barreaux structuraux » qui sont des éléments abstraits permettant de résister à une certaine sollicitation (compression-traction/moment fléchissant/moment de torsion). L'ensemble de ces barreaux modélise le tunnel dans sa fonction mécanique. Cette décomposition n'est pas faite ici.

10.3.3.2 Exigences associées

Sémantique : le <composant ou système> doit <faire qqch> avec un <niveau de performance> dans un <contexte donné>.

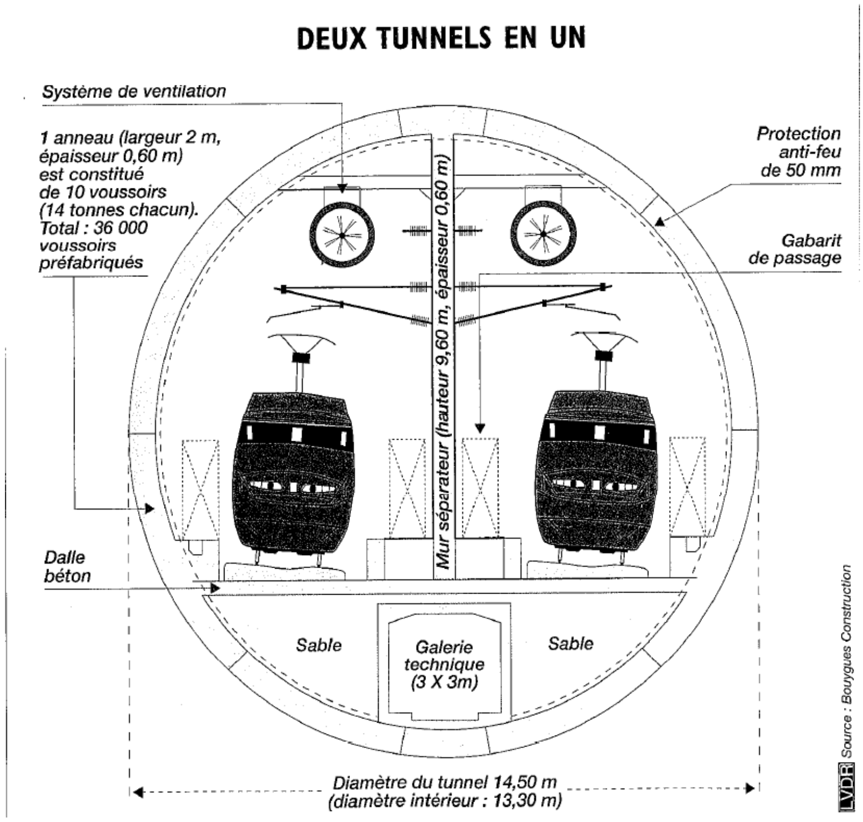
Ainsi et pour continuer dans les besoins précédemment identifiés pour les transformer en exigences fonctionnelles :

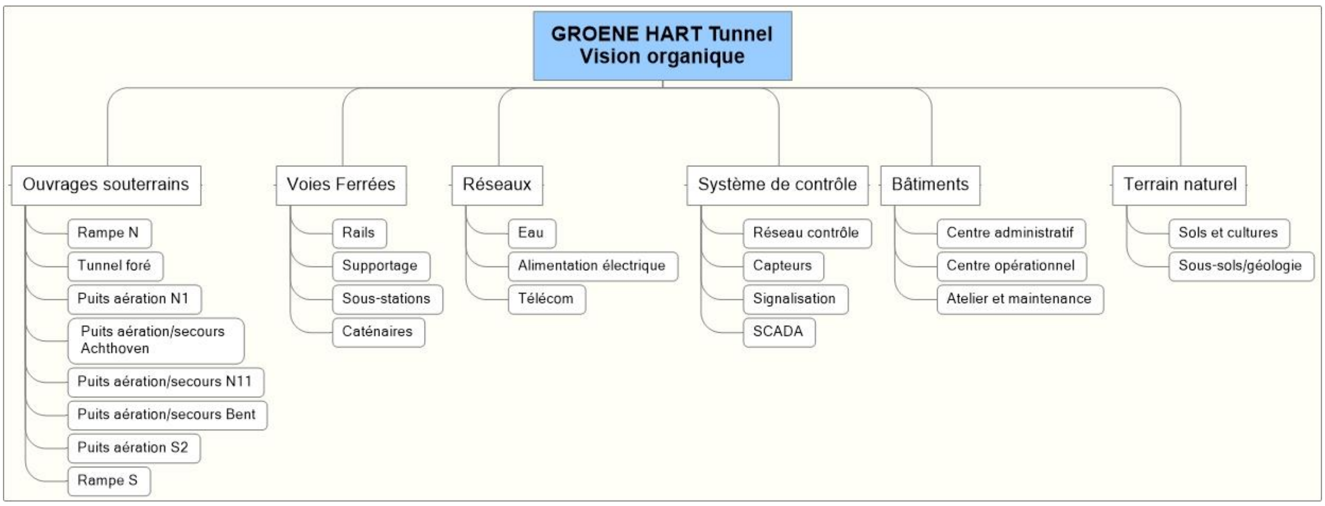
1. Le tunnel doit faire passer ***n*** trains/jour 360 jours/an sur 24h pour les deux sens confondus.
    - Le tunnel doit faire passer ***n***/2 trains/jour … par sens
    - Le tunnel doit suivre un profil adapté pour un trafic ferroviaire passager à grande vitesse
2. La structure du tunnel doit être capable de résister à un incendie interne sans ruiner son étanchéité au point que cela entraîne l'inondation complète du tunnel.
3. Le tunnel doit être capable d'évacuer les passagers d'un train à l'arrêt dans le tunnel (panne, incendie…)
4. Un arrêt d'exploitation sur un sens de circulation ne doit pas empêcher l'exploitation de la ligne dans l'autre sens
5. *L'exigence 5 opérationnelle portant sur la construction ne peut être résolue sans considérer la vision organique. En fait elle sautera directement de la vision opérationnelle à la vision organique. Aucune intermédiation théorique n'est réellement nécessaire.*
6. La maintenance ne doit pas avoir à intervenir pour des réparations majeures sur l'ouvrage dimensionné pour une durée de vie de 100 ans.

10.3.4 Vision organique

10.3.4.1 Architecture

En complément de la vision précédente, le point de vue est celui des composants dont l'ouvrage lui-même est constitué et que le concepteur organise en solutions concrètes qu'il sait pour répondre aux fonctions identifiées lors de l'élaboration de la vision fonctionnelle (voire directement aux besoins opérationnels. A nouveau, celles-ci sont déstructurées en autant de niveaux hiérarchiques que de besoin, que l'on choisit naturellement selon une logique d'intégration constructive (ou de désintégration si l'on choisit le sens inverse).





- Ouvrages souterrains
    - Rampe d'accès nord

        - Raccordement à la ligne ferroviaire hors de l'ouvrage
        - Tranchée ouverte
        - Tranchée couverte
        - Bâtiment technique incluant une issue de secours, le puits d'entrée du tunnelier transformé ensuite en puits d'aération

    - Tunnel principal foré au tunnelier

        - Creusement au tunnelier et pose des anneaux en béton
        - Pose des tronçons de galerie de service
        - Lestage du tube avec du sable
        - Réalisation de la dalle
        - Réalisation du voile séparateur central
        - Réalisation des circulations piétonnes

    - Puits d'aération N2

    - Puits de secours et d'aération d'Achthoven, N11 et de Bent

    - Puits d'aération S2

    - Rampe d'accès sud

        - Raccordement à la ligne ferroviaire hors de l'ouvrage
        - Tranchée ouverte
        - Tranchée couverte
        - Bâtiment technique incluant une issue de secours, le puits de sortie du tunnelier transformé ensuite en puits d'aération

    - Revêtement de protection incendie

- Voies ferrées

    - Rails

    - Liaisons rail/tunnel

    - Sous-stations

    - Caténaires

- Réseaux

    - Eau

    - Alimentation électrique

    - Télécom

- Système de contrôle

    - Réseau de contrôle

    - Capteurs

  - Signalisation
  - SCADA
- Bâtiments
  - Centre administratif
  - Centre opérationnel
  - Centre de maintenance
- Terrain naturel
  - Sols et cultures
  - Sous-sols / géologie

La décomposition en paliers d'intégrations est assez intuitive pour un constructeur. Celle-ci est plus fouillée que les précédentes mais elle est très loin de la décomposition réelle. Cependant, elle oblige déjà – dès lors que l'on doit toujours considérer le pont dans tous ses états successifs et donc aussi durant la construction – à incorporer des structures temporaires ou des équipements majeurs de la construction ou d'autres éléments de décomposition tenant compte des choix constructifs.

10.3.4.2 Exigences associées

Sémantique : le <composant du système> doit <être constitué de qqch> qui satisfait à un <niveau de performance visé> dans un <contexte donné>.

1. [trafic]
   - Le tunnel doit présenter deux sens de circulation séparés par un voile pour protéger les effets néfastes d'une circulation sur l'autre sens.
   - La voie doit suivre le profil requis pour l'exploitation d'une ligne ferroviaire à grande vitesse
   - Le tunnel principal doit être constitué d'anneaux en béton étanche à la nappe phréatique externe dont le niveau est celui du terrain naturel, résistant au feu d'un train en tunnel, capable de supporter les efforts appliqués par le tunnelier lors du creusement.
   - La voie ferroviaire est du type sans ballast.

MINnD – UC3.6

Description d'un portique PMV selon
les visions opérationnelle, fonctionnelle & organique.

10.4 Cas d'étude : portique de signalisation sur voie portée par digue

10.4.1 Contexte :

Portique support de système de signalisation pour une voie de 6km portée par une digue en pleine mer destinée à procurer une liaison sûre en alternative à une route existante située en contrebas d'une falaise volcanique fragilisée de laquelle émanent des éboulements fréquents et dangereux conduisant à des coupures partielles voire totales.

Les contraintes principales de ce système concernent sa lisibilité, de tout temps, et de nuit comme de jour, de nature à satisfaire à une circulation à 110km/h, son piquetage dans une emprise contrainte, avec réseaux enterrés et dispositifs de retenue et de protection contre le bruit, et son dimensionnement pour résister à des vents cycloniques de 200km/h.

10.4.2 Vision opérationnelle

NB : Vision opérationnelle : description de ce que les parties prenantes – tierces parties et acteurs directs - attendent de l'ouvrage / le « POURQUOI »

10.4.2.1 Parties prenantes (liste partielle) :

MOA/exploitant, mainteneur, constructeurs, usagers/clients et riverains, conditions climatiques.

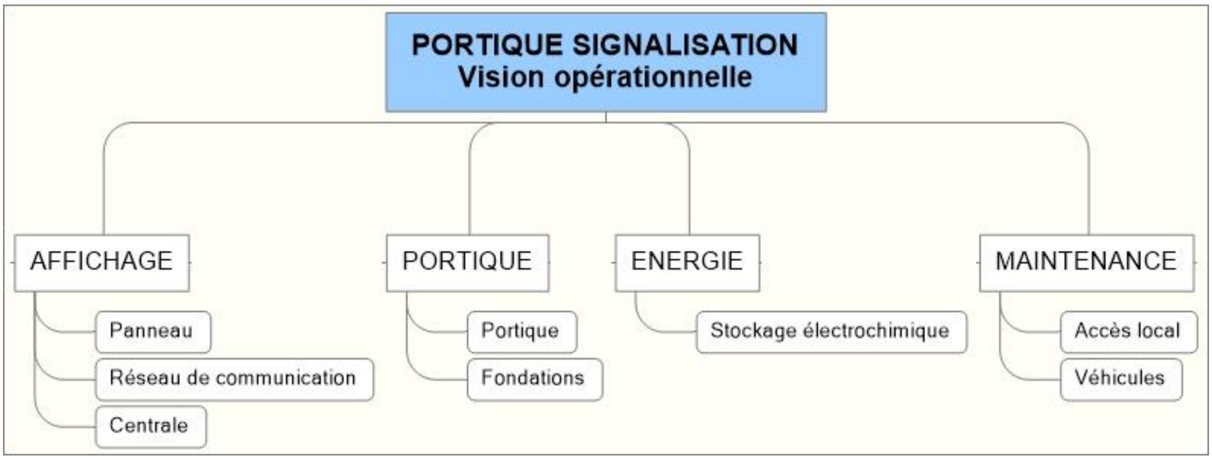
10.4.2.2 Architecture de l'équipement

On décrit ici la structure de l'équipement d'un point de vue d'un MOA/exploitant qui demande une fonctionnalité de mise à disposition d'information dynamique aux usagers empruntant la voie, sans préjuger de la solution technique.

Même si le langage apparait « organique » il reste du langage commun et fait référence aux préoccupations du MOA/exploitant.

Celui-ci sait qu'il a à faire à un équipement connecté à d'autres systèmes : alimentation électrique et réseau numérique de circulation des datas.

Il y a des réseaux à installer, et des opérations de maintenance pour conserver l'équipement en condition de fonctionnement 24/24.



10.4.2.3 Exigences associés à l'équipement

NB : Le <système externe> doit être capable ou non de <faire qqch> grâce au <système> ou <composant> avec un certain <niveau de performance> dans un <certain contexte>.

A la description opérationnelle sont attachés des exigences :

1. Lisibilité pour circulation à 110km/h selon développée du projet.
2. Affichage des messages 1 mn après leur création au centre de surveillance du trafic, en 24/24, pour les deux sens de circulation.
3. Affectation dynamique des voies depuis centre de surveillance du trafic.
4. Auto-suffisance énergétique pour une durée de 24h.
5. Résistance à des vents de 200km/h dans les régions à risques cycloniques.
6. Conditions d'obsolescence.
7. Accessibilité pour les personnels de maintenance sécurisée.

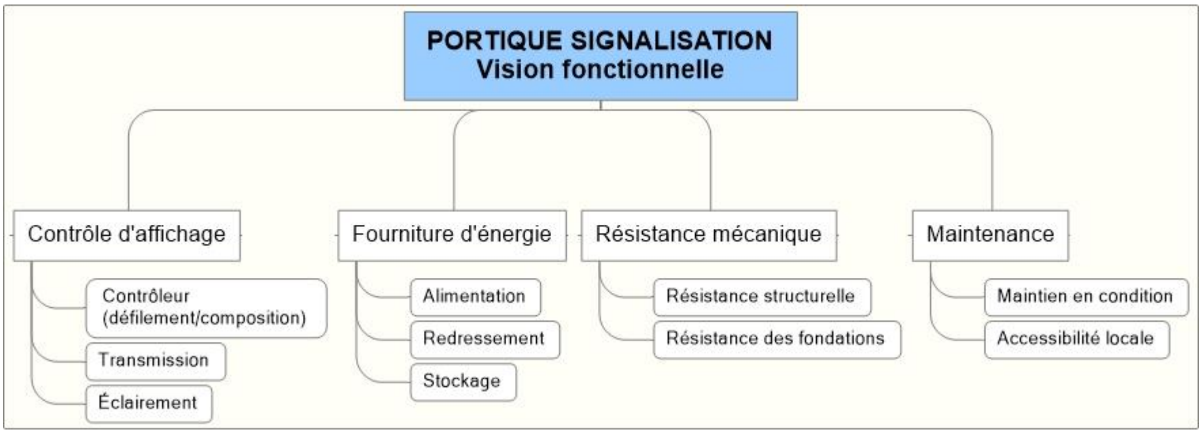
Ce sont là des exigences de niveau opérationnel. Ils ne préjugent pas des solutions.

10.4.3 Vision fonctionnelle

NB : vision fonctionnelle : description des fonctions abstraites assurées par l'ouvrage / le QUOI

10.4.3.1 Architecture de l'équipement

On décrit ici l'ouvrage lui-même tel que son concepteur prévoit les fonctions qu'il devra assurer pour répondre aux besoins identifiés dans la vision opérationnelle.



10.4.3.2 Exigences associés à l'équipement

NB : le <composant ou système> doit <faire qqch> avec un <niveau de performance> dans un <contexte donné>.

A la description fonctionnelle sont attachés des exigences :

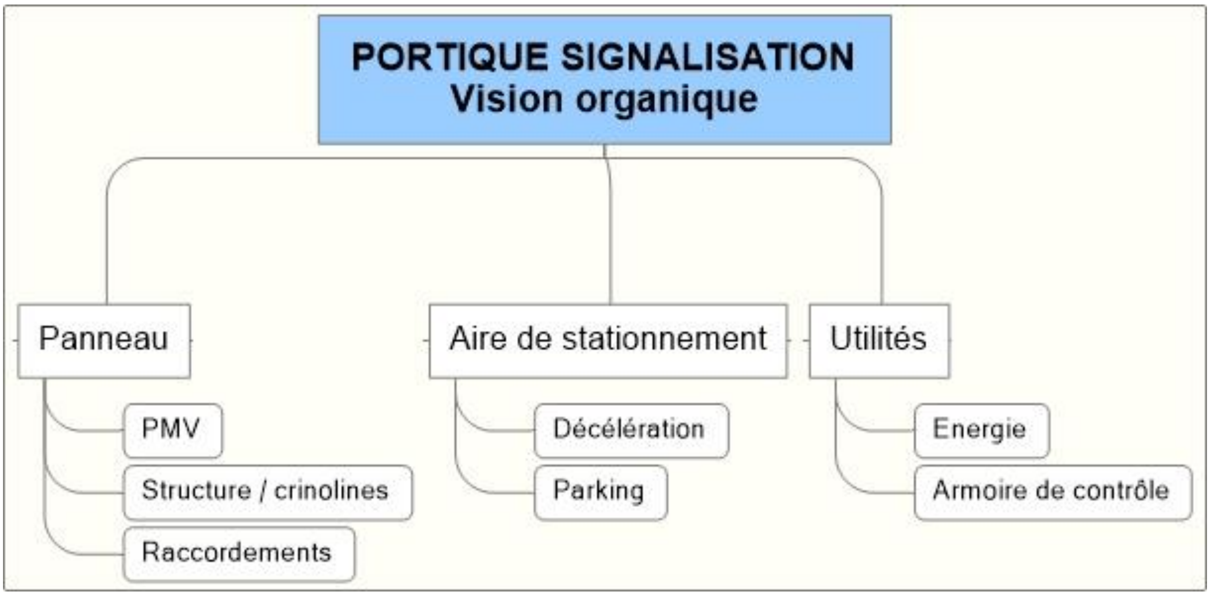
1. Piquetage déterminé par études de visibilité.
2. Réseau numérique à mm d'assurer l'affichage de messages 1 mn après leur création au centre de surveillance du trafic.
3. Vitesse de défilement des messages paramétrable.
4. Système d'accumulation d'énergie (accus) pour pallier une absence temporaire d'alimentation électrique de 24h.
5. Dimensionnement du massif, du support et du panneau pour résister à des vents de 200km/h.
6. Programmation de l'obsolescence.
7. Zone de stationnement pour véhicule de maintenance ; accès sécurisé au panneau.

10.4.4 Vision organique

NB : description des composants de l'ouvrage / le COMMENT

10.4.4.1 Architecture

On décrit ici les composants dont l'équipement est constitué et que le concepteur envisage pour répondre aux fonctions requises par la vision fonctionnelle.



10.4.4.2 Exigences associés à l'équipement

NB : le <composant du système> doit <être constitué de qqch> qui satisfait à un <niveau de performance visé> dans un <contexte donné>.

A la description organique sont attachés des exigences :

- Mise en place d'une aire de stationnement pour service (L=10m x l=3m), avec biseau d'entrée et biseau de sortie (longueur totale de 30m), en amont du support, et garantie de visibilité en accès/sortie ; avec incidence sur dimensionnement digue et talus raidi ;
- Mise en place de GS de protection + marquage spécifique ;
- Réservation pour mise en place du massif du support ; avec incidence sur couche structure digue ;
- Ajustement des réseaux secs et humides ;
- Accès d'intervention pour obsolescence.
- PMV à caractères conformes aux distances de visibilité normalisés ICTAAL.

MINnD – UC3.6

Infrastructure domains objects priorization

10.5 Infrastructure domains objects IFC priorization matrix

	Domains objects	Interest (1 to 5)	Easiness (1 to 5)	Variance Interest	Variance Easiness	Rate Method 1	Rank Method 1	Rate Method 2	Rank Method 2
1	**In relation to the existing environment in which the civil infrastructure must be integrated :**	4.3	3.5						
1a	a. Georeferencing grid;	5.0	4.8	0.00	0.25	9.8	1	23.8	1
1b	b. Topography and data acquisition;	4.8	4.5	0.25	0.33	9.3	2	21.4	2
1c	c. Geology and geotechnics;	4.5	2.8	0.33	0.92	7.3	10	12.4	17
1d	d. Cadastral mapping, soil usages, ownership; existing buildings and structures in the vicinity;	4.0	3.8	1.33	0.25	7.8	8	15.0	12
1e	e. Existing networks;	4.8	3.5	0.25	1.00	8.3	6	16.6	8
1f	f. Hydrographic system ;	3.8	3.0	0.92	0.67	6.8	12	11.3	20
1g	g. Biosphere and generally environment;	3.7	2.3	0.33	2.33	6.0	14	8.6	23
2	**In relation to the description of the geometry of the project (more or less what should be covered by *IfcAlignment*):**	4.9	4.5						
2a	a. Alignment of the infrastructure and its connection to existing networks;	5.0	4.8	0.00	0.25	9.8	1	23.8	1
2b	b. Alignments of the networks and reinstated networks;	4.8	4.3	0.25	0.92	9.0	3	20.2	3
3	**In relation to the main infrastructure itself:**	4.4	3.2						
3a	a. Permanent earthworks such as dykes, embankments, cut and fill, dams;	4.8	3.3	0.25	0.92	8.0	7	15.4	11
3b	b. Roads and carriage ways, subgrades, subbases, base courses, surface ciurses, pavements, platforms, ballast, sidewalk, gu	4.8	4.0	0.25	1.33	8.8	4	19.0	4
3c	c. Rails and guided transport systems and structures (more or less what should be covered by *IfcRail*)	4.8	3.0	0.25	1.33	7.8	8	14.3	14
3d	d. Cut and cover, tunnels;	4.5	2.5	1.00	0.33	7.0	11	11.3	20
3e	e. Sewers;	3.8	3.0	0.92	0.67	6.8	12	11.3	20
3f	f. Dry (buried cables, ...) and wet networks (pipes, ...), culverts, storm sewers;	3.8	3.3	0.25	0.92	7.0	11	12.2	18
3g	g. Foundations;	4.5	3.5	0.33	0.33	8.0	7	15.8	10
4	**In relation to ancilliary infrastructures or necessary utilities, incidental construction:**	4.5	3.7						
4a	a. Longitudinal drainage, ditches;	4.5	3.8	1.00	0.25	8.3	6	16.9	7
4b	b. Special structures connecting ground and abutments;	4.8	3.8	0.25	0.92	8.5	5	17.8	6
4c	c. Special structures enabling the transition between infrastructures such as ramps,	4.8	3.5	0.25	0.33	8.3	6	16.6	8
4d	d. (Soil) Retaining structures;	4.5	3.3	0.33	0.25	7.8	8	14.6	13
4e	e. Noise protection devices and walls;	3.8	3.8	0.92	0.25	7.5	9	14.1	15
4f	f. Passive safety system and equipment (railing, ...);	4.5	4.0	0.33	0.67	8.5	5	18.0	5
5	**In relation to safety, traffic and energy related utilities:**	3.4	3.2						
5a	a. Information and signing, marking;	4.0	4.0	0.00	0.00	8.0	7	16.0	9
5b	b. ITS (traffic control, traffic management, tolling, ...);	3.5	2.5	1.00	0.33	6.0	14	8.8	22
5c	c. Energy supply and lighting;	3.3	3.5	1.58	0.33	6.8	12	11.4	19
5d	d. Ventilating;	3.0	3.5	0.67	0.33	6.5	13	10.5	21
5e	e. Structural Health Monitoring system;	3.0	2.7	1.00	0.33	5.7	15	8.0	24
6	**In relation to reinstatements (disturbed networks to be reinstated):**	4.2	3.5						
6a	a. Hydrographic network reinstatement;	4.3	3.0	0.92	0.67	7.3	10	12.8	16
6b	b. Networks reinstatement structures (bridges, ...);	4.5	3.8	1.00	0.92	8.3	6	16.9	7
6c	c. Biosphere reinstatement structures (bridges, animal-ducts, ...).	3.8	3.8	0.92	0.92	7.5	9	14.1	15