Transforming National Guidelines into Operable Solutions in IFC: Case Study of REB 22.001

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Abstract
The study at hand explores and reports on an quantity take-off (QTO) business case for road projects using the Industry Foundation Classes (IFC) data model. It follows the Information Delivery Manual (IDM)/Model View Definition (MVD) development process. We take the Regeln für die elektronische Bauabrechnung – Verfahrensbeschreibung (REB-VB) (Regulations for Electronic Billing in Construction – Procedural Description) 22.001 guideline as an IDM defining the QTO requirements for road objects. A specialized MVD *MVD_REB_22001* has been developed and prototypically implemented to test its correctness. The resulting MVD is light-weight and can be used for exchange and quality control of REB-VB 22.001 compliant road quantities using IFC. The results showcase the great flexibility of IFC as well as the robustness of the IDM/MVD methodology. Additionally, this study may serve as a template for future endeavours showcasing how national guidelines can employ IFC to ensure semantically crisp and seamless information exchanges.

1. Introduction
One of the benefits of any information provided within digital models is its readiness for immediate consumption by algorithms without any need for human interaction. Moreover, repetitive tasks and computationally demanding analysis can be fully automated. The focus of this study is a standardized exchange of road quantities in the architecture, engineering and construction (AEC) domain. That is, a commonly applicable information model (IM) for road quantity take-off (QTO) is sought for, which could support improved workflows when creating bill of quantities with precise road data.
On the one hand, International Organization for Standardization (ISO) published a new version of Industry Foundation Classes (IFC) in 2024 – IFC4.3 – which introduces many new concepts from the infrastructure domain in general, and road domain in particular. As such, it is now possible to define specifications for IFC exchanges in the infrastructure sector with clear semantic assignment of objects and their attributes. On the other hand, Regeln für die elektronische Bauabrechnung – Verfahrensbeschreibung (REB-VB) (Regulations for Electronic Billing in Construction – Procedural Description, in German) include the procedural descriptions for the billing of roadway structures, e.g. road construction sites. Specifically, REB-VB 22.001 standardises the minimum set of quantities

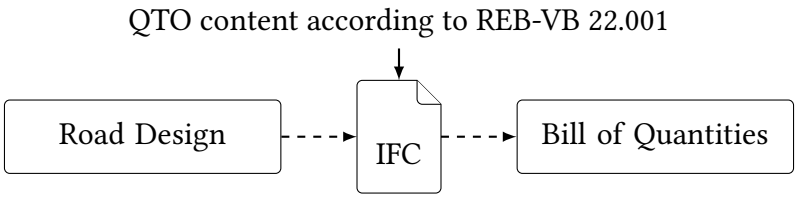

Figure 1: The business case in focus: exchange of QTO data for road facilities following REB-VB 22.001 using the IM IFC (following ISO 29481, 2016).

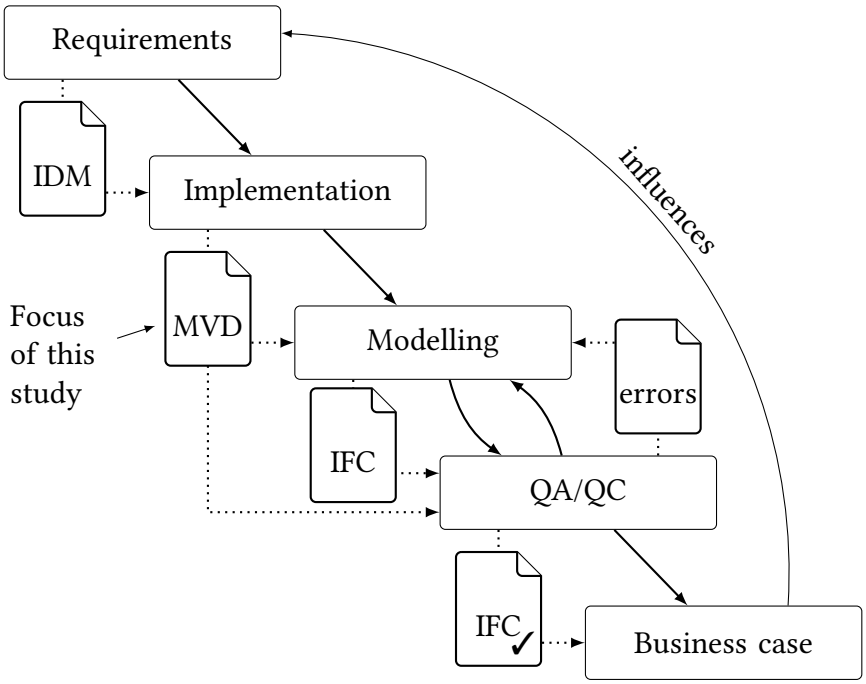

Figure 2: The IDM/MVD methodology used for this study. The requirements stemming from the envisioned business case are captured in an IDM document. The exact mapping to the IFC IM is defined glsifc with an MVD, which represents the basis for modelling as well as for the QA/QC loop (based on ISO 29481, 2016).

applicable to road objects for the German market (REB-VB 22.001, 2022). The study at hand explores and reports on the exchange of road quantities following REB-VB 22.001 using IFC as depicted in Figure 1.

In order to systematically approach business cases in the AEC domain, buildingSMART International (bSI) community developed multitude of documentation standards together with the methodology as shown in Figure 2. An Information Delivery Manual (IDM) encapsulates the requirements of the scope of the data exchange, focusing on its business case, the actors involved, the process, the exchange requirements, and the information units (ISO 29481, 2016). From this, an implementation guideline for a specific IM in the form of an Model View Definition (MVD) can be derived, defining which entities shall be used in what constellation, and which attributes shall be filled with concrete data. Having defined the IDM and the MVD, AEC experts can produce their models and exchange them using the underlying IM, e.g. the non-proprietary, open IM: IFC[1]. These models can be continuously checked in an automated quality assurance / quality control (QA/QC) loop using the MVD definitions. This ensures the availability and correctness of the exchanged data for the business case described within the IDM.

[1] An example MVD for the IFC data model is the Reference View 1.2 (RV) (bSI, 2020).

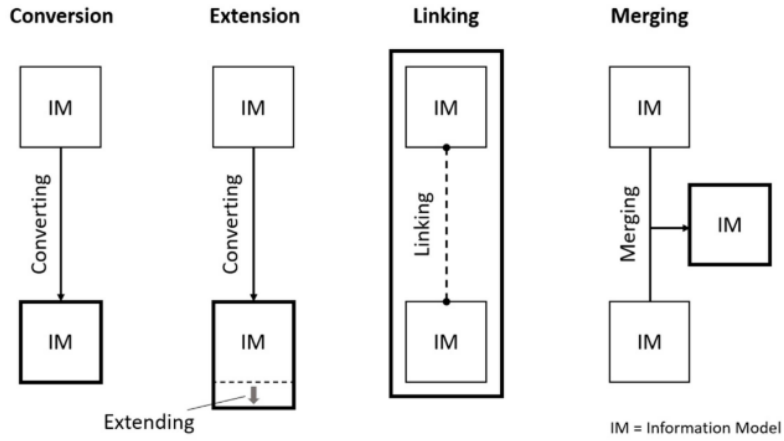

Figure 3: The different integration methods of two IMs (Beck et al., 2021). This study follows the left-most method: Conversion.

We take the REB-VB 22.001 guideline as an IDM, defining the QTO requirements for road objects. Its initial implementation in Objekt Katalog Straße (road catalogue for roads, in German) (OKSTRA) is considered as a complete requirement model and transformed into a specialized MVD for the IFC IM: *MVD_REB_22001*. For this, mapping tables between OKSTRA and IFC standards are derived and appropriate concept templates and template usages from the RV selected. In a nutshell, we convert the subset REB-VB 22.001 of the OKSTRA IM to the subset *MVD_REB_22001* of the IFC IM.

The integration of IMs is a common topic in current research, e.g. between the research fields Building Information Modelling (BIM) and Geographic Information System (GIS). Beck (2023) has conducted an extensive literature research on the integration of IMs of BIM and GIS and found that the research on information integration differs both in terms of integration methods and IMs. For example, the information integration can be applied on either instance or schema levels. There are four major types of integration methods: conversion, extension, merging, or linking as presented in Figure 3 (Beck et al., 2021).

A specialized MVD for IFC to support road QTO exchanges is unknown to the authors. However, MVDs have been successfully created before for related business cases from the AEC domain. Weise et al. (2016) explored how MVD can be employed to check IFC models of hospitals with promising results. Oostwegel et al. (2022) developed an IDM based on a national guideline and derive an MVD for historical BIM models. Moreover, the developed rules have been used for QA/QC of the IFC model with all intentional modelling mistakes correctly identified. Related, Schamne et al. (2024) successfully developed a conceptual model for construction waste management based on IFC, but did not develop a complete MVD.

The paper is structured as follows. This section presents our motivation, problem statement, the methodology followed, and related works. Section 2 presents background information on REB-VB, IFC, and MVD, as required for this study. The main contribution of this paper is described in depth in Section 3 with the developed MVD as well as a prototypical implementation. We discuss our results and conclude with Section 4.

2. Background

REB-VB contains the procedural descriptions for the billing of works, e.g. road construction sites. In particular, REB-VB 22.001 regulates the exchange of objects with their geometric definitions and associated quantities. The geometric objects are transferred between the source and the target systems with the quantities determined in the source

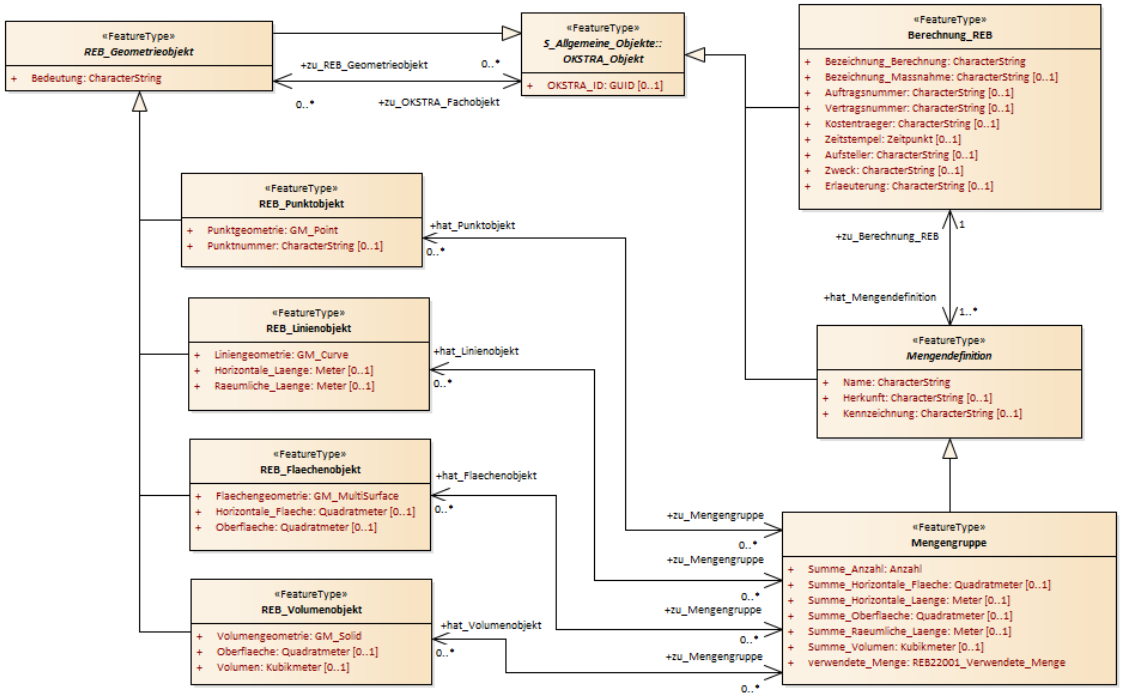

Figure 4: An UML diagram of REB-VB 22.001 for OKSTRA IM (REB-VB 22.001, 2022).

system provided as an attribute of the object in question, together with the associated quantity groups. The target system can check that the quantities determined in the source system do not exceed certain tolerances when compared with the quantity calculation within the target system (REB-VB 22.001, 2022). The initial implementation has been achieved within the OKSTRA IM. An Unified Modeling Language (UML) diagram is presented in Figure 4 (REB-VB 22.001, 2022). The quantities in scope of REB-VB 22.001 are i) count [pcs], ii) horizontal length [m], iii) spatial length [m], iv) horizontal area [m^2], v) surface area [m^2], and vi) volume [m^3]. These are assigned to the objects a) point, b) line, c) area, and d) solid, as applicable[2] (cf. *REB_Geometrieobjekt* with its children on Figure 4). Quantity groups can contain one or more objects and provide the (quantity) totals of all the objects they reference (cf. *Mengengruppe* on Figure 4). The groups themselves are assigned to the exchange container, which holds additional metadata of the exchange (cf. *Berechnung_REB* on Figure 4).

IFC is an IM that enables the exchange of high-quality geometric and semantic data of built environment (ISO 16739, 2024). Its development began in the 1990s and manifested several published versions. The IFC2x3 version was the first practical version and is widely used, both by software providers in their products and by experts in their workflows. The IFC4 version extends and standardizes the existing concepts from IFC2x3, for example witha general purpose MVD: RV (bSI, 2020). However, the development of the two IFC versions mentioned above only focused on the exchange of building models and completely neglected the infrastructure sector. Over the last ten years, interest in extending IFC to support infrastructure workflows has continued to grow. The resulting new version IFC4.3 with a multitude of new concepts for the infrastructure domains was ratified in early 2024 (ISO 16739, 2024).

IFC supports multitude of business cases from the AEC industry. Since no software product supports all of them, and no information exchange employs the whole IM, bSI

[2]For example, an area (Item c) shall have both horizontal and surface areas (Items iv and v) assigned.

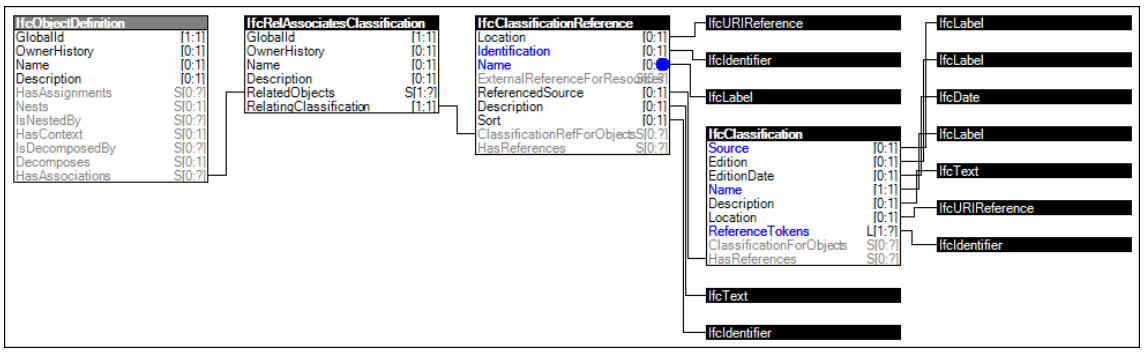

Figure 5: Graphical representation of *Classification for Objects* (bSI, 2020).

Table 1: Mapping between OKSTRA and IFC data types.

OKSTRA	**IFC**
GUID	IfcGloballyUniqueId
CharacterString	STRING, IfcLabel, IfcIdentifier, IfcText
Zeitpunkt	IfcDateTime
Anzahl	NUMBER, IfcCountMeasure
Meter	IfcLengthMeasure
Quadratmeter	IfcAreaMeasure
Kubikmeter	IfcVolumeMeasure
GM_Point	IfcPoint
GM_Curve	IfcCurve
GM_Multisurface	IfcSurface
GM_Solid	IfcSolid
REB22001_Verwendete_Menge	IfcLabel (with corresponding restrictions)

developed some MVDs to limit the scope of implementation and thus ensure faster adoption by the industry as well as make certification more achievable. In a nutshell, an MVD limits the amount of entities from the IFC schema by carefully selecting a subset. For example, IfcExtrudedAreaSolid is part of RV, while IfcTask is not. Additionally, specific graphs and combinations of attributes are explicitly allowed and/or required to be populated. As presented in Figure 5, to assign classification to an object, the entities IfcClassification, IfcClassificationReference and IfcRelAssociatesClassification have to be correctly connected among one another and to the object in question, with the attributes shown in blue being testable and queryable.

3. MVD_REB_22.001

The REB-VB 22.001 data schema uses several OKSTRA data types (see Figure 4). The matching data types in IFC were identified and compiled in Table 1. For some data types several suitable IFC types are listed, that should be selected sensibly in the respective context of use (e.g. CharacterString). Similarly, any entity from the inheritance tree shall be used for abstract entities (e.g. IfcSolid).

The main components of an MVD are carefully selected functional blocks that apply to individual entities. Table 2 contains the assignment of relevant concepts with the corresponding applicable entities for the functional blocks identified from Figure 4. For

Table 2: Enumeration of the concepts and the applicable entities for *MVD_REB_22.001*. The complete documentation of the concepts can be found in chapter 4 of bSI (2020).

ID	Concept	IFC Entity	Comment
-1-	Product Geometric Representation	IfcElement	Assigns geometry to objects
-2-	Quantity Sets	IfcElement	Assigns quantities to objects
-3-	Quantity Sets	IfcGroup	Assigns quantities totals to groups
-4-	Project Declaration	IfcProject	Declares groups of the exchange
-5-	Group Assignment	IfcGroup	Assigns groups to objects
-6-	Assignment to Group	IfcElement	Assigns objects to groups
-7-	Project Classification Information	IfcProject	Defines classification OKSTRA
-8-	Classification for Objects	IfcElement	Assigns classification to objects
-9-	Property Sets for Objects	IfcProject	Assigns exchange metadata

Table 3: The mapping for OKSTRA elements *OKSTRA_Objekt* and *Berechnung_REB* to IFC entities and attributes, as well as concepts from Table 2.

OKSTRA	IFC Entity	Attribute	Ref.
OKSTRA_Objekt	IfcElement	-	
OKSTRA_ID	IfcRoot	GlobalId	
zu_REB_Geometrieobjekt	-	ignored, same object	
Berechnung_REB*	IfcPropertySet	-	-9-
Bezeichnung_Berechnung*	IfcPropertySingleValue	Value	-9-
Bezeichnung_Massnahme*	IfcPropertySingleValue	Value	-9-
…	…	*simile for other attributes*	-9-
hat_Mengendefinition	IfcProject	Declares	-4-

* The value of the IFC entity's attribute Name equals this exact string.

example, the concept template *Quantity Sets* enables attaching different quantities (IfcPhysicalQuantity) to individual model elements (IfcObject) and the quantity totals to the quantity groups (IfcGroup) (cf. -2- and -3-, respectively).
To enable the implementation of *MVD_REB_22.001* in software, it was necessary to map each element from Figure 4 with all of its attributes to IFC. Meaningful entities and/or their attributes were identified and the results are listed in Tables 3 to 5. For example, the Name attribute of a quantity group (*Mengengruppe*) can be mapped to the Name attribute of an IfcGroup. Some attributes have already been assigned using the selected concepts from Table 2, such as the *hat_Mengendefinition* attribute of the *Berechnung_REB* object. Here, the *Project Declaration* concept is used to create a link between the exchange container (IfcProject) and the individual quantity groups (IfcGroup) using IfcRelDeclares (cf. -4- with Table 3). Additionally, not all quantities have to be assigned to all objects, but are selected according to the dimensionality of the object's geometry (cf. *REB_Geometrieobjekt* with its children on Figure 4).
Figure 6 shows an exemplary structure of an IFC file according to *MVD_REB_22.001*. The entity IfcProject (left centre) represents the container for the data exchange. The necessary metadata is attached using a specialized IfcPropertySet as defined in Table 3

Table 4: The mapping for OKSTRA element *Mengengruppe* to IFC entities and attributes, as well as concepts from Table 2.

OKSTRA	IFC Entity	Attribute	Ref.
Mengendefinition	IfcGroup	-	
Name	IfcGroup	Name	
Kennzeichnung	IfcGroup	ObjectType	
Herkunft	IfcGroup	Description	
zu_Berechnung_REB	IfcGroup	HasContext	-4-
Mengengruppe	IfcElementQuantity	-	-3-
Summe_Anzahl*	IfcQuantityCount	CountValue	-3-
Summe_Horizontale_Laenge*	IfcQuantityLength	LengthValue	-3-
Summe_Raeumliche_Laenge*	IfcQuantityLength	LengthValue	-3-
Summe_Horizontale_Flaeche*	IfcQuantityArea	AreaValue	-3-
Summe_Oberflaeche*	IfcQuantityArea	AreaValue	-3-
Summe_Volumen*	IfcQuantityVolume	VolumeValue	-3-
verwendete_Menge	IfcElementQuantity	MethodOfMeasurement	
hat_Punktobjekt	IfcGroup	IsGroupedBy	-5-
hat_Linienobjekt	IfcGroup	IsGroupedBy	-5-
hat_Flaechenobjekt	IfcGroup	IsGroupedBy	-5-
hat_Volumenobjekt	IfcGroup	IsGroupedBy	-5-

* The value of the IFC entity's attribute Name equals this exact string.

Table 5: The mapping for OKSTRA element *REB_Geometrieobjekt* and its subclasses to IFC entities and attributes, as well as concepts from Table 2.

OKSTRA	IFC Entity	Attribute	Ref.
REB_Geometrieobjekt	IfcElement	-	
zu_OKSTRA_Fachobjekt		ignored, same object	
Bedeutung	IfcClassificationReference	Identification	-8-
Punktgeometrie	IfcElement	Representation	-1-
Punktnummer	IfcElement	Tag	
Liniengeometrie	IfcElement	Representation	-1-
Flaechengeometrie	IfcElement	Representation	-1-
Volumengeometrie	IfcElement	Representation	-1-
zu_Mengengruppe	IfcElement	HasAssignments	-6-
-	IfcElementQuantity	Name = "REB_Mengen"	-2-
Horizontale_Laenge*	IfcQuantityLength	LengthValue	-2-
Raeumliche_Laenge*	IfcQuantityLength	LengthValue	-2-
Horizontale_Flaeche*	IfcQuantityArea	AreaValue	-2-
Oberflaeche*	IfcQuantityArea	AreaValue	-2-
Volumen*	IfcQuantityVolume	VolumeValue	-2-

* The value of the IFC entity's attribute Name equals this exact string.

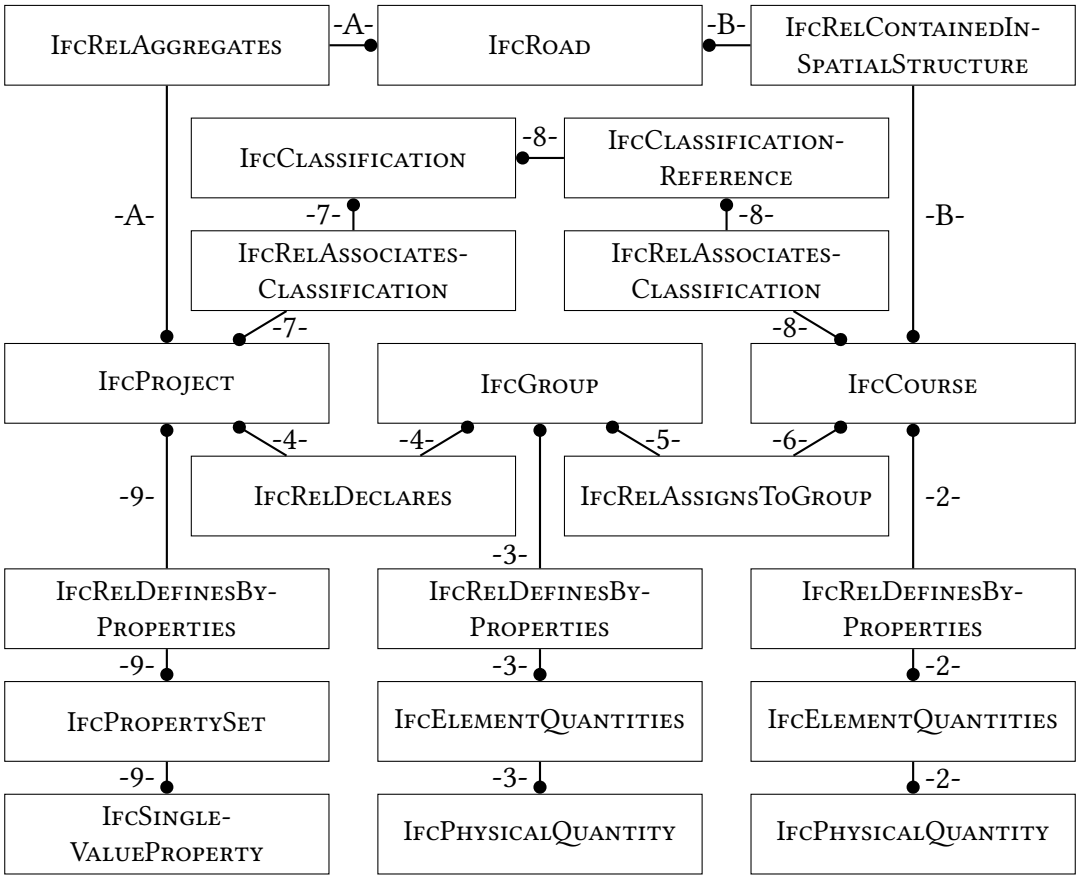

Figure 6: Example instance diagram for a complete QTO of a road's pavement layer according to *MVD_REB_22001*. The numbers on the connections correspond with concept templates from Table 2. The names of the attributes as well as IfcCourse.Representation from -1- not shown for brevity. -A- and -B- stand for *Spatial Aggregation* and *Spatial Containment*, respectively, which are not required by REB-VB 22.001, but included to be in line with RV (bSI, 2020).

(bottom left). The dataset contains a road's pavement layer IfcCourse (right centre), which is assigned to a quantity group IfcGroup (centre). These are linked to each other by the relation IfcRelAssignsToGroup. The quantity group is declared in the project via the IfcRelDeclares relation.

Both the pavement layer and the quantity group have corresponding quantities IfcPhysicalQuantity assigned via the relation IfcRelDefinesByProperties and the entity IfcElementQuantity (bottom right and centre, respectively). The project defines the "OKSTRA" classification with IfcClassification via the relation IfcRelAssociates-Classification (top centre). The corresponding classification in accordance with OKSTRA is assigned to the pavement layer via the relation IfcRelAssociatesClassification and the entity IfcClassificationReference.

In order to complete the example, some additional entities are added. The pavement layer belongs to a road spatial container IfcRoad via the relation IfcRelContainedIn-SpatialStructure, which itself then belongs to the project via the relation IfcRelAggregates (top, -B- and -A-, respectively). These requirements do not stem from REB-VB 22.001, but rather ensure that the developed *MVD_REB_22.001* remains in scope of the well-established RV (bSI, 2020).

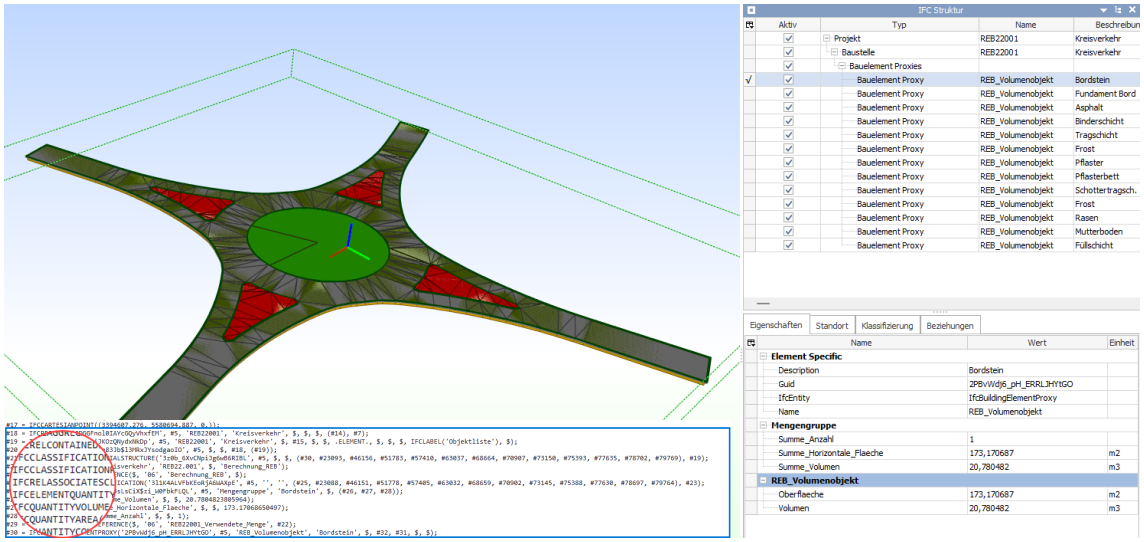

Figure 7: Import of the exemplary roundabout project into an IFC viewer. A snippet of IFC content is shown at the bottom. The quantities for the selected curb element can be seen on the right bottom.

3.1. Prototype Implementation

The newly developed MVD was prototypically implemented in *VESTRA INFRAVISION* and *KOSTRA PRO* software products of *AKG Software Consulting GmbH*. The former supports roadway design, while the latter supports cost calculations and billing, thus employing a software product for both activities from Figure 1.

First, we modelled a simple roundabout and exported an *MVD_REB_22.001* compliant IFC dataset. Second, we loaded the dataset into a general-purpose IFC viewer (cf. Figure 7, left). The *MVD_REB_22.001*-compliant data structure for a curb, represented with a solid, and the associated quantity groups in accordance with REB-VB 22.001 can be seen in the detailed view (cf. Figure 7, bottom right). A snippet of the IFC file created by the export highlights the entities required for -2-, -7-, and -8- concepts (cf. Figure 7, bottom left). Third, the quantities have been imported into *KOSTRA PRO*, where a cost estimate/cost calculation has been carried out using the provided QTO specifications. For example, the unit prices for the items in the bill of quantities were fetched from a price catalogue and adjusted depending on the quantity.

4. Conclusions

The study at hand explores and reports on a standardized QTO for road projects using the IFC4.3 as presented in Figure 1. We base our study on the IDM/MVD development process from ISO 29481 (2016). The IFC schema is very generic and offers great flexibility for defining a tailor-made MVD.

We take the REB-VB 22.001 guideline from Figure 4 as an IDM defining the QTO requirements for road objects. A specialized MVD dubbed *MVD_REB_22001* has been developed as presented in detail in Section 3. For this, the OKSTRA definitions were mapped to their equivalent in IFC. We succeeded to transform a German regulation REB-VB to the globally applicable IFC IM. Additionally, the developed MVD has been prototypically implemented to prove its viability. An exemplary roundabout project has been successfully exchanged between two software products serving both ends of the process from Figure 1 as presented in Section 3.1 and Figure 7.

During the development of *MVD_REB_22001*, we limited ourselves on the set of concept templates from the RV (bSI, 2020). As a consequence, the developed MVD can be used

(with minimal adjustments) also in the previous major versions IFC2x3 and IFC4. As such, we do not impose additional burden on the existing implementations of IFC export and import interfaces within commercial software solutions, which shall enable quick adoption of *MVD_REB_22001* by the industry.

It is necessary to continue and comprehensively document the knowledge gained for the implementation of further procedures. On the one hand, procurement documents and project documentation shall have an easy and transparent way of including and/or referencing (specific) MVD requirements without the technical hassle. Combinations between different MVDs shall be standardized and made accessible to the broader AEC public. On the other hand, MVD documentations shall be openly available for any software vendor interested in supporting any business case around the world. We call for the development of sample data sets and the development of suitable methods for sustainable software certification.

In conclusion, we have successfully processed a national guideline as an IDM and developed as well as implemented a specialized MVD for the IM IFC. The results showcase the great flexibility of the IFC IM as well as the robustness of the IDM/MVD methodology to support national use cases. The resulting MVD is light-weight and can be used for exchange and quality control of REB-VB 22.001 compliant road quantities. Additionally, this study may serve as a template for future endeavours showcasing how national guidelines can employ IFC data model to ensure semantically crisp and seamless information exchanges, providing the necessary instructions for software implementation.

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