Towards the Exchange of Parametric Bridge Models using a Neutral Data Format

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ABSTRACT

While there are mature data models for exchanging semantically rich building models, no means for exchanging bridge models using a neutral data format exist so far. A major challenge lies in the fact that a bridge's geometry is often described in parametric terms, using geometric constraints and mathematical expressions to describe dependencies between different dimensions. Since the current draft of IFC-Bridge does not provide a parametric geometric description, this paper presents a possible extension and describes in detail the object-oriented data model proposed to capture parametric design including geometric and dimensional constraints. The feasibility of the concept has been verified by actually implementing the exchange of parametric models between two different computer-aided design (CAD) applications.

1. INTRODUCTION

Planning and realizing roadways and bridges are important aspects of infrastructure construction projects. Nowadays, road and bridge models are usually generated using completely different modeling systems. However, since bridges form part of the roadway, a bridge's geometry depends significantly on the course of the carriageway, i.e. its main axis. Small modifications in the road design occur frequently during the planning process. When a conventional computer-aided design (CAD) system is used to create the bridge model, these modifications involve a tedious, time-consuming manual adaptation of the bridge's geometry. Researchers belonging to the research cluster ForBAU - "The Virtual Construction Site" (Borrmann et al., 2009), have accordingly been investigating the application of parametric CAD technology, which makes it possible to model dependencies between geometric objects explicitly (Hoffmann and Peters, 2004; Sachs et al., 2004). With the help of this technology the bridge model can be coupled with the axis of the carriageway, enabling a fast and automatic update whenever the roadway design is modified. At the same time, a parametric description allows for an advanced modeling of the bridge itself, especially with respect to varying cross-sections along the axis (Figure 1).

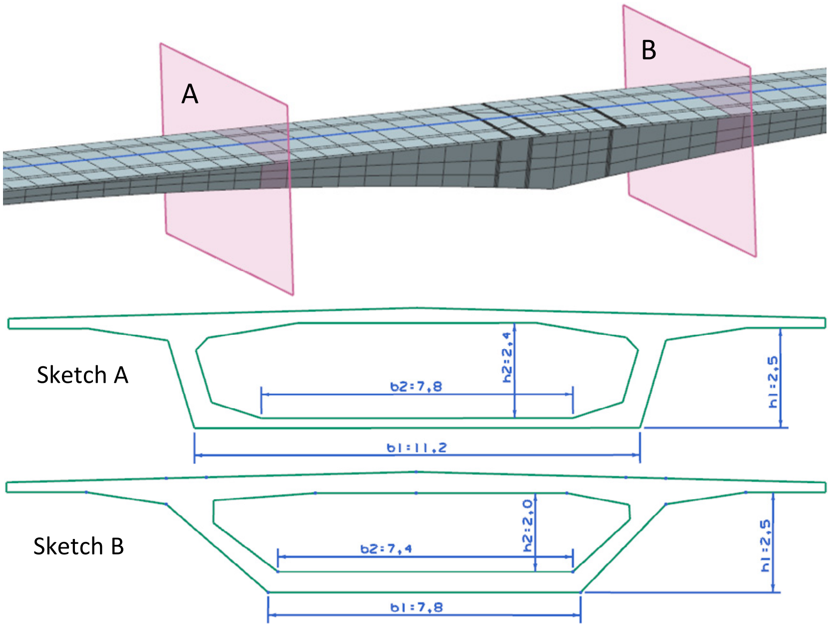

Figure 1. A parametric description helps in defining varying cross-section along the superstructure's axis.

To support the design of bridges even more, it is desirable to provide ways and means to exchange parametric bridge models between different applications. Doing so will provide a way of transferring the concept of the design and consequently speed up variation studies. This applies in particular to the integration of structural analysis applications in the bridge design process. In general, data transfer can be realized on the basis of bilateral data interfaces that are specifically implemented for a source and a target system. A more promising solution is to employ a neutral data format enabling the exchange of data between arbitrary applications and ensuring long-term readability (Eastman et al. 2008). The latter aspect is particularly important for the bodies or corporations that own the infrastructure (usually public authorities), which typically has to be maintained over long periods of time. It is to this end that the IFC-Bridge data model is being developed (Yakubi et al., 2006; Arthaud and Lebegue, 2007). It is based on the Industry Foundation Classes (IFC), the standardized data exchange format for construction engineering (ISO, 2005a), re-using a large extent of its entities. The IFC-Bridge development currently focuses on standardizing definitions of bridge components and their hierarchical relationships. With regard to the geometric description, 3D bridge models can be represented by extruding 2D cross-sections along a 3D path. However, a parametric geometric description using design parameters, geometric and dimensional constraints, as well as mathematical interdependencies between the parameters is not available (Ji et al., 2010).

To fill this gap, this paper presents in detail a neutral data structure for exchanging parametric geometry models, which is proposed as an extension of the emerging IFC-Bridge schema.

2. PARAMETRIC BRIDGE MODELING

Parametric design refers to the use of geometric parameters and the mathematical formulation of interdependencies between them. It also includes the option of defining geometrical and topological constraints (Shah and Mäntylä, 1995). Using parametric design features, bridges can be coupled with the axis of the roadway, which enables an automatic update of the bridge's geometry and saves a laborious manual adaptation whenever modifications of the road axis become necessary. In any case, bridges are structures with a complicated geometry (Katz, 2008). They are frequently located in a bend in the road which, more often than not, simultaneously features a longitudinal camber. This creates a superstructure with a highly complicated, three-dimensionally curved surface (Figure 2). To construct such a superstructure in a CAD system, the cross-section (2D sketch) is positioned on the road axis, which acts as the 3D extrusion path. The geometric form of the superstructure accordingly depends on both the sketch and the associated extrusion path. Any modification to the road axis results in an update of the bridge's superstructure. To realize this functionality, an advanced CAD system, which not only provides parametric features but also freeform and volume modeling, is required. The parametric design approach is good for producing fast design variations and thus enables the extensive re-use of existing models.

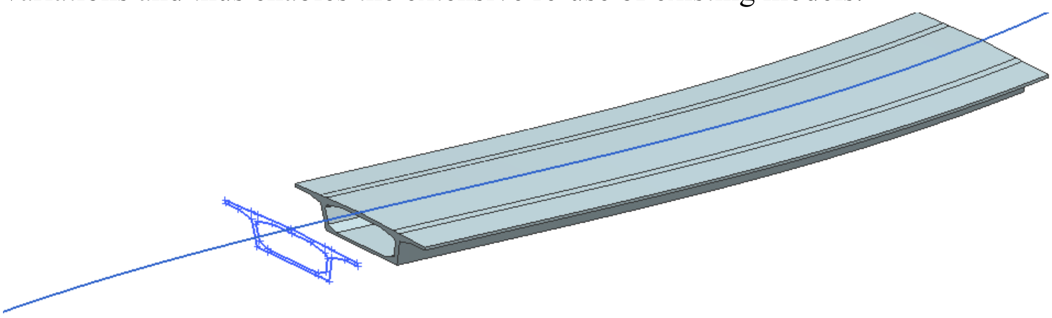

Figure 2. The bridge's superstructure is coupled with the road's main axis.

A more detailed example of a parameterized design is illustrated in Figure 3. The sketch describes the superstructure of a beam bridge consisting of geometric objects, i.e. lines and points, the geometric constraints *Parallel* and *Perpendicular*, and design parameters *h1* to *h8* and *b1* to *b6*. A complete list of the geometric and dimensional constraints commonly used for bridge modeling is depicted in Figures 4 and 5Figure 5.

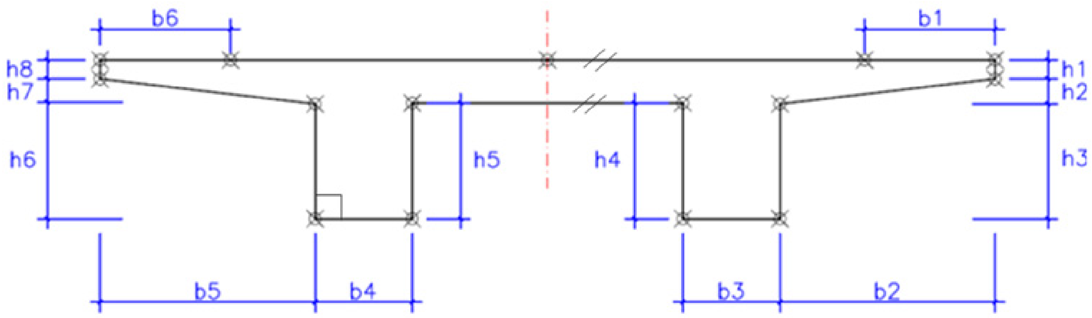

Figure 3. Parameterized cross-section of a beam bridge superstructure

3. NEUTRAL FORMATS FOR EXCHANGING PARAMETRIC MODELS

In order to achieve interoperability between different software applications used in the design and construction process, it is necessary to establish a standardized data model. The most mature data model standards in the AEC domain are the IFC standards. For historical reasons, the IFC data model has been developed on the basis of the ISO STEP standard for the exchange of product model data (ISO, 1995).

While the STEP data models have not achieved acceptance in the AEC industry, they have become comparatively well established in the mechanical engineering domain, and new features have subsequently been added. In 2005, the ISO Technical Committee 184 published STEP Part 108 for transferring design parameters and geometric constraints of 2D sketch elements (ISO, 2005b). This part contains more than 40 cases of geometric constraints (ProSTEP, 2006). The ProSTEP Association launched an implementation project of Part 108 for the mechanical modeling systems CATIA, Pro/E and NX. The major problem, however, was the high complexity of mapping the geometric constraints from individual CAD systems to the neutral standard (Pratt et al., 2005). Up to now, STEP Part 108 import/export functionality has not been available in these CAD systems.

At the same time, IFC-Bridge, a data schema for exchanging bridge models based on IFC, has been developed. As mentioned above, the current draft of the IFC-Bridge schema is not capable of capturing design parameters and sketch constraints, which is an essential aspect of transferring design concepts during the project phases. Since STEP Part 108 is not a common exchange standard in the AEC industry, it is more appropriate to extend the IFC-Bridge data schema in such a way that it satisfies the requirement of transferring design concepts contained in parametric bridge models. To this end, a small set of geometric constraints (**Fehler! Verweisquelle konnte nicht gefunden werden.**4) and dimensional constraints (Figure 5) have been identified. They are commonly used for bridge modeling and widely supported by commercial parametric CAD systems on the current market. Accordingly the implementation effort and mapping process required is within reason.

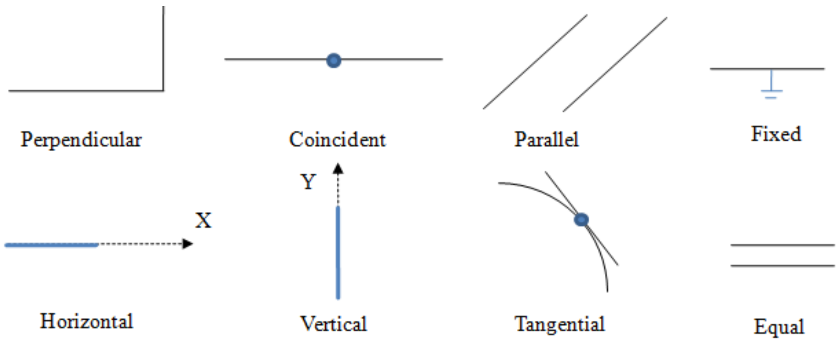

Figure 4. Supported types of geometric constraints

The developed data model has been formulated using UML (Unified Modeling Language). The resulting class diagram is depicted in **Fehler! Verweisquelle konnte nicht gefunden werden.**6. The model focuses on the representation of parametric 2D sketches. When extruded, they enable parametric 3D volumetric design. This particularly applies to the design of bridge superstructures.

A sketch (class *Sketch*) consists of three components, geometric objects (*SketchGeometry*) which may be lines (*SketchLine*), points (*SketchPoint*) and arcs (*SketchArc*), geometric dependencies (*GeometricConstraint*) between these objects such as the parallelism (*ParallelGeometricConstraint*) of two lines, and dimensional constraints (*DimensionalConstraint*) referring to the size of a dimension (*Parameter*). A user-defined or system-inferred value can be assigned to each dimension. In the first draft of the data model, mathematical expressions describing relationships mbetween parameters are represented as strings. The subclasses of *DimensionalConstraint* define which kind of dimension is referred to (distance, angle or radius) and how the distance is measured (horizontally, vertically or parallel to the line).

The relations between design constraints and their associated sketch geometry objects are explicitly defined. Explicit specifications enhance the clarity of the data structure and reduce the possibility of misinterpretation in sending and receiving systems. A concrete example will be presented in the following section.

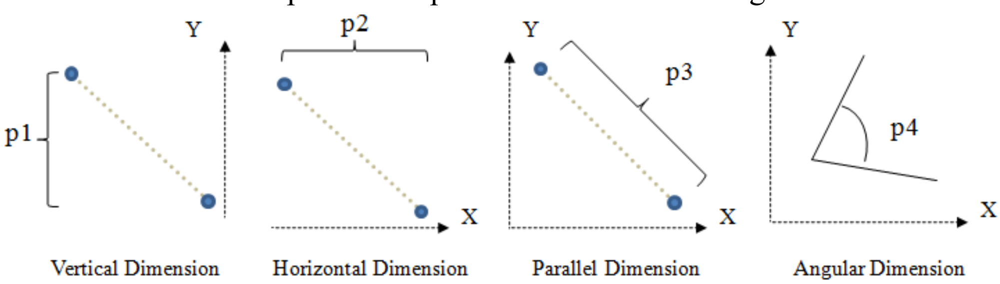

Figure 5. Supported types of dimensional constraints

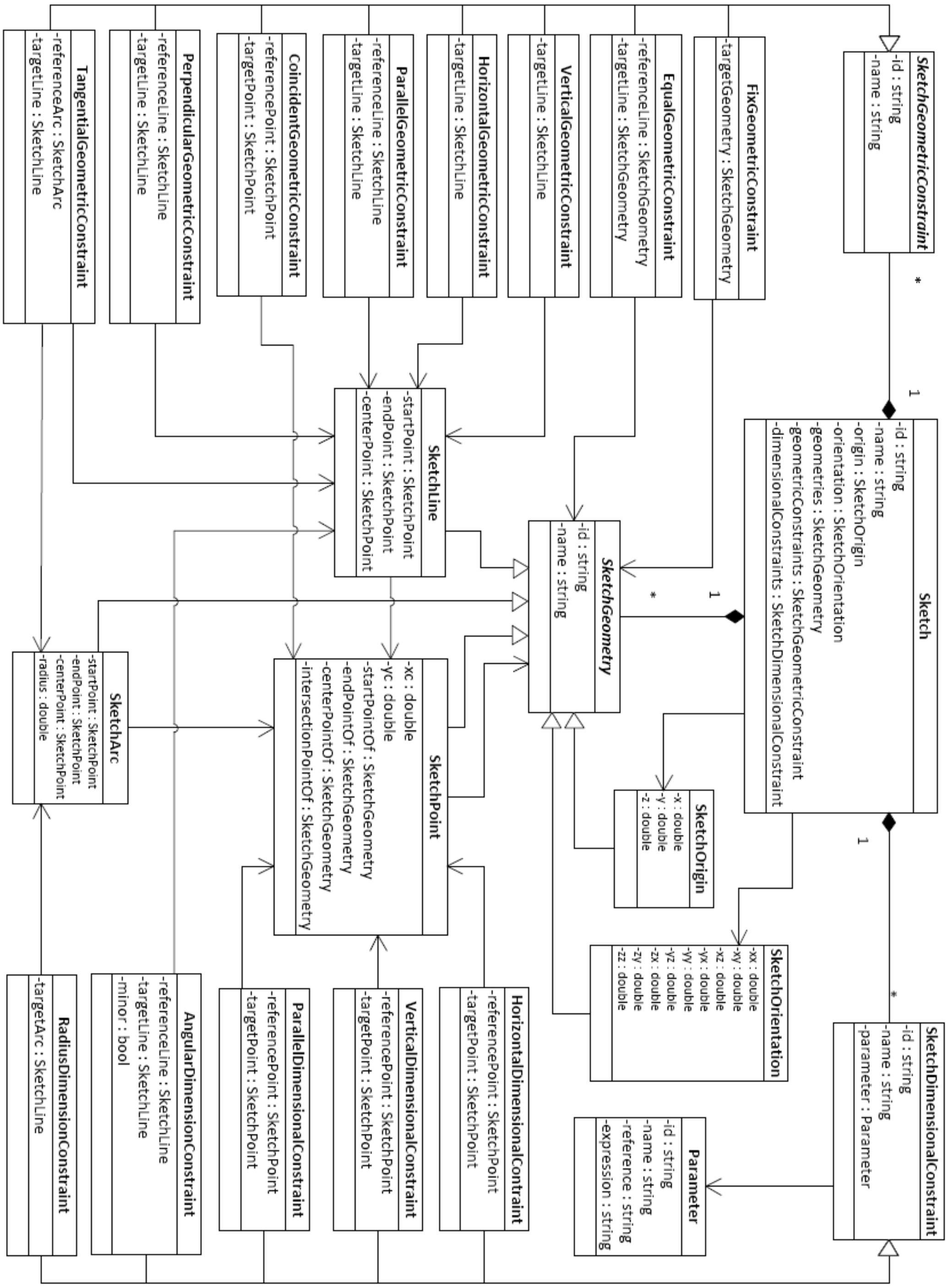

Figure 6. UML diagram of the proposed data structure for representing parametric geometry

4. IMPLEMENTATION AND CASE STUDY

The modeling language used for defining STEP and IFC data models is EXPRESS which provides a wide range of object-oriented modeling features including the definition of *entity types* (the equivalent of a *class*) and *attributes* representing the common properties of the objects belonging to the same entity type. While support for STEP data is rather limited, reading and writing XML documents is supported by a large variety of libraries available for almost every programming language. For an initial evaluation, the proposed data structure was therefore implemented as an XML schema.

To illustrate the proposed data structure, Figure 7 depicts a specimen sketch and the corresponding XML instance file. The points of the sketch *P_1* to *P_5* are defined by means of explicit coordinates. The lines *Line_1* to *Line_5* are defined using the respective start and end points. The geometric constraint parallel (*ParallelGeometricConstraint*) is associated with *Line_2* and *Line_4*. Similary, the perpendicular constraint (*PerpendicularGeometricConstraint*) is associated with Line_2 and Line_3. The vertical dimensional constraint (*VerticalDimensionalConstraint*) refers to the design dimension *p4* to which the string value “8.7” has been assigned.

```xml
<SketchGeometry name="P_1" xsi:type="SketchPoint">
    <xc>10.0</xc>
    <yc>2.0</yc>
    <StartPointOf xsi:nil="true" ref= "Line_2" xsi:type="SketchLine"/>
    <EndPointOf xsi:nil="true" ref ="Line_1" xsi:type="SketchLine"/>
</SketchGeometry>
<SketchGeometry name="Line_1" xsi:type="SketchLine">
    <StartPoint xsi:nil="true" ref="P_5"/>
    <EndPoint xsi:nil="true" ref="P_1"/>
</SketchGeometry>
<SketchGeometricConstraint xsi:type="ParallelGeometricConstraint">
    <ReferenceLine xsi:nil="true" ref="Line_2"/>
    <TargetLine xsi:nil="true" ref="Line_4"/>
</SketchGeometricConstraint>
<SketchGeometricConstraint xsi:type="PerpendicularGeometricConstraint">
    <ReferenceLine xsi:nil="true" ref="Line_2"/>
    <TargetLine xsi:nil="true" ref="Line_3"/>
</SketchGeometricConstraint>
<SketchDimensionalConstraint xsi:type="VerticalDimensionalConstraint">
     <Parameter name="p4">
         <expression>8.7</expression>
     </Parameter>
     <ReferencePoint xsi:nil="true" ref="P_4"/>
     <TargetPoint xsi:nil="true" ref="P_5"/>
</SketchDimensionalConstraint>
```

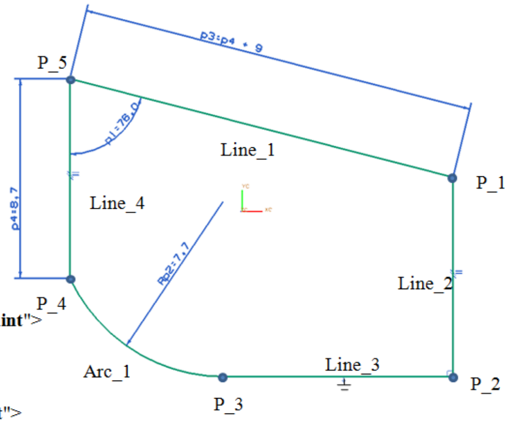

Figure 7. XML instance of a parametric sketch.

Prototypical sketch translators have been implemented and tested as add-on programs for two commercial parametric modeling systems, Autodesk AutoCAD and Siemens NX. They are able to read and write instance files for the proposed XML schema, to interpret the parametric design described and to create parameterized sketches in the receiving system. The corresponding solid model is then generated accordingly by extruding the 2D sketches along an extrusion path.

5. CONCLUSION AND OUTLOOK

The paper has presented a data model which is able to capture parametric geometry descriptions as a first step towards realizing the exchange of parametric bridge models between different software applications. The proposed neutral data format has been implemented on the basis of XML Schema. In a follow-up step, this data model will be transformed into an EXPRESS schema and integrated with the current IFC-Bridge draft. Future research will also include developing methods of describing mathematical relationships between dimensional constraints in an object-specific way. This will make the neutral data format even clearer and prevent misinterpretations.

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