GeoMVD: the Journey to High-Quality Georeferencing Profiles in IFC Datasets

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Abstract

Georeferencing of civil engineering models is required to correctly relate geometries of digital objects to their placement on the Earth. Clemen and Görne (2019) introduce five levels of georeferencing (LoGeoRefs) for Industry Foundation Classes (IFC) datasets. However, these can be provided simultaneously and independently from one another within the same IFC dataset. This means that not only one has to check their fulfilment, but we need to forbid encoding contradictory or duplicate information. We provide check-lists for domain experts to set up the georeferencing right for their projects. Additionally, we address this gap by developing a specialized profile for IFC based data exchanges dubbed *GeoMVD*. The usefulness of the profile for georeferenced IFC models is demonstrated on a real world dataset.

1. Introduction

Georeferencing of civil engineering models is required to correctly relate geometries of digital objects to their placement on the Earth (Jaud et al., 2020). The non-proprietary, open data format Industry Foundation Classes (IFC) provides multiple possibilities for georeferencing embedded in the data schema (ISO 16739, 2024). This enables support for multitude of use cases, as each may have different requirements on the precision of the geometric location and cover various spatial extents of digital objects. For example, the street address of a building might be sufficient for daylight analysis, while more precise information about position and orientation is needed for meaningful clash detection.

The requirements can be derived from the pursued use cases and result in an information delivery manual (IDM). This document is used as input to develop the corresponding profile(s) for a selected data schema, i.e. model view definitions (MVDs). An MVD can be readily encoded in an model view definition Extensible Markup Language (mvdXML) dataset and employed for automatic quality assurance / quality control (QA/QC) (Weise et al., 2016). Based on this, the modelling and subsequent QA/QC can be repeatedly performed and the design improved upon. In the end, the high-quality data can be employed in the use cases foreseen by the IDM. Thus, the transparency of requirements, how to follow them, and how to assure their fulfilment are ensured.

One of the benefits of digital information within IFC models is its readiness for immediate consumption by algorithms without any need for human interaction. Moreover, repetitive tasks and computationally demanding analysis can be automated. Clemen and Görne (2019) introduce five levels of georeferencing (LoGeoRefs) for IFC datasets. However, these can be provided simultaneously and independently from one another within the same IFC dataset and can thus encode contradictory information. Depending on the use case pursued, specific combinations thereof are required, while others might even be forbidden. Additionally, we include the recently published new version IFC4.3 in our study (ISO 16739, 2024).

We address this research gap by developing specialized profiles for IFC data model dubbed *GeoMVD*. We follow the IDM/MVD methodology from Weise et al. (2016) as presented in Figure 1. First, all the requirements that support georeferencing are collected and ordered. From them, 5 (partial) profiles are derived – one for each LoGeoRefs. These are then exemplary combined into two general purpose MVDs: one for linear structures (prevalent in infrastructure sector), and one for compact structures (e.g. buildings and small bridges). These *GeoMVDs* shall ensure sufficient quality of the IFC datasets for the whole industry.

The paper is structured as follows. This section presents our motivation, problem statement and the methodology followed. Next section briefly summarizes related works. Section 3 presents background information on coordinate reference system (CRS) and LoGeoRef required for this study. The main contribution of this paper is described in depth in Section 4, where the requirements as well as two different implementations of derived profiles are presented. We discuss our results in Section 5, where we demonstrate the usefulness of the developed mvdXML profile on a real world dataset. We conclude with Section 6, where we present possible future endeavours.

2. Related Works

The problem of georeferencing has been addressed by multitude of previous publication by the authors themselves and the scientific community and industry alike. Jaud et al. (2020) presents a thorough analysis of the topic in general, with in-depth descriptions of the underlying concepts and equations. At the international standardization level, the topic of georeferencing in building information modelling (BIM) is addressed by the Joint Working Group JWG14 *GIS-BIM interoperability* by International Organization for Standardization (ISO)/TC 59/SC 13 and ISO/TC 211 (ISO 23262, 2021) as well as by the buildingSMART International (bSI) and OGC roadmap. Certain aspects – such as quality models and standardized guidelines for georeferencing – are still not deemed sufficiently clear and implemented (Mallela and Bhargav, 2023).

Biljecki and Tauscher (2019) state, that the quality of the input data (document instances) is crucial for practical implementa-

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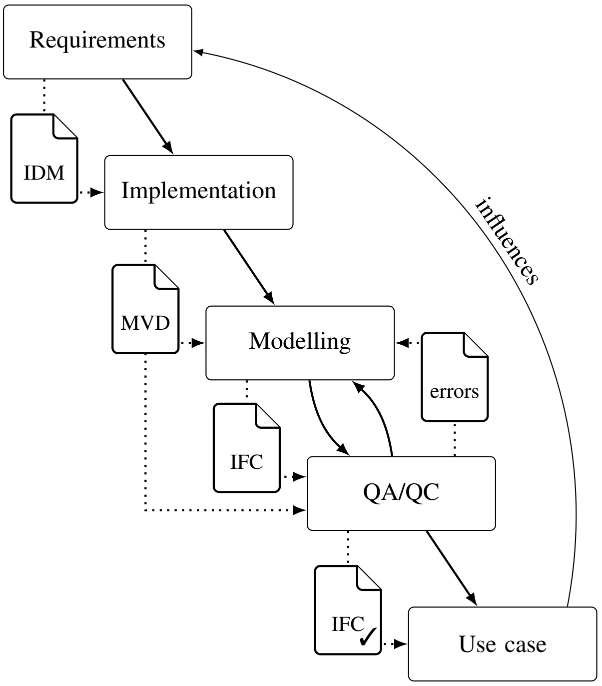


Figure 1. The methodology followed in this study. The requirements stemming from the end goal in mind are captured in an IDM document. The exact mapping to the IFC standard is defined with an MVD, which represents the basis for modelling and QA/QC loop. Finally, the use case can be performed using the quality-assured information (based on ISO 29481, 2016).

tion, in addition to the potential convertibility of the information models, i.e. schemas. Zhu and Wu (2021) critically evaluate the capabilities of IFC data schema and develop a systematic for a common georeferencing approach in IFC. Noardo et al. (2020) provide a detailed analysis of how software systems interpret georeferencing in building models in IFC format. The authors also demonstrate the software tools that can be used to georeference building models. Their GeoBIM benchmark is structured around the key questions about software support for georeferencing as well as for vendor-neutral data formats IFC and CityGML. The authors find that georeferencing tools are not typically used transparently and software users have limited control or configuration options (Noardo et al., 2020).

Moreover, it is evident that the georeferencing of BIM models lacks clear standardisation in terms of geometric accuracy and unambiguous use of certain classes and attributes in IFC. Markič et al. (2018) have found that the IFC4 version provides adequate support for typical georeferencing cases occurring in the majority of projects. The importance of CRSs for the success of BIM projects was noted by Mitchell et al. (2020). Here, members of bSI produced an IDM for georeferencing in IFC and provided a guideline for software implementers. The document covers both the currently most widespread version, IFC2x3, and the succeeding release, IFC4 (ISO 16739, 2024). Jaud et al. (2022) explores the insufficiencies of the IFC schema to support infrastructure requirements and proposes schema extensions together with corresponding usages. In parallel, so-called *MicroMVD* for geolocation and geocoding were developed by Open-Source Architecture Community (2022). However, these are based on the Gherkin language specification and Blender-specific checker implementation and do not make use of the standards and vocabularies developed by bSI.

The IDM/MVD methodology has been successfully utilized in neighbouring fields within the architecture, engineering and construction (AEC) domain. For example, Weise et al. (2016) showcase the development process on the use case of designing energy-efficient buildings. The authors define the requirements on spaces within a hospital, derive a corresponding MVD and present a proof-of-concept tool which automates QA/QC with corresponding reporting. A more complex example from the heritage domain is described in detail by Oostwegel et al. (2022). Here, the authors define a comprehensive IDM based on the Slovenian national guidelines. From it, an MVD for IFC4 is derived and the IFC model of a heritage structure is checked with it. All (intentionally included) mistakes are successfully reported (Oostwegel et al., 2022).

3. Background

3.1 Description of CRSs

CRS is a coordinate system (CS) that is related to an object (e.g. Earth) by means of a datum (ISO 19111, 2019). The datum is a parameter set that defines the position of a CS by means of origin, scale and orientation in relation to the chosen reference. European Petroleum Survey Group (EPSG) collects a comprehensive database of common CRSs, assigning each an individual identifier – an EPSG code.

Three-dimensional (3D) building models (e.g. for structural engineering) are usually created in a local Cartesian and object-related (i.e. construction-related) CRS. This CS is true-to-size, i.e. distortion-free between the model and the real-world object it models (1:1). In BIM projects, surveyed and/or geospatial data are used as a baseline for design (Jaud et al., 2020), however these may lie in a national, regional, or engineering CRSs. The CRSs usually used for geospatial data are distorted as a consequence of projections and separate horizontal position and vertical elevation (i.e. compound CRS in ISO 19111 (2019)). A 3D building model is georeferenced, if the set of transformation parameters from the object-related CS to an Earth's related CRS are explicitly stored in the dataset.

Systematic geometric deviations between geospatial data and transformed BIM geometries occurs when some of the geodetic concepts are not applied carefully. The extent of these deviations depends on: i) the selected CRS, ii) the overall length and height of BIM geometries, and iii) the location and elevation of the construction project. Depending on the accuracy requirements and application the resulting deviations can be neglected or not (Jaud et al., 2020).

Since BIM projects usually consist of many federated 3D models, their georeferencing must be clearly stated and easily checkable. The transformation chain requires to distinguish the following CSs (see also Figure 2).

GeoCRS is a geodetic CRS used by the national survey and in geographic information systems (GIS), e.g. ETRS89/UTM32 with EPSG code 25832. It usually separates horizontal location and elevation as separate CRS parts (2D+1D). Measured or planned natural distances must be converted on the basis of the elevation and map projection as well as their position with the CRS (CRS scale). GIS can transform between diverse GeoCRSs if an EPSG code or a well-known text (WKT) are known (OGC, 2018; ISO 19162, 2019).

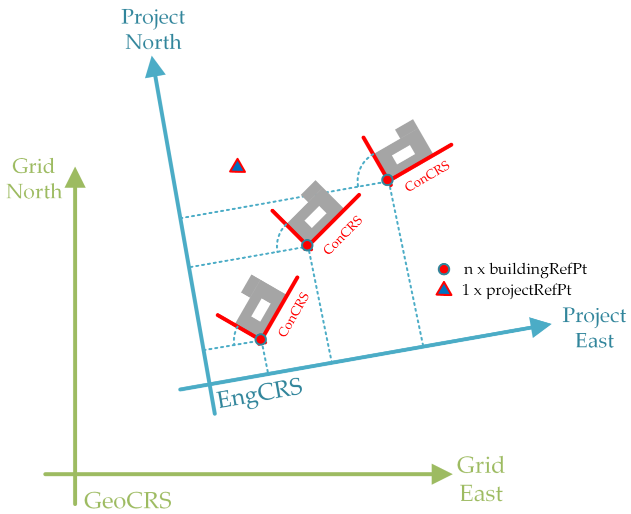


Figure 2. The construction elements of federated 3D-building models use a local, 3D CS (ConCRS). The models are georeferenced in the distortion-free engineering CRS (EngCRS) and/or the geodetic (map-)projected CRS (GeoCRS).

EngCRS is an engineering CRS created by engineering surveyors when a high internal geometric accuracy is required (e.g. for major construction projects). An EngCRS is usually defined separately for horizontal location and elevation (2D+1D). If defined correctly, and because it is only used locally, the geometries can be assumed not distorted as a valid approximation.

ConCRS is a construction-related CRS created for the design of an individual structure in such a way that it is distortion-free and lies within "small" coordinate values, i.e. close to the CRS's origin. A ConCRS usually defines three equal coordinate axes (3D) which lie parallel to the building axes or the longest side of the structure. The position and orientation of the ConCRS with respect to the planned construction must be clearly stated, also considering layered walls, or fine granulated levels.

SoftCS is the "inertial" 3D CS internal to every 3D modelling software used for geometric calculations. This CS is often (and quite misleadingly for the GIS community) called the "world coordinate system".

The transformation parameters between GeoCRS, EngCRS and ConCRS are usually defined by the project management and/or calculated using control points. In order to reduce the complexity in model exchange between different geometry engines, it is recommended that the SoftCS should be identical to the ConCRS. However, if this is not possible, translation and potential rotation between the SoftCS and ConCRS systems must also be taken into account.

Additionally, two specific concepts (points) have been identified: **buildingRefPt** is the building reference point, which stores the geometric parameters for transformation, and **projectRefPt** is the project reference point, which serves for visual QA/QC only. At an early stage of a BIM project the latter point is defined within GeoCRS or, if applicable, in the EngCRS. During the BIM project the projectRefPt supports QA/QC, as it is visualized with a "reference body" in each of the individual BIM models. When these models are aligned during the federation process, the reference bodies have to be exactly at the same location and elevation. Within a BIM project there might be as many buildingRefPt as there are buildings, but only a single projectRefPt for the whole project (see Figure 2).

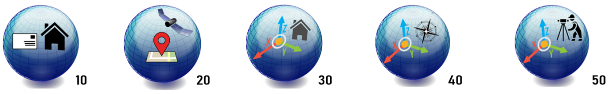


Figure 3. LoGeoRef – a metric for the quality of georeferencing data within IFC datasets (Clemen and Görne, 2019).

3.2 Description of LoGeoRefs

Five possible levels (10, 20, 30, 40 and 50) classify the georeferencing data within an IFC dataset. Steps of 10 were introduced to enable project-specific intermediate levels (e.g. for the elevation specification). Figure 3 provides an overview of the LoGeoRefs developed by Clemen and Görne (2019) and available in ISO 23262 (2021).

The higher the level, the better the georeferencing is conceptually modelled. However, the levels do not refer directly to the quality (precision and accuracy) of the transformation parameters. Additionally, higher levels do not automatically contain information of lower levels, i.e. each level requires specific IFC attributes and stands for itself.

LoGeoRef 10 references address information (IfcAddress) from the construction site (IfcSite) or the building (IfcBuilding). In version IFC4.3, this information is provided with an IfcPropertySet named Pset_Address attached to either of the two entities above instead.

LoGeoRef 20 georeferences construction site's location via its ellipsoidal coordinates in WGS84, i.e. employing IfcSite's attributes RefLatitude, RefLongitude and RefElevation.

LoGeoRef 30 defines the construction site's placement without conceptualizing a CRS, using IfcSite's attribute ObjectPlacement with a 3D CS from IfcAxis2Placement3D assigned.

LoGeoRef 40 defines a project CS (ConCRS) and specification of North direction for orientation in EngCRS or GeoCRS. For this, IfcGeometricRepresentationContext's attributes WorldCoordinateSystem and TrueNorth have to be provided.

LoGeoRef 50 specifies the 3D-translation and horizontal rotation for coordinate conversions between the EngCRS or GeoCRS systems and the geometric context of the model, i.e. ConCRS. The CRS shall be defined via an unique identifier, e.g. an EPSG code. This variant is only possible in versions IFC4 and younger. A workaround exists for IFC2x3, where two IfcPropertySet objects named ePSet_ProjectedCRS and ePSet_MapConversion shall be assigned to the project (IfcProject) (Mitchell et al., 2020). In IFC4.3, the CRS can be defined using IfcWellKnownText string literal following ISO 19162 (2019) as well.

3.3 Description of mvdXML Data Model

An mvdXML dataset consists of the following main elements (bSI, 2020; Weise et al., 2016):

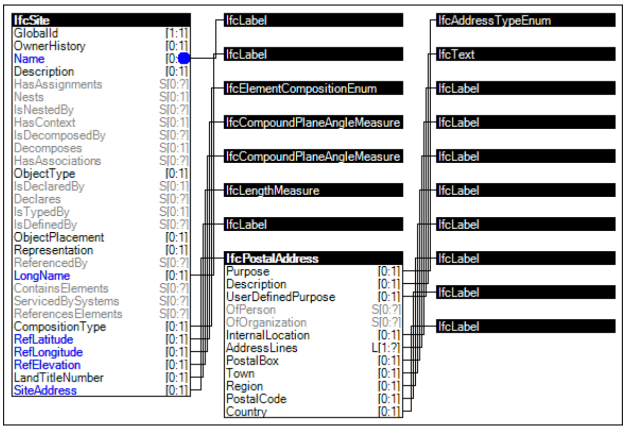


Figure 4. Graphical representation of the concept template *Site Attributes* from bSI (2020). The checkable object is IFCSITE, with the relevant attributes for the template drawn with their names and types in blue.

ModelView represents the top node of the mvdXML dataset. It includes multiple **View** elements, which are the main container for exchange requirements and concept roots.

ExchangeRequirement carries the data that is relevant for a specific use case.

ConceptRoot represents a collection of constraints for a selection of objects of type denoted with the *applicableRootEntity* attribute.

Applicability defines the rules by which objects are selected from the model.

Concept defines one constraint on applicable objects and how it is used in exchange scenarios.

ConceptTemplate defines a unit of functionality – a template for rules – that is used by the *Applicability* and *Concept* elements that configure the constraints.

TemplateRules is a collection of *TemplateRule* objects combined freely using boolean logic.

TemplateRule provides the parameters needed to configure the templates and denote the type of checks, following a specialized grammar.

When using mvdXML with IFC, the objects in question are normally entities deriving from IFCROOT, which acts as the main testable element of an IFC model. The IFC standard already provides multitude of templates, which are used in the so-called *General Usage* MVD as well as in other standardized MVDs, like *Reference View 1.2* (ISO 16739, 2024; bSI, 2020). As an example, Figure 4 and Listing 1 show the template *Site Attributes*, which provides the means necessary to query construction site's attributes and postal address (bSI, 2020).

Listing 1. mvdXML excerpt from the concept template *Site Attributes* from Figure 4 (bSI, 2020).

```
<ConceptTemplate uuid="f6c9eecc-f5fc-4096-a037-12
↪c2cd4d9d97" name="Site␣Attributes" applicableSchema=
↪"IFC4" applicableEntity="IfcSite">
 <Rules>
  <AttributeRule RuleID="Latitude" AttributeName="
  ↪RefLatitude">
   <EntityRules>
    <EntityRule EntityName="
    ↪IfcCompoundPlaneAngleMeasure" />
   </EntityRules>
  </AttributeRule>
  <AttributeRule RuleID="Longitude" AttributeName="
  ↪RefLongitude">
   <EntityRules>
    <EntityRule EntityName="
    ↪IfcCompoundPlaneAngleMeasure" />
   </EntityRules>
  </AttributeRule>
  <AttributeRule RuleID="Elevation" AttributeName="
  ↪RefElevation">
   <EntityRules>
    <EntityRule EntityName="IfcLengthMeasure" />
   </EntityRules>
  </AttributeRule>
  <!-- truncated -->
 </Rules>
</ConceptTemplate>
```

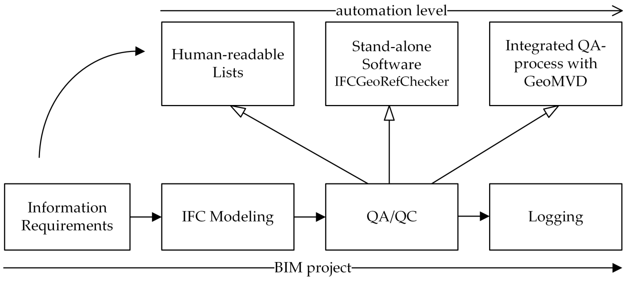


Figure 5. The journey of QA/QC automation based on Figure 1. This contribution focuses on the *checking rules* for QA/QC.

4. Derivation of Rules

In this section, the derivation of the checking rules for georeferencing is explained, as developed in a research project with the state building administration from Bavaria, Germany. To determine the extent of the necessary checks, we conducted expert interviews with project managers, BIM coordinators, BIM modellers, and surveyors. The interviews revealed that the task of georeferencing is perceived as particularly complex due to a lack of basic geodetic knowledge, uniform terminology and simple methods for parametrizing the CAD/BIM software.

The checks are parametrized at three different automation levels as depicted in the upper part of Figure 5. First, the results were recorded as a simplified IDM in a human-readable, manually executable checklist (Section 4.1). Second, a specialized software was developed to automate the checking of IFC models (Section 4.2). Last, the requirements were parametrized with the mvdXML standard to separate the checking rules from their implementation (Section 4.3). In this way, the check can be combined with other checking tasks (e.g. fire protection).

4.1 Formalization of Requirements

The collected criteria are structured in human-readable checklists (Tables 1 to 5) which group requirements for buildingRefPt, projectRefPt, reference body, georeferencing metadata, and IFC, respectively. These shall ensure that contractors and clients have a common and verifiable understanding of georeferencing.

The lists are generic, i.e. applicable for very different BIM projects. Therefore, some checks are combined with an exclusive or (i.e. XOR, denoted with ⊕). This means that the checks shall not be fulfilled at the same time (e.g. see Table 1, requirement 1.3). The client may choose the preferred XOR variant in their information requirements documentation. Additionally, some criteria depend on the authoring software used. For example,

Table 1. Georeferencing requirements for buildingRefPt. The variants are combined exclusively, i.e. $a \oplus b$.

Id	Requirement
1.1	Georeferencing relates to:
a	a (low distortion projected) EngCRS; xor
b	the (national/regional) GeoCRS.
1.2	The SoftCS and the building coordinate system are identical, i.e. not shifted.
1.3	The construction grid is:
a	aligned with buildingRefPt; xor
b	not aligned with buildingRefPt.
1.4	The georeferencing parameters for translation and rotation (easting, northing, north direction, elevation) are:
a	set according to the contractually agreed information requirements and/or BIM execution plan; xor
b	determined by the contractor.
1.5	The transformation parameters in buildingRefPt are precise to three decimal places. The units are meters and decimal degrees, where applicable.
1.6	(R) Reference layer for origin of vertical datum has been created, e.g. Mean Seal Level $= 0.000\,\mathrm{m}$.

Table 2. Georeferencing requirements for projectRefPt. The variants are combined exclusively, i.e. $a \oplus b$.

Id	Requirement
2.1	The projectRefPt is
a	equal to buildingRefPt; xor
b	not equal to buildingRefPt.
2.2	(R) *Survey point* is positioned at projectRefPt.
2.3	(R) *Project base point* and *Survey point* are pinned.
2.4	WGS84 geographic coordinates (latitude and longitude) of projectRefPt are provided as metadata.

the software-dependent requirements for AutoDesk Revit are marked with *(R)* in the tables.

Table 1 concerns the provision of the transformation parameters in each buildingRefPt. The table's entries can be used to specify and check the georeferencing in BIM authoring tools. For example, an explicit reference layer is required for the insertion of 3D surveys and digital terrain models in Autodesk Revit (see Requirement 1.6). This is created at height $= 0.000\,\mathrm{m}$ of the EngCRS or GeoCRS (often mean sea level).

Tables 2 to 4 concern the verifiability of the relative positioning of projectRefPt, the visualization with the reference body, and the metadata for georeferencing, respectively. The tables' entries can be used to define and check how the BIM-coordination of several federated models works with regard to georeferencing in a specific project.

Table 5 concerns projects using IFC datasets. The table's entries are targeting software developers and QA/QC managers focusing on IFC. These are derived from LoGeoRefs 10-50 as defined by Clemen and Görne (2019) and mapped to corresponding requirements from Tables 1 to 4. In a nutshell, Table 5 lists the mapping of these requirements to individual IFC entities and their attributes for each of the LoGeoRefs.

4.2 Implementation of LoGeoRefs

A lightweight open-source checking tool *IFCGeoRefChecker* was developed as a stand-alone application to check the georeferencing of IFC datasets, available at DD-BIM (2024). The tool can be used as a command line application or with a graphical user interface, as portrayed in Figure 6. Several IFC instances can be loaded and checked and the user receives immediate feedback on LoGeoRefs passing the requirements from Table 5.

Table 3. Georeferencing requirements for reference body.

Id	Requirement
3.1	The reference body is positioned at the location of projectRefPt.
3.2	The reference body stores the 3D coordinates of projectRefPt in the EngCRS or GeoCRS as attributes.

Table 4. Georeferencing metadata requirements. The variants are combined exclusively, i.e. $a \oplus b$.

Id	Requirement
4.1	The model contains multiple survey control points next to buildingRefPt and projectRefPt with coordinates specified in different CRSs.
4.2	The identification of the CRS used is specified in modelling software as metadata:
a	with an EPSG code for commonly used EngCRS or GeoCRS; xor
b	the WKT string in the custom made, distortion-minimized EngCRS or ConCRS.
4.3	The postal address is provided for:
a	the whole project; xor
b	the construction site; xor
c	the building.

The intended user of this application are BIM-coordinators who do not have a deep understanding of the IFC schema. The *IFCGeoRefChecker* extracts the concepts and attribute values for georeferencing and displays them in a clear log file. In addition to the LoGeoRefs 10-50 checks, the geographical coordinates of the IfcSite are evaluated (LoGeoRef20). The resulting region/state in which this WGS84 coordinate is located is displayed in the log file. This feature is primarily used to manually check the plausibility of LoGeoRef20, as practice has shown that the coordinate values are often set incorrectly.

4.3 Serialization as GeoMVD

To separate the rules' definition from the checking functionality, a specialized MVD dubbed *GeoMVD* was developed and serialized using the mvdXML data format. To achieve this, we employed concept templates available in the *Reference View 1.2* MVD used by bSI to certify software products (bSI, 2020). The descriptions of LoGeoRefs that were formalized in Clemen and Görne (2019) and summarized in Section 3.2 and Table 5 were considered as our requirements, representing a finalized IDM document.

The selected concept templates for LoGeoRefs are listed in Table 6 and are based on the class diagrams from Clemen and Görne (2019). As an example, Figure 4 and listing 1 show the template *Site Attributes*, which provides the means necessary to query construction site's attributes and postal address required for LoGeoRef20. Some entities required for specific templates are not available in all IFC versions, e.g. IfcProjectedCRS in IFC2x3 or IfcPostalAddress in IFC4x3. The workaround employs specialized property sets attached to appropriate entity as explained in Section 3.2.

Table 5. Georeferencing requirements for IFC based on LoGeoRefs mapped to the requirements from Tables 1 to 4. The variants are combined exclusively, i.e. $a \oplus b$.

Id	Requirement	Lvl.	Map
5.1	The IFC dataset contains the georeferencing transformation parameters and metadata in:		1.4
a	IfcProjectedCRS and IfcMapConversion connected to the IfcGeometricRepresentationContext with its attributes ContextType and CoordinateSpaceDimension equal to *Model* and 3, respectively; xor	50	
b	IfcGeometricRepresentationContext.WorldCoordinateSystem and IfcGeometricRepresentationContext.TrueNorth; xor	40	
c	IfcSite.ObjectPlacement.	30	
5.2	The identifiers (e.g. as EPSG codes) of the horizontal and vertical datums are given as metadata.	50	4.2
5.3	The geographic WGS84 coordinates of the project area are stored in IfcSite.RefLatitude and IfcSite.RefLongitude.	20	2.4
5.4	The base elevation is stored in:		1.4
a	IfcSite.RefElevation; xor	20	
b	elsewhere (see 5.1).		
5.5	The postal address is assigned to		4.3
a	IfcBuilding; xor	10	
b	IfcSite.	10	

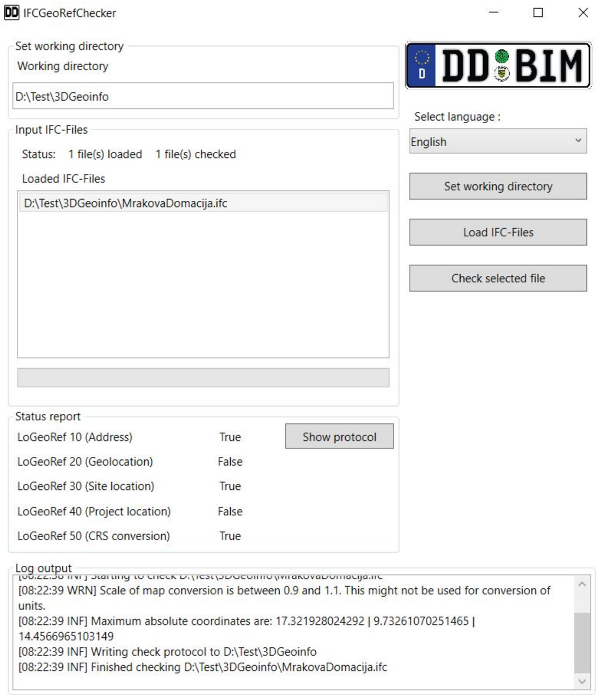
Having selected the needed concept templates, we define the parameters for rule checking to complete the *GeoMVD*. The basis for their values are Table 5 together with the limits defined in Clemen and Görne (2019). Two snippets of the resulting mvdXML serializations for LoGeoRef20 and Requirement 5.1 are presented in Listings 2 and 3, respectively.

The *ConceptRoot.Concepts* in Listing 2 apply to all IfcSite objects within the IFC dataset, since the *Applicability* is empty. The UUID reference *f6c9...* points to the *ConceptTemplate* defined in listing 1. The *TemplateRule.Parameters* attribute holds the checking settings (i.e. rules written in the correct grammar), where the keys to the attributes have been defined with *RuleID* attributes in Listing 1. The constraints require the corresponding referenced attribute to have any value (`[EXISTS]=TRUE`), or be empty (`[EXISTS]=FALSE`).

Listing 3 only provides the necessary checking settings for each of the three LoGeoRefs combined with XOR operator. In order to combine LoGeoRef30 with others, an additional concept template *Spatial Decomposition* is employed. The constraint for LoGeoRef50 showcases value checks with different data types and a regular expression, while the constraint for LoGeoRef30 showcases a type check.

5. Discussion

It is very challenging to summarize the practical perspectives of geodesy/surveying, AEC and the technical differences of authoring systems as well as GIS and BIM standards in an applicable checklist. The most important check takes place in



Status: 1 file(s) loaded 1 file(s) checked

LoGeoRef 10 (Address) True
LoGeoRef 20 (Geolocation) False
LoGeoRef 30 (Site location) True
LoGeoRef 40 (Project location) False
LoGeoRef 50 (CRS conversion) True

```
[08:22:38 INF] Starting to check D:\Test\3DGeoinfo\MrakovaDomacija.ifc
[08:22:39 WRN] Scale of map conversion is between 0.9 and 1.1. This might not be used for conversion of
units.
[08:22:39 INF] Maximum absolute coordinates are: 17.321928024292 | 9.73261070251465 |
14.4566965103149
[08:22:39 INF] Writing check protocol to D:\Test\3DGeoinfo
[08:22:39 INF] Finished checking D:\Test\3DGeoinfo\MrakovaDomacija.ifc
```

Figure 6. *IFCGeoRefChecker* – a simple stand-alone checker tool available at DD-BIM (2024).

Listing 2. mvdXML excerpt of a *ModelView* for Requirements 5.3 and 5.4a (i.e. LoGeoRef20). Irrelevant attributes and nodes are not shown for brevity.

```
<ModelView applicableSchema="IFC4">
 <ExchangeRequirements>
  <ExchangeRequirement applicability="both" uuid="375
  ↪beddf-a19a-5acd-1749-9121ea23e312" />
 </ExchangeRequirements>
 <Roots>
  <ConceptRoot applicableRootEntity="IfcSite">
   <Applicability/>
   <Concepts>
    <Concept name="Requirement␣5.3">
     <Template ref="f6c9eecc-f5fc-4096-a037-12
     ↪c2cd4d9d97" /> <!-- Site attributes -->
     <Requirements>
      <Requirement requirement="recommended"
      ↪exchangeRequirement="375beddf-..." />
     </Requirements>
     <TemplateRules operator="or">
      <TemplateRule Parameters="Latitude[Exists]=TRUE␣
      ↪AND␣Longitude[EXISTS]=TRUE" />
     </TemplateRules>
    </Concept>
    <Concept name="Requirement␣5.4a">
     <Template ref="f6c9eecc-f5fc-4096-a037-12
     ↪c2cd4d9d97" /> <!-- Site attributes -->
     <Requirements>
      <Requirement requirement="mandatory"
      ↪exchangeRequirement="375beddf-..." />
     </Requirements>
     <TemplateRules operator="or">
      <TemplateRule Parameters="Elevation[EXISTS]=FALSE
      ↪" />
     </TemplateRules>
    </Concept>
   </Concepts>
  </ConceptRoot>
 </Roots>
</ModelView>
```

Table 6. GeoMVD: Utilized concept templates for each LoGeoRefs referenced by their name from chapter 4 of bSI (2020). Additionally, we list the IFC schema version(s) with the corresponding applicable entity(ies).

Lvl.	Template Name	IFC	Entity
10	Building Attributes, Site Attributes	2x3, 4	IfcSite, IfcBuilding
	Property Sets for Objects	4x3	IfcSite, IfcBuilding
20	Site Attributes	all	IfcSite
30	Product Local Placement	all	IfcSite
40	Project Representation Context 3D	all	IfcProject
50	Property Sets for Objects	2x3	IfcProject
	Project Global Positioning	4, 4x3	IfcProject
	Project Global Positioning Mapped	4x3	IfcProject

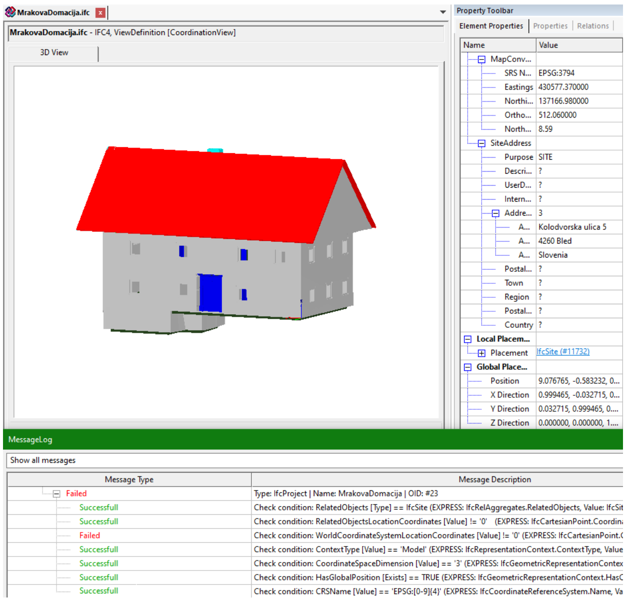
Listing 3. Template rules combination with corresponding parameters for Requirement 5.1 from Table 5 for IFC4.

```
<TemplateRules operator="xor">
 <TemplateRule Parameters="RelatedObjects[TYPE]='
 ↪IFCSITE'␣AND␣RelatedObjectsLocationCoordinates[
 ↪VALUE]!=0" /> <!-- LoGeoRef30 -->
 <TemplateRule Parameters="
 ↪WorldCoordinateSystemLocationCoordinates[VALUE]!=0␣
 ↪AND␣TrueNorth[EXISTS]=TRUE" /> <!-- LoGeoRef40 -->
 <TemplateRule Parameters="ContextType[VALUE]='Model'␣
 ↪AND␣CoordinateSpaceDimension[VALUE]=3␣AND␣
 ↪HasGlobalPosition[EXISTS]=TRUE␣AND␣CRSName[VALUE]=
 ↪reg'EPSG.*'" /> <!-- LoGeoRef50 -->
</TemplateRules>
```

the building reference point (buildingRefPt) where the transformation parameters of the model are defined (cf. Table 1). During our discussions with practitioners, it turns out that the mnemonic *pivotal point* explains the concept vividly.

Both the stand-alone checker and the standardized MVDs show advantages and disadvantages. On the one hand, the benefit of a specialized solution from Section 4.2 is the flexibility of the programming language used, which enables to encode most of the peculiarities from the IDM. However, this comes at the cost of programming, which might not be the expertise of many domain experts. On the other hand, the benefit of serialized profiles from Section 4.3 is the split between the formalization of the rules in a non-proprietary data format and the implementation of a general-usage checker. This comes at the cost of the limitations of the data format to encode the requirements and their combinations (in our case mvdXML).

Our study considers the different LoGeoRefs and lays special emphasis on their combinations. On the one hand, LoGeoRefs 10 and 20 do not constitute enough information to be considered useful for surveying work. Thus, they represent meta information of the IFC dataset that shall be provided as add-on option. Observe the `recommended` exchange requirement for the top *concept* node in Listing 2. On the other hand, LoGeoRefs 30, 40 and 50 provide sufficient information for surveying work. However, these can destructively interfere with one another, resulting in wrong overall placement of the IFC geometries. Thus, these shall never be provided simultaneously. This has been realised with a XOR combination of individual *TemplateRule* nodes in Listing 3.



Name	Value
MapConv...	
SRS N...	EPSG:3794
Eastings	430577.370000
Northi...	137166.980000
Ortho...	512.060000
North...	8.59
SiteAddress	
Purpose	SITE
Descri...	?
UserD...	?
Intern...	?
Addre...	3
A...	Kolodvorska ulica 5
A...	4260 Bled
A...	Slovenia
Postal...	?
Town	?
Region	?
Postal...	?
Country	?
Local Placem...	
Placement	IfcSite (#11732)
Global Place...	
Position	9.076765, -0.583232, 0...
X Direction	0.999465, -0.032715, 0...
Y Direction	0.032715, 0.999465, 0....
Z Direction	0.000000, 0.000000, 1....

Message Type	Message Description
Failed	Type: IfcProject | Name: MrakovaDomacija | OID: #23
Successfull	Check condition: RelatedObjects [Type] == IfcSite (EXPRESS: IfcRelAggregates.RelatedObjects, Value: IfcSit
Successfull	Check condition: RelatedObjectsLocationCoordinates [Value] != '0' (EXPRESS: IfcCartesianPoint.Coordin
Failed	Check condition: WorldCoordinateSystemLocationCoordinates [Value] != '0' (EXPRESS: IfcCartesianPoint.
Successfull	Check condition: ContextType [Value] == 'Model' (EXPRESS: IfcRepresentationContext.ContextType, Value
Successfull	Check condition: CoordinateSpaceDimension [Value] == '3' (EXPRESS: IfcGeometricRepresentationContex
Successfull	Check condition: HasGlobalPosition [Exists] == TRUE (EXPRESS: IfcGeometricRepresentationContext.Has
Successfull	Check condition: CRSName [Value] == 'EPSG:[0-9]{4}' (EXPRESS: IfcCoordinateReferenceSystem.Name, Va

Figure 7. Real world example *Mrakova Domacija* from Oostwegel et al. (2022). The CRS attributes as well as construction site's address and placement can be seen on the right. The individual checking results for Listing 3 are shown at the bottom (Karlsruhe Institute of Technology, 2024).

We test the developed *GeoMVD* on a real world example from Oostwegel et al. (2022). The model fulfils requirements 1.1b, 1.3a, 1.4b, 1.5, 2.1b, 4.2a, 4.3b, 5.1a, 5.2, 5.4b and 5.5b. The latter (5.*) are confirmed by both the specialized *IFCGeoRefChecker* as presented in Figure 6 as well as an independent implementation of mvdXML based checking tool as shown in Figure 7. Observe that LoGeoRef30 and 50 are passing, thus making the requirement 5.1 fail through the XOR operator.

6. Conclusions

Georeferencing of civil engineering models is required to correctly relate geometries of digital objects to their placement on the Earth. In this study, we develop several high-quality georeferencing profiles for IFC datasets. These are i) human-readable checklists (Section 4.1), ii) a stand-alone, specialized software *IFCGeoRefChecker* (Section 4.2), and iii) standardized MVDs *GeoMVD* serialized as mvdXML datasets (Section 4.3).

The selection of the transformation chain from ConCRS, EngCRS and GeoCRS must be considered at an early stage of the construction project and should be guided by a geospatial engineer being familiar with the concepts of geodetic coordinate transformations. In the future, professional associations and chambers could develop instructions that are short and easy to understand, while remaining geodetically correct. These instructions should preferably use national CRSs usually employed in everyday surveying practice.

We lay special emphasis on the usability of the IFC geometries *as-is* for immediate consumption by surveying activities or analysis within GIS. Although the concepts of LoGeoRef30 have been upgraded by LoGeoRef50 in the IFC standard, LoGeoRef30 is currently the only available option in most BIM authoring and collaboration software. This circumstance may make it necessary for project management to set a lower standard. The profile *GeoMVD* supports both the common case as well as the alternatives as presented in Table 5.

We call for fast adoption of the newer standard by the industry. Additionally, a set of guidelines for practitioners could improve project successes. These should specify how to approach georeferencing in a robust and transparent manner – for example, using the check lists from Tables 1 to 4.

6.1 Future Works

The stand-alone checker (DD-BIM, 2024) currently mainly checks the existence of certain IFC objects and attributes. In the future, the values could also be increasingly checked for plausibility and consistency. For example, whether the geographical coordinate roughly matches the projected coordinate of the building reference point. The project reference point is currently not checked by the tool because there is no tailored concept for this point in the IFC schema.

We were unable to specify exact coordinate values for individual coordinates (i.e. x, y and z) when writing constraints in the mvdXML grammar, since coordinates are saved as a list of three numbers in IFC. As such, the constraints in Listing 3 only check that these values are not equal to 0, comparing all three coordinates with only one number. Thus, the mvdXML grammar could be extended with the possibility to check individual entries in a list of values.

References

Biljecki, F., Tauscher, H., 2019. Quality of BIM-GIS conversion. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, IV-4/W8, 35–42. `https://doi.org/10.5194/isprs-annals-IV-4-W8-35-2019`.

bSI, 2020. Industry Foundation Classes 4.0.2.1: Reference View 1.2. `standards.buildingsmart.org/MVD/RELEASE/IFC4/ADD2_TC1/RV1_2/HTML/`, 2024-02-15.

Clemen, C., Görne, H., 2019. Level of Georeferencing (LoGeoRef) using IFC for BIM. *Journal of Geodesy, Cartography and Cadastre*, 2019(10), 15–20.

DD-BIM, 2024. IFCGeoRefChecker. `github.com/dd-bim/City2BIM/wiki/IFCGeoRefChecker`, 2024-04-15.

ISO 16739, 2024. ISO 16739-1:2024: Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries – Part 1: Data schema. Standard, International Organization for Standardization, Geneva, CH.

ISO 19111, 2019. ISO 19111:2019: Geographic information — Referencing by coordinates. Standard, International Organization for Standardization, Geneva, CH.

ISO 19162, 2019. ISO 19162:2019: Geographic information Well-known text representation of coordinate reference systems. Standard, International Organization for Standardization, Geneva, CH.

ISO 23262, 2021. GIS (geospatial) / BIM interoperability. Technical report, International Organization for Standardization, Geneva, CH.

ISO 29481, 2016. ISO 29481-1:2016: Building information models: Information delivery manual – Part 1: Methodology and format. Standard, International Organization for Standardization, Geneva, CH.

Jaud, Š., Clemen, C., Muhič, S., Borrmann, A., 2022. Georeferencing in IFC: Meeting the Requirements of Infrastructure and Building Industries. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, X-4/W2-2022, 145–152. `https://doi.org/10.5194/isprs-annals-X-4-W2-2022-145-2022`.

Jaud, Š., Donaubauer, A., Heunecke, O., Borrmann, A., 2020. Georeferencing in the context of building information modelling. *Automation in Construction*, 118, 103211.

Karlsruhe Institute of Technology, 2024. FZKViewer. `https://www.iai.kit.edu/1648.php`, 2024-04-30.

Mallela, J., Bhargav, A., 2023. Enabeling Information Continuity across BIM-GIS domains: A BSI-OGC strategic roadmap. `https://youtube.com/watch?v=c4GfQOOIt48`.

Markič, Š., Donaubauer, A., Borrmann, A., 2018. Enabling Geodetic Coordinate Reference Systems in Building Information Modelling for Infrastructure. *Proceedings of the 17th International Conference on Computing in Civil and Building Engineering*, Tampere, Finland.

Mitchell, J., Bennett, D., Brown, N., Gregory, L., Karlshøy, J., Nisbet, N., Parslow, P., 2020. User Guide for Geo-referencing in IFC. Technical report, bSI.

Noardo, F., Harrie, L., Arroyo Ohori, K., Biljecki, F., Ellul, C., Krijnen, T., Eriksson, H., Guler, D., Hintz, D., Jadidi, M. A., Pla, M., Sanchez, S., Soini, V.-P., Stouffs, R., Tekavec, J., Stoter, J., 2020. Tools for BIM-GIS Integration (IFC Georeferencing and Conversions): Results from the GeoBIM Benchmark 2019. *ISPRS International Journal of Geo-Information*, 9(9), 502. `https://doi.org/10.3390/ijgi9090502`.

OGC, 2018. Well-known text representation of coordinate reference systems. `https://ogc.org/standard/wkt-crs`, `2024-02-15`.

Oostwegel, L., Jaud, Š., Muhič, S., Malovrh Rebec, K., 2022. Digitalization of culturally significant buildings: ensuring high-quality data exchanges in the heritage domain using OpenBIM. *Heritage Science*, 10. `https://doi.org/10.1186/s40494-021-00640-y`.

Open-Source Architecture Community, 2022. MicroMVDs for exchange requirements. `wiki.osarch.org/index.php?title=MicroMVDs_for_exchange_requirements`, 2024-04-30.

Weise, M., Nisbet, N., Liebich, T., Benghi, C., 2016. IFC model checking based on mvdXML 1.1. S. Christodoulou, R. Scherer (eds), *eWork and eBusiness in Architecture, Engineering and Construction – Proceedings of the 11th European Conference on Product and Process Modelling, ECPPM 2016*.

Zhu, J., Wu, P., 2021. A Common Approach to Geo-Referencing Building Models in Industry Foundation Classes for BIM/GIS Integration. *ISPRS International Journal of Geo-Information*, 10(6). `https://doi.org/10.3390/ijgi10060362`.