IFC Railway: A Semantic and Geometric Modeling Approach for Railways based on IFC

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Abstract:

A major effort of the ongoing IFC5 standard is the infrastructure project such as roads, railways, bridges and tunnels, which is urgent to meet the need of standardized data on the infrastructure area. This paper presents an information modeling approach for railways, which aims to achieve the cross-platform and cross-discipline data interoperability in railways. The presented data model could be applied to railway construction management and relevant software development. Our modeling approach refers to the IFC standard, and our principle is compatible with the existing IFC specifications and some ongoing IFC extensions. Our approach mainly consists of two aspects: semantic modeling and geometric modeling. Our approach has been preliminarily tested through visual inspection of some examples including geometric shapes, entities and properties in a prototype software. In addition, the data model is also applied to a pilot railway project in China.

Keywords: BIM, Information Modeling, IFC, Railway.

1. INTRODUCTION

The railway transport, especially for the high-speed rail (HSR), is an important way of transportation in densely populated areas or metropolitans. The design and construction of railway is a complex engineering in that various disciplines and widely-differing scales have to be considered. Traditional designers are still designing and delivering 2D drawings for railway projects, which is time-consuming and error-prone. During the last decade, Building Information Modeling (BIM) technology has received a considerable amount of attentions in the AEC (Architecture, Engineering and Construction) industry to support lifecycle data sharing (Eastman et al., 2011). For the building construction sector, Industry Foundation Classes (IFC) (buildingSMART, 2015) has been established for a de jure standard, which has been widely supported by major BIM software vendors. Recently, the scope of BIM applications is intended to support the infrastructure domain such as bridges, tunnels, roads and railways. However, there is very limited data exchange support for the infrastructure sector at present. Although some recent efforts including LandXML (LandXML, 2014) and TransXML (TransXML, 2006) could be used for the representation of roads, they do not cover various infrastructure facilities and cannot represent the infrastructure elements with a fine granularity.

In order to meet the interoperability need of the infrastructure domain, some data models based on IFC have be developed, which provide the well-organized kernel and contain rich information objects used in construction industry. For instance, IFC-Bridge is an extension of the IFC standard to cover the bridge entities, which is still in the development (Yakubi et al., 2006; Lebegue et al., 2012). Another ongoing extension IFC-Tunnel is mainly driven by the German IFC Tunnel Project (Amann et al., 2013; Borrmann et al., 2012; Borrmann et al., 2013; Hegemann et al., 2012) and the Japanese Shield-Tunnel Project (Yabuki et al., 2007; Yabuki, 2008). IFC-Road (Lee & Kim, 2011) extend the IFC schema for road structures. In addition, the OpenINFRA consortium was founded in 2012 within buildingSMART to establish the IFC-based models for infrastructure including roads, bridges, tunnels and railways in the IFC 5 standard (Liebich, 2014). However, as for information modeling of railway engineering, there is no such IFC-based counterpart yet. To address this issue, we present an information modeling approach for railway engineering based on IFC. Meanwhile, we also develop an initial data model of railway engineering based on the approach and the exchange mechanism of IFC standard.

2. METHODOLOGY

The existing IFC standard identifies construction project information as the entities and the properties. For the information modeling of railway engineering, we follow several principles: (1) "Compatible principle" for achieving the compatibility with the existing IFC standard and the ongoing extensions, (2) "Abstract principle" for defining the generic entities that are widely understood and used, and (3) "Minimum principle" for making minimal modifications and extensions to the existing data model.

The proposed data model (named *IFC Railway*) is based on IFC, which is also an object-oriented generalized model. It enables the interoperable sharing and exchanging of projects' data, such as geometric shapes, attributes and relationships, among heterogeneous software packages throughout the lifecycle of the infrastructure. The basic elements of the model are named the *entities*. The framework of IFC Railway is in a hierarchy manner, as shown in Figure 1.

- From top to down, the top tier shows the existing entities in IFC 4x1. All the entities of IFC Railway will be inherited from these entities to make use of the current IFC mechanism. Note that the previous IFC development mainly focused on building entities such as building stories, slabs, walls and windows.
- The second tier is the extended entities of IFC Railway to define the generic entities in railways. The third tier is the predefined type enumerations of the extended entities, which define the specific types of the extended entities. The second and third tiers make changes to the EXPRESS schema of IFC, which are based on the *static extension*.
- The bottom tier is based on the *dynamic extension*, which is a way to extend the expressiveness of IFC entities referred to an external railway classification system in a certain country/region. Such a way does not change the IFC schema. In particular, the value of the ObjectType is linked to the external classification number, which indicates the most specific entity according to the specific country or region.
- The attributes of IFC entities can be associated with the properties or a group of properties (Property Set). We added the new Property Sets of IFC Railway entities by PSD (Property Set Definition), which do not make any change of the IFC schema either.

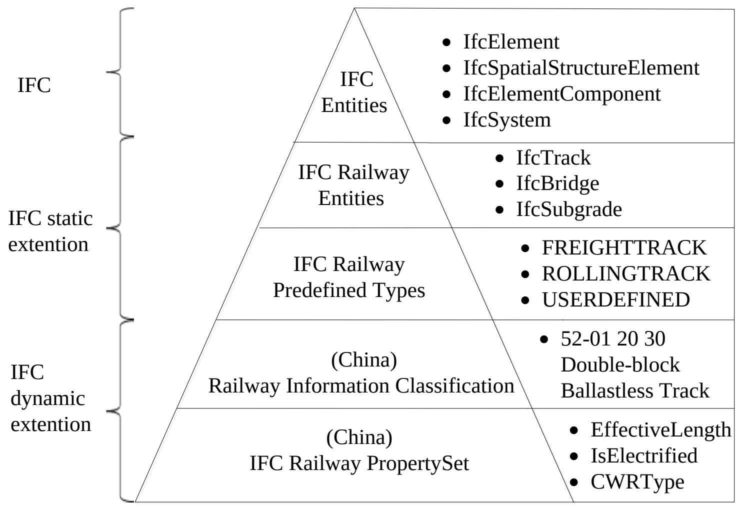

Figure 1. The framework of IFC Railway

In this paper, the static extension is mainly addressed, while the dynamic extension is implemented by referring to the "*Chinese Railway Engineering Information Classification System*" (based on ISO 120006-2). The IFC standard provides a clear separation between semantic definition and geometric representation. Correspondingly, the proposed IFC Railway model consists of the two aspects as follows.

- **Semantic modeling**. It aims to develop the new railway entities, which are inherited from IfcProduct and denoting various railway elements including the track, subgrade, contact network, station, tunnel, bridge, terrain, etc. (see Section 3).
- **Geometric modeling**. It aims to provide the new shape representations of railway entities, where we utilize some existing IFC geometric entities only with some small extensions such as the new types of transition curves (see Section 4).

3. SEMANTIC MODELING

Based on the IFC framework, we have developed 83 entities to denote the semantics of railway engineering. These entities can be divided into 19 spatial structure elements, 56 physical elements and 8 element components according to their characteristics and functions. All the new entities are the subtypes of IfcProduct, each of which holds an attribute of IfcProductRepresentation for geometric representations, and an attribute of PredefinedType for their subtypes. Many entities of IFC Railway, especially for the subgrade, terrain, bridge and tunnel, are expected to be shared with other ongoing IFC infrastructure projects such as the IFC Road (Lee & Kim, 2011).

3.1 Spatial Structure Elements

Spatial structure elements represent the structure decomposition of a project. To be compatible with other ongoing IFC infrastructure projects, we first develop the IfcCivilStructureElement (which is derived from the IfcSpatialStructureElement) as the supertype of all new spatial structure elements (Figure 2, the entities in IFC 4x1 are indicated in grey shading). Then, the IfcSubgradeStructureElement, the IfcBridgeStructureElement and the IfcTunnelStructureElement are directly derived from the IfcCivilStructureElement, so that they can be shared between the railway engineering and other types of infrastructure (e.g. the road engineering). The spatial structure elements used in the railway engineering are derived from the IfcRailwayStructureElement, and they could refer to the shared spatial structure elements. For example, a segment of railway could be composed of a segment of track and a segment of subgrade/bridge/tunnel underneath. This is denoted by an IfcRelAggregates entity which has an IfcRailway entity as the RelatingObject attribute, and has an IfcTrack entity and an IfcSubgrade/IfcBridge/IfcTunnel entity as the RelatedObjects attribute.

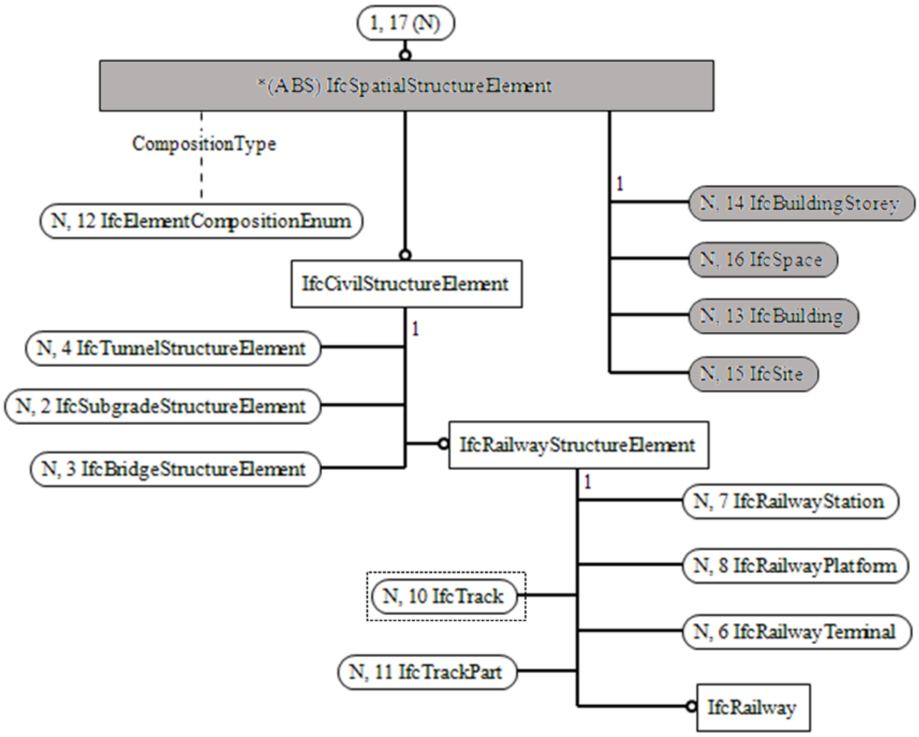

Figure 2. Illustration of the spatial structure elements of IFC Railway

3.2 Physical Elements

Physical elements in IFC are the entities that exist physically and can be contained or referenced in the spatial structure. In the IFC Railway, all railway physical elements are inherited from the IfcElement. Similar to the spatial structure elements, the physical elements that could be shared between the railway and the road engineering are categorized into the group of IfcSubgradeElement, IfcBridgeElement and IfcTunnelElement. The elements specifically used in the railway engineering are categorized into the group of IfcRailwayElement. For example, the IfcTrackElement illustrated in Figure 3 is one of the IfcRailwayElement's subtypes.

3.3 Element Components

Element components are the small objects that are attached to, included in, or plays the reinforcing (or connecting) role in the physical elements. The element components generally do not contain specific spatial boundaries. We develop the IfcCivilElementComponent entity (which is derived from the IfcElementComponent) as the supertype of all developed element components (see Figure 4). The element components are further subtyped by the predefined type enumerations. For example, the "IfcTrackRailJoint" has the subtypes RAILJOINTFASTENING, COMPROMISINGJOINT, INSULATEDJOINT, WELDEDJOINT, CONDUCTIVEJOINT and UNCHANGEABLEJOINT.

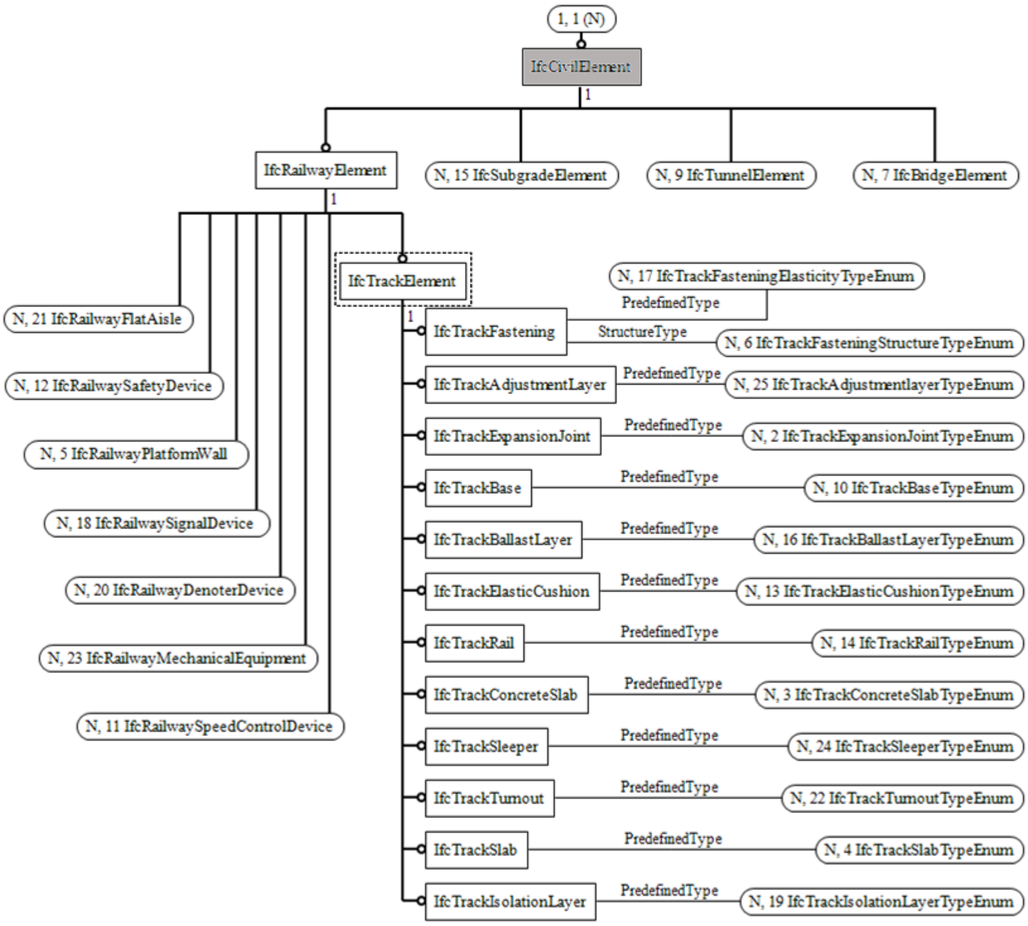

Figure 3. Illustration of railway physical elements

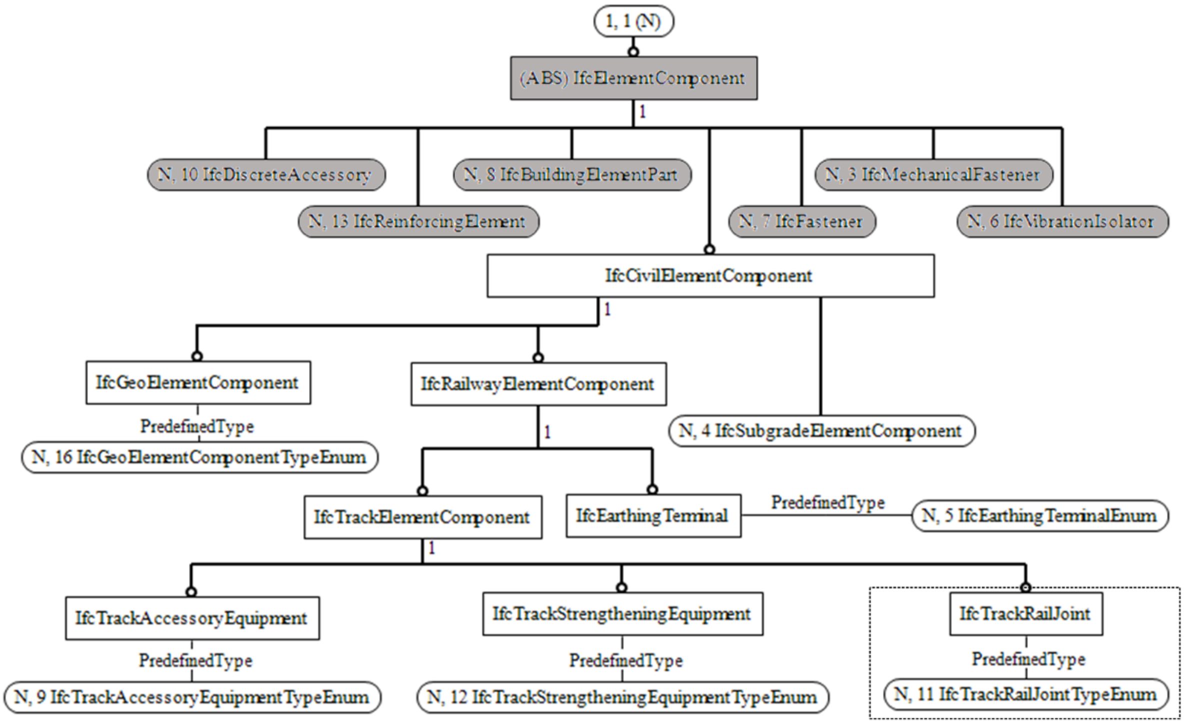

Figure 4. The railway element components

4. GEOMETRIC MODELING

Within the IFC data model, the semantic definition of a product object can be connected to different geometric representations through the entity IfcShapeRepresentation. Following the “minimum principle”, we illustrate the geometric representations of railway entities with existing geometric resources and necessary extension, respectively.

4.1 Geometric Representation for Railway Elements

The IFC model allows various geometric representations such as Boundary Representation (B-rep), Constructive Solid Geometry (CSG) and extrusion/sweep based geometry descriptions. Table 1 lists the geometric representations used in the IFC Railway. Due to the railway’s nature of being a linear infrastructure facility, large parts of the railway elements are the continuous elements. For describing the geometry of these elements, we use the swept area geometry representation (IfcSweptAreaSolid) to define geometry by means of cross-sections extruded along a given axis. For describing the geometry of the discrete elements, the straightforward boundary representations are adopted. The position of non-continuous elements along the axis is defined by a reference to the corresponding chainage value of the underlying alignment curve.

Table 1. The geometric representations of IFC Railway elements

Entity types	Examples of entities	Geometry representations
Railway alignment	IfcTransitionCurve2D	Curve geometry eg. IfcTrimmedCurve
Continuous railway elements	IfcTrackRail, IfcTrackBase, IfcTrackSlab, IfcSubgradeRetainingElement, IfcBridgePart, IfcCable, IfcTunnelPrimarySupport	Profile geometry eg. IfcSweptAreaSolid
Discrete railway elements	IfcTrackSleeper, IfcTrackTurnout, IfcRailwaySignalDevice, IfcRailwayDenoterDevice, IfcBridgeMember	B-rep geometry eg. IfcManifoldSolidBrep
Terrain (IrregularShape)	IfcGeographicElement, IfcSubgradeFillingWorks,	Mesh geometry eg. IfcTriangulatedFaceSet

4.2 Railway Transition Curve

One main difference between the infrastructure domain and the building domain lies in that the infrastructure is built along the alignment. The alignment is often described by 2D curves, namely the horizontal alignment and the vertical alignment (Scarponcini, 2014). In general, the horizontal alignment consists of line segments, arcs and transition curves, while the vertical alignment consists of line segments and parabola arcs. We extend the latest IFC Alignment in the IFC 4x1 (buildingSMART, 2015) to the railway transition curve.

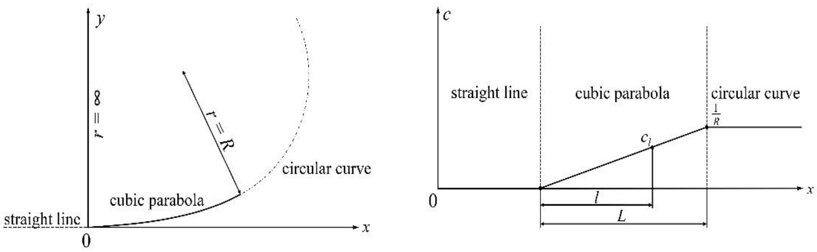

Figure 6. The railway transition curve

To design a railway alignment, if an arc segment directly follows a straight-line segment, the resulting (continuous) alignment curve will have a discontinuity in the curvature. The transition curves ensure a smooth transition between curves with different curvature in order to avoid curvature discontinuities (see Figure 6). With the transition curves, the curvature changes from zero to a finite value. In addition, the transition curve provides a gradual change of superelevation. The Clothoid Curve is the only transition curve defined in the latest IFC 4x1 data model; however, the Cubic Parabola is always used as the transition curve in China railway engineering. Therefore, the Cubic Parabola should be also included in the IFC Railway, which is defined as Eq. (1):

$$y_l = \frac{l^3}{6RL},\ h_l = h(\frac{l}{L}) \text{ and } c_l = \frac{1}{R}(\frac{l}{L}) \tag{1}$$

where R: The radius of the circular curve,
l: The length of the transition curve to a point,
L: The total length the transition curve,
h: The superelevation of the circular curve,
y_l: The y coordinate of on the transition curve at l,
h_l: The superelevation of the transition curve at l,
c_l: The curvature of the transition curve at l.

Accordingly, we define the railway transition curve as a subtype of IfcCurveSegment2D (see Table 2). The IfcCurveSegment2D holds three attributes (StartPoint, StartDirection and SegmentLength), which represent the start point of the curve, the direction of the tangent at the start point, and the total length of the curve. We add the three attributes to represent the radius and the orientation of the transition curve. Besides, we add an attribute TransitionCurveType to support possible extension use for the entity as other types of transition curves.

Table 2. The IFC Railway transition curve entity

```
ENTITY IfcTransitionCurve2D
 SUBTYPE OF (IfcCurveSegment2D);
        StartRadius : IfcPositiveLengthMeasure;
        IsCCW : IfcBoolean;
        EndRadius : IfcPositiveLengthMeasure;
        TransitionCurveType : IfcTransitionCurveTypeEnum;
END_ENTITY;
```

4.3 Railway Chainage System

In the process of railway design, the alignment might be modified with various reasons, resulting in the change of all reference linear values. Hence, in the IFC Railway a mechanism named chainage system is added to minimize the impact of alignment changes (Table 3). To identify the position where a specific railway element is placed, we store the stationing of each railway element within the chainage system. This also enables us to generate the new railway elements such as signal devices, when the alignment of the railway is changed.

With the help of the chainage, it is possible to set the "broken chainage", where the chainge value before a point and the value after the point are discontinuous to achieve the stability of chainage of a railway. As an example in Figure 7(A), the chainage is continuous. Due to the change of the alignment, the length of the red section of the line is shortened in Figure 7(B). In order to maintain the chainage value unchanged except the range of DK1+000 to DK2+000, only the attribute StartChainageNamely of the corresponding IfcChainageSystemElementSeg is changed.

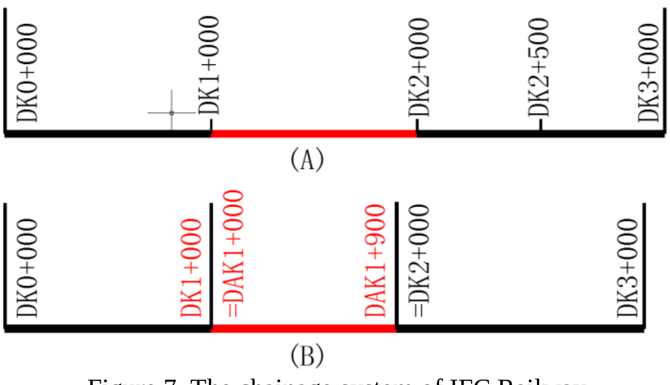

Figure 7. The chainage system of IFC Railway

Table 3. The chainage entities of IFC Railway

```
ENTITY IfcChainageSystemElement;
        Segments : LIST [1:?] OF IfcChainageSystemElementSeg;
        ToHorizontal : IfcAlignment2DHorizontal;
END_ENTITY;
```

```
ENTITY IfcChainageSystemElementSeg;
	StartDistAlong : IfcLengthMeasure;
	LengthOfChain : IfcLengthMeasure;
	StartChainageNamely : IfcReal;
	IsChainageNamelyIncreaseAlongAlignment : IfcBoolean;
	Prefix : IfcLabel;
	ToChainageSystemElement : IfcChainageSystemElement;
END_ENTITY;
```

5. SOFTWARE VALIDATION

To validate the proposed approach, the proposed data model is implemented in the Dassault CATIA V6 and the open source IFC-compatible visualization tool IfcPlusPlus (Gerold, 2016). The data model has also been applied to an actual railway construction project since September of 2015 in order to verify its applicability. The tested railway is with 90.669 kilometers, which starts from the Yangquan North Station and ends at the Dazhai Station in Shanxi Province of China. Figure 9 shows a segment of railway at the Yangquan North station, which is designed in CATIA. The model is then exported to the IFC Viewer through the STEP file. The visualization of the railway model is displayed on the left, and the semantic structure of the model is showed on the right. Our experiments shows that the geometric and semantic information can be kept between the software prototypes based on the IFC Railway data model. However, we also found that the new IFC file is redundant and needs a lot of time to load, which can be further optimized through the IFCCompressor toolkit developed in our previous work (Sun et al., 2015).

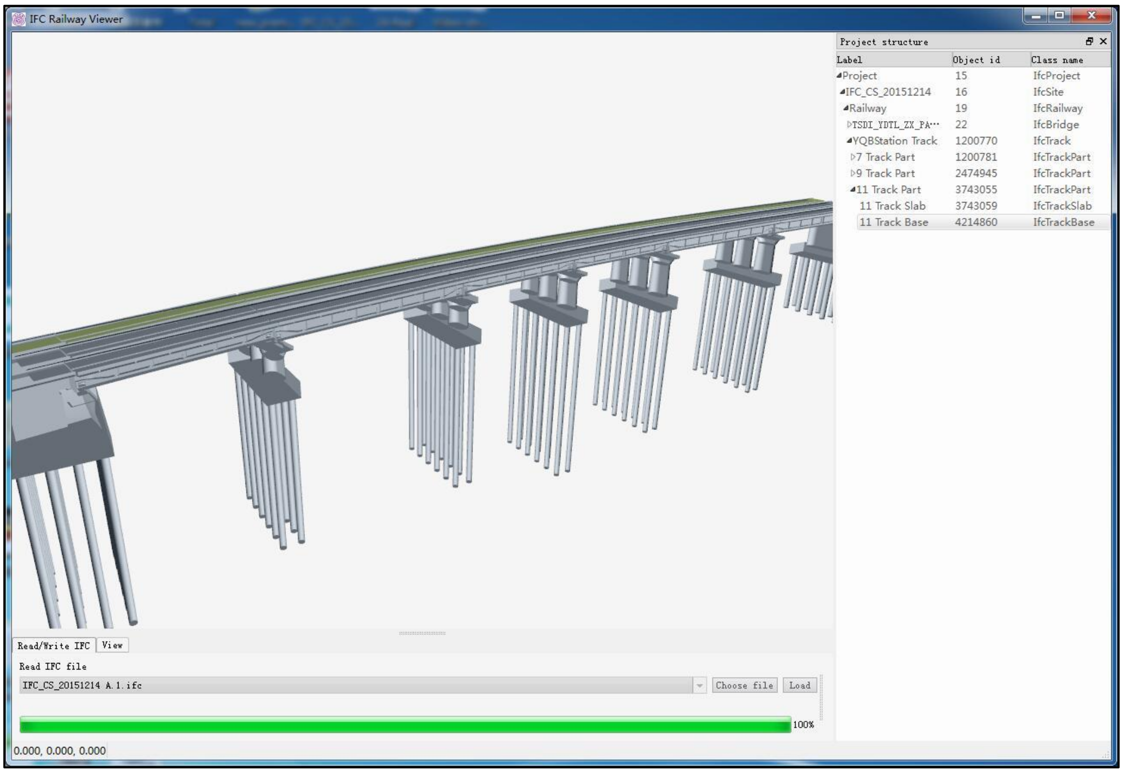

Figure 9. Displaying the IFC model of the Yangquan North Station in our IFC Railway Viewer

6. CONCLUSIONS

This paper introduces an IFC Railway data model, which is under development in China. Our approach consists of the static and dynamic extensions based on IFC. For various railway disciplines, we describe the definition of spatial structure elements, physical elements and element components in details. This new data model has been preliminarily supported in a prototype system to validate its usability. Our approach has several advantages. On the one hand, it is compatible with the IFC 4 standard and some ongoing IFC infrastructure extensions. On the other hand, it makes use of the IFC extension mechanism and could be supplemented with various railway information classification systems or libraries. However, the information modeling techniques and operation strategies for the infrastructures are in an early development stage, which still remains some research challenges.

Some common parts between different IFC extensions need to be further coordinated. For example, a considerable numbers of entities from the ongoing IFC Road project and our IFC Railway entities could be shared. Moreover, most of existing IFC software cannot recognize the newly added entities and geometries yet.

In the future, the coordination with other IFC 5 infrastructure projects including IFC Tunnel, IFC Road and IFC Road will be our major concern. It looks promising that these projects are being coordinated with each other with the help of the newly founded buildingSMART InfraRoom Overall Architecture Group (Borrmann, 2016). The software development for our data model such as efficient converter and web-based viewer is also our future work.

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