Enabling Geodetic Coordinate Reference Systems in Building Information Modeling for Infrastructure

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Abstract:

The design and engineering of built facilities is performed in a Cartesian Coordinate System (CS). This CS is created by projecting the physical (curved) world onto a plane which introduces a distortion in lengths and distances. When bringing the design information to the real world, a re-projection must be performed, i.e. the set-out values need to be calculated on the basis of the geodetic Coordinate Reference System (CRS) applied. This is a well-known process in geodesy, however it has also significant implications for Building Information Modelling (BIM) work flows, in particular when applied for long, linear civil engineering assets such as roads or railways.

In this paper, we take a close look at the vendor-neutral BIM data format Industry Foundation Classes (IFC) and investigate how it describes geodetic CRS. The support for georeferencing has been added in the latest version (IFC4) where the main reference is taken from the European Petroleum Survey Group (EPSG) database. However, it is very common that infrastructure projects define their own, project-specific geodetic CRS that cannot be referenced by an EPSG code. We propose an extension to the IFC data format to include support for such particularities by including grid shift datasets (e.g., NTv2).

Keywords: BIM, IFC, infrastructure, CRS, geodetic projection, bilinear transformation.

1. INTRODUCTION

1.1 Geospatial Data within BIM

The Architecture, Engineering and Construction (AEC) domain is in its transition from two-dimensional (2D) design processes to three-dimensional (3D) object-oriented modelling. Building Information Modelling (BIM) is steadily gaining importance replacing the conventional Computer Aided Design (CAD) practices and getting implemented in every aspect of the very complex software and stakeholder landscape (Borrmann et al., 2015). Lately, the infrastructure sector has shown increased interest in switching to BIM practices and the benefits they bring (Barazzetti & Banfi, 2017). However, when large linear objects are being modeled, aspects of geodetic Coordinate Reference Systems (CRS) and the distortions they imply have a much more significant impact than when considering buildings with comparatively limited extends. These aspects need to be adequately addressed when expanding the established work flows and data formats.

The established design and engineering in CAD and BIM systems is usually performed in a local Cartesian Coordinate System (CS) (also called the engineering CS) with an arbitrarily chosen Project Base Point (PBP). This point may be defined as a local topocentric base or merely referenced in a geodetic projection diminishing the overall coordinates of elements. In the first case, the dimensions and coordinates in the built facility correspond pretty well to those modelled in the BIM model. In the latter case, the coordinates are distorted through both the used projection and the applied mathematical model of the Earth. Thus, a discrepancy in the dimensions (lengths and distances) exist between the BIM model and the real world.

In both cases, the real coordinates (the set-out values) need to be calculated before construction starts for which surveying expertise is required. Earth's curvature, irregularities in the gravity field and the used map projection are considered. While the discrepancy between the models and the real-world dimensions is (almost) negligible for structures spanning less than 1 km, this is not the case for linear civil engineering objects like roads or railways easily spanning several hundreds of kilometers. While these distortions are conventionally handled by surveyors, the use of BIM models as direct input for pre-fabrication requires their explicit consideration (Heunecke, 2017).

The support for georeferencing has been added to the Industry Foundation Classes (IFC) in the latest version (IFC4) where the main reference is taken from the European Petroleum Survey Group (EPSG) database (ISO 16739:2013). However, it is very common that infrastructure projects define their own, project-specific geodetic CRS that cannot be referenced by an EPSG code. We present two case studies in this regard.

1.2 Related Work

Currently, a project led by the Australasia chapter of buildingSMART is concerned with the correct model setup (buildingSMART, 2017). There, one of the main questions is the correct georeferencing and its setup when the project begins. Some studies and discussions were published concerning the topic, either approaching the subject academically (Heunecke, 2017; Kaden & Clemen, 2017) or on examples in the areas of urban planing (Del Giudice et al., 2014) and infrastructure design (Barazzetti & Banfi, 2017).

Kaden & Clemen (2017) walk through an example study on the coordinate systems from geodetic perspective. They noted that a correct understanding of geodetic CRS is crucial for the success of BIM projects, especially in the infrastructure sector. However, in their words, *most CAD data is created without this consideration*. Heunecke (2017) provides the equations and the reasoning behind the distortions and even exemplarily calculates their exact values. For example, a curve's radius of $R_{BIM} = 1000\ m$ changes to $R_{UTM} = 999.46\ m$ when projected to a distorted coordinate system (here, UTM) and to $R_{real} = 1000.54\ m$ when calculating the set-out values. This distortion is location-dependent (!) and influences the drive dynamics insignificantly; however, it can be the reason to violate a compulsory point's margin like a railway platform's edge.

1.3 Structure of the Paper

The paper is structured as follows. This Section presents the motivation for this paper and related. Section 2 defines CSs, geodetic datums and projections. We also depict two examples which render current implementation insufficient. The IFC schema is explained in Section 4. Our proposal on how to expand the IFC schema is introduced in Section 5. We conclude this paper with discussion and conclusion in Sections 6 and 7, respectively.

2. GEODETIC COORDINATE REFERENCE SYSTEMS

In order to understand the idea presented in Section 5 we begin with a quick excursus on Coordinate Systems (CS) and (geodetic) Coordinate Reference Systems (CRS) (buildingSMART, 2017, ISO 19111:2007).

2.1 Cartesian Coordinate System

A Cartesian CS *(x,y,z)* is defined as a right-handed orthogonal CS with Unit of Measurment (UoM) being meter on all three axes. In geodesy, the Earth Centered Earth Fixed (ECEF) CRS *(X,Y,Z)* is spanned in the Earth's centre of mass. Its *Z*-axis is going from geocentre through the International Reference Pole (IRP), similarly, its *X*-axis from geocentre through International Reference Meridian (IRM) in the mean equatorial plane, and its *Y*-axis defining a right-hand orthogonal CS (buildingSMART, 2017).

In order to transform the coordinates between two Cartesian CSs, a relationship between the originating *(u,v,w)* and transformed coordinates *(x,y,z)* needs to be established. A so-called 7-parameter Helmert transformation $(t_u,t_v,t_w,\lambda,\alpha,\beta,\gamma)$ for a point $P_i = (x_i,y_i,z_i)$ is defined with Equations (1) and (2).

$$\begin{bmatrix} u_i \\ v_i \\ w_i \end{bmatrix} = \begin{bmatrix} t_u \\ t_v \\ t_w \end{bmatrix} + \lambda R(\alpha,\beta,\gamma) \begin{bmatrix} x_i \\ y_i \\ z_i \end{bmatrix} \tag{1}$$

where

$$R(\alpha,\beta,\gamma) = \begin{bmatrix} \cos\gamma\cos\beta & \cos\gamma\sin\beta\sin\alpha + \sin\gamma\cos\alpha & -\cos\gamma\sin\beta\cos\alpha + \sin\gamma\sin\alpha \\ -\sin\gamma\cos\beta & -\sin\gamma\sin\beta\sin\alpha + \cos\gamma\cos\alpha & \sin\gamma\sin\beta\cos\alpha + \cos\gamma\sin\alpha \\ \sin\beta & -\cos\beta\sin\alpha & \cos\beta\cos\alpha \end{bmatrix} \tag{2}$$

The simplest example of a geodetic CRS is a topocentric system. A local Cartesian CS *(X,Y,Z)* is spanned in a chosen point on the Earth's surface (hence the name *topo*), where the *Z*-axis coincides with the negative local direction of gravity pull and *X*- and *Y*-axes being chosen arbitrarily. Such a point is usually chosen within another CRS, for example the ECEF and the CS transformed using Equation (1).

2.2 Ellipsoid and Geoid

The Earth is roughly a sphere and as such, the use of spherical coordinates offers itself as a way of referencing points on Earth surface. This principle has already been used to define the orientation of the ECEF axes with IRP and IRM following the definitions of azimuth and zenith axes. For easier notation, the distance is usually given to some reference plane and not to the point of origin. This reference plane – the zero height $H = 0$, usually the mean sea level – is the Earth's equipotential gravity field and defines the geoid form (see Figure 1) (ISO 19111:2007). Between two points with the same height the water does not flow which is very practical in construction.

The geoid can be reasonably well approximated by an oblate ellipsoid, which is an ellipsoid rotated around the minor axis – the sphere is squashed at the north and south pole due to the rotation (ISO 19111:2007). Through the history, many ellipsoids have been defined and used with different areas of best fit. The "best fit" objective is to

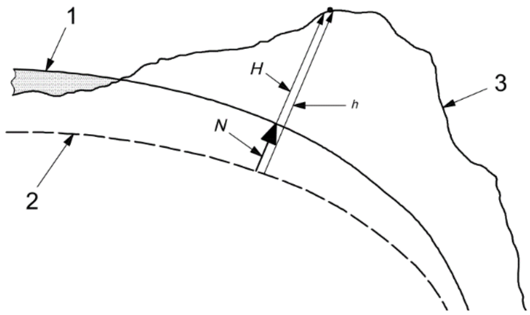

Figure 1. The ellipsoidal (2) and geoid (1) heights of Earth (3) are *h* and *N*, respectively. *H* is the gravity-related height measured along the direction of gravity (ISO 19111:2007).

minimize the differences between the geoid and ellipsoid in a specific area or globally. For example, the ellipsoid WGS84 (used in World Geodetic System 1984) is the Earth-centered ellipsoid with axis $R_{major} = 6378137.0\ m$ and inverse flattening as presented in Equation (3) (buildingSMART, 2017).

$$\frac{1}{f} = \frac{R_{major}}{R_{major} - R_{minor}} = 298.257223563 \text{ m} \tag{3}$$

The choice of ellipsoid's size, position and orientation together with the height reference define the so-called geodetic and vertical datums, respectively.

2.3 Projection

The engineers usually prefer to work in a Cartesian CS as it is easier for visualization and performing calculations and hence less error-prone. For that, the ellipsoidal coordinates are projected onto a plane using some sort of map projection. Since projecting the curved surface of an ellipsoid onto a plane without any deformation is not possible, a map projection can only preserve either angles, distances or surface areas. The compromise most frequently chosen is to preserve angles by using the so-called conformal map projections, such as the Transverse Mercator projection.

To keep the distortions of distances and surface areas in an acceptable range for applications like large-scale topographic mapping or cadastral surveying, strips of the ellipsoid are defined and projected onto a cylinder's surface. Figure 2 shows two conformal map projections, that differ from each other in the radius of the cylinder and the width of the strips. The Gauss-Krüger projection (GK, see Figure 2, left) uses a cylinder that touches the ellipsoid at a meridian. Therefore, only the distances along the meridian are not distorted. The strips have a width of 3 degrees in Germany. In the Universal Transverse Mercator projection (UTM, see Figure 2, right), the cylinder intersects with the ellipsoid east and west of the central meridian of a specific strip, which has a width of 6 degrees. To keep distance distortions in an acceptable range, even at the borders of the strip, the central meridian is distorted with a scale of 0.9996 (see Figure 3).

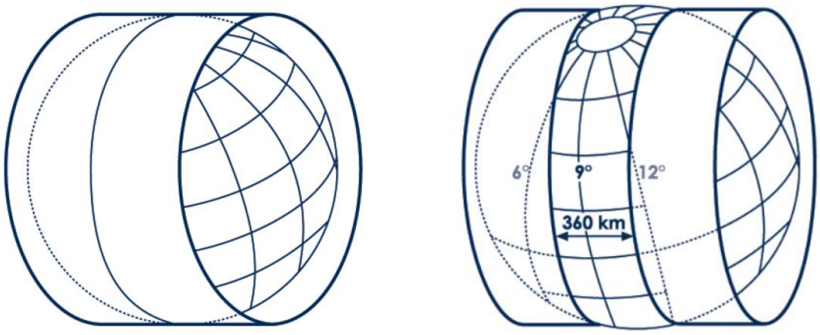

Figure 2. Different ways of projecting the ellipsoid on a cylinder: left the Gauss-Krüger projection (GK) and right the Universal Transverse Mercator (UTM) projection (Kaden & Clemen, 2017).

The map projection together with a geodetic datum is called a projected CRS, which uniquely defines the transformation of a Cartesian CS to the Earth surface. In combination with a vertical CRS, the reference system is called a compound CRS.

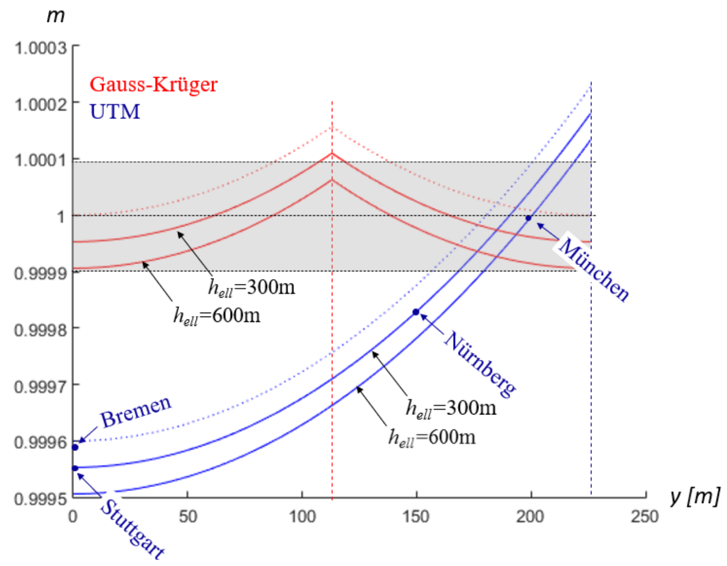

Figure 3. The values of length distortion because of projection as correction factors *m* for both GK and UTM. $y = 0$ is the meridian. The dashed lines are the distortions on the ellipsoid surface. Additionally, the distortions for some ellipsoidal heights h_{ell} and German cities are shown (Heunecke, 2017).

The distortions induced by projection are exemplarily shown in Figure 3 with dashed lines (GK in red, UTM in blue). One can observe that the GK combined with Bessel's ellipsoid allows for ignoring the distortions, as the factors vary close to one (the gray strip). Nowadays, with the switch to UTM, more attention should be given to the specifics of projections. Distortions of distances are also influenced by the height above the ellipsoid. Length distortions due to the UTM projections and due to the height *N* above the ellipsoid for the state Bavaria, Germany are shown in Figure 4 (Donaubauer & Kolbe, 2017).

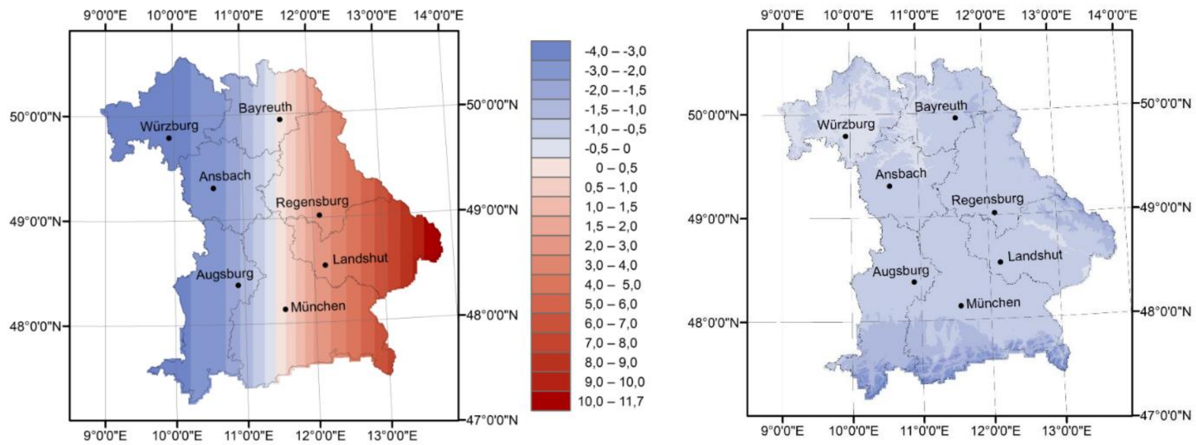

Figure 4. The values of length distortions in Bavaria, Germany, in [cm/100m]. Left due to UTM projection (from Figure 2, left) and right due to $N \neq 0$ projection (from Figure 1) (Donaubauer & Kolbe, 2017).

2.4 Coordinate System Change

When converting coordinates from one CRS to another, two cases can be distinguished according to (ISO 19111:2007). A coordinate *conversion* converts coordinates from one CRS to another based on the same datum, e.g., the conversion of WGS84 coordinates given in an ECEF CRS to UTM coordinates, both based on the WGS84 datum. Coordinate conversions can be performed with identical parameters regardless of the location on Earth. In a coordinate *transformation* the source and target CRS are based on a different datum, e.g., the conversion of GK coordinates based on the German datum DHDN to UTM coordinates based on the European datum ETRS89. Coordinate transformations rely on empirically derived parameters which may vary with location. This discrimination is of immense importance when a coordinate operation method is chosen (ISO 19111:2007).

An uncomplicated way to change from one geodetic datum to another (for example, WGS84 to a topocentric CRS) is to use the 7-parameter Helmert transformation from Equation (1). If this is used for a small enough area (like a building construction site), the discrepancies between the two systems are negligible. However, for a larger area (like a road construction site) the accuracy might not be sufficient. For example, an accuracy of only 3m is assured when a Helmert transformation is carried out for a datum change between DHDN and ETRS89 for the whole Germany, which is useful for mid-scale cartography but useless in the AEC domain (Donaubauer & Kolbe, 2017).

A more precise option is a so-called grid shift transformation. Here, a set of points is chosen in both the originating as well as in the receiving CRS, measured, and a grid of local delta vectors is calculated (see Figure 5). With these vectors every point can be transformed with bi-linear interpolation of the 4 points of the grid cell in which it lies (Donaubauer & Kolbe, 2017). The precision of such transformation depends solely on the quality of the grid and the vectors. An example is the National Transformation version 2 (NTv2) – a quasi-standard for grid shift transformations in the geospatial domain.

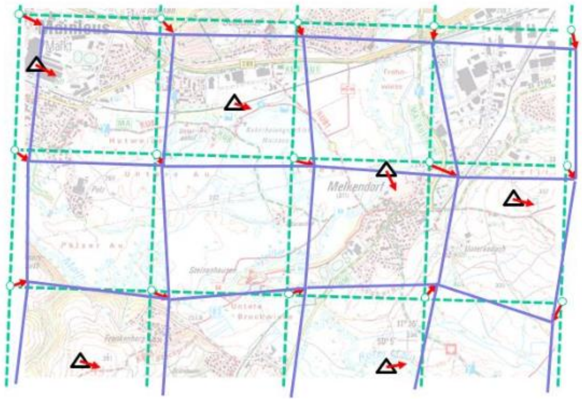

Figure 5. A schematic visualization of the grid shift transformation approach. The source CRS is drawn in green, the target CRS in violet. The delta vectors of prominent points as well as each grid node are shown in red (Donaubauer & Kolbe, 2017).

3. EXAMPLES

3.1 Brenner Base Tunnel

The Brenner base tunnel is an international project between Innsbruck (Austria) and Fortezza (Italy) where a 55 km long tunnel under the Alps is being constructed (BBT SE, 2018). It got complicated already at the beginning since both participating countries use different national geodetic CRS. Moreover, the biggest uncertainties of the country's geodetic network are at its borders, exactly where this project takes place.

To avoid confusion among the project stakeholders and to simplify the planing process, a new, project-specific CRS was established and set out along the tunnel. The CS was defined in such a way, that the prime meridian of the GK projection mostly coincides with the axis of the tunnel thus ensuring minimal length distortions from the geodetic projection (see Figure 3).

3.2 Transrapid Project Study

The project ran 1992-2000 and should have connected Hamburg and Berlin (Germany) with a magnetic levitation train track (Maglev) (MSB, 2007). However, the track runs mostly in the East-West direction which introduces biggest geometric distortions between the real world and the model's CRS originating from the chosen projection (see Figure 4, left).

The specifics of Maglev technology demanded for maximal distortion due to the projection to be less than 1 mm per 100 m. This introduced the need to explore possible local CRS of different precision in which the planning then occurred. The transrapid study demanded a project's CRS to be defined in two stages: first being a coarse custom grid with distance between points being ≈ 3 km and the second a refinement of it with the distance between points being ≈ 200 m. All the compulsory points should then be recorded in this new CRS and the alignment design may have started.

Since the distortions are equal to zero along the prime meridian, it was beneficial to rotate the projection cylinder in such a way that the Maglev alignment would be as close as possible to the prime meridian. Two different configurations were tried –a singular projection and a combination of two projections (see Figure 6).

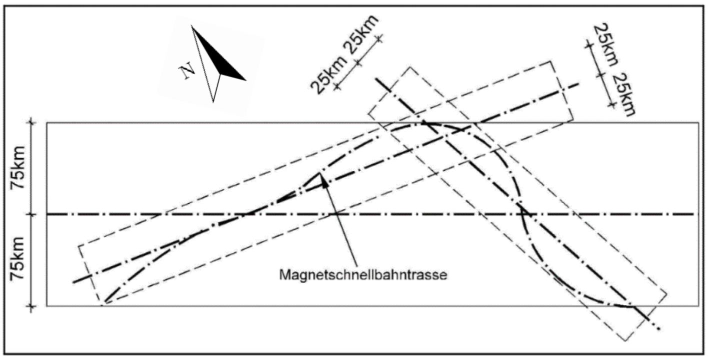

Figure 6. Two considered configurations of the GK projection for the transrapid project. The meridians lie arbitrarily in space in order to incorporate the entire alignment within some predefined distance and are not North-oriented in order to limit distortions. *Magnetschnellbahntrasse* stands for Maglev alignment (MSB, 2007).

4. DEFINITION OF CRS IN THE INDUSTRY FOUNDATION CLASSES

The established BIM data schema Industry Foundation Classes (IFC) has been developed for the last two decades and has been certified as ISO standard (ISO 16739:2013). The schema itself has remained in development, e.g., with the recent additions of the IFC Infra Overall Architecture project (Borrmann et al., 2017).

All elements with spatial context (e.g., a wall or an alignment) derive from the *IfcProduct* class, which provides attributes *ObjectPlacement* and *Representation* for defining the position and geometry, respectively. The latter is not of interest here, however, a clear understanding of the former is necessary. The positioning of the elements is modelled with the *IfcObjectPlacement* entity which places object's local CS relatively within another object's CS. Here, individual elements (e.g., *IfcWall*) are placed relative to the respectful object higher in the spatial hierarchy (e.g., *IfcBuildingStorey*). A placement may be absolute, relative or in a grid, e.g., *IfcLocalPlacement* models a Helmert transformation following Equation (1) with $\lambda = 1$. If an element does not specify its position relative to another element, its coordinates are seen as absolute within the geometric representation context (*IfcGeometricRepresentationContext*) of the root element, *IfcProject*.

IFC4 added classes to include information on the underlying geodetic CRS used (ISO 16739:2013). The abstract *IfcCoordinateReferenceSystem* and the *IfcProjectedCRS* deriving from it provide information about the chosen projection and datums. The main identifier is the code from the European Petroleum Survey Group (EPSG) database saved in the *Name* attribute. There, the underlying geodetic and vertical datum together with the projection are referenced. According to the IFC specification, only one *IfcProject* and thus one *IfcProjectedCRS* pro file are foreseen (ISO 16739:2013).

The abstract *IfcCoordinateOperation* class links the aforementioned geometric context of the project in the *TargetCRS* attribute with the geodetic CRS defined with *IfcProjectedCRS* in the *SourceCRS* attribute. With this the BIM model and the coordinates are set as distorted. The derived *IfcMapConversion* class then defines the parameters of the transformation for the coordinate origin of the project's PBP (Kaden & Clemen, 2017). Its 6 parameters (*Eastings*, *Northings*, *OrthogonalHeight*, *XAxisAbsissa*, *XAxisOrdinate* and *Scale*) uniquely define the position of the PBP within the referenced geodetic CRS. With this, the BIM-global CS is defined.

The transformation of project's BIM-global coordinates $(x,y,z) := (X,Y,Z)$ to the geodetic global coordinates $(u,v,w) := (E,N,H)$ according to *IfcMapConversion* is calculated following Equation (1) (buildingSMART, 2017). According to the definition in ISO 16739:2013, the vertical directions are parallel, setting $\alpha = \beta = 0$. Thus, the conversion is calculated as in Equation (4).

$$\begin{bmatrix} E \\ N \\ H \end{bmatrix} = \begin{bmatrix} IfcMapProjection{::}Eastings \\ IfcMapProjection{::}Northings \\ IfcMapProjection{::}OrthogonalHeight \end{bmatrix} + \lambda R(0,0,\gamma) \begin{bmatrix} X \\ Y \\ Z \end{bmatrix} \tag{4}$$

where $\lambda = IfcMapProjection{::}Scale,$
$\gamma = \tan^{-1}\left(\frac{IfcMapProjection{::}XAxisAbscissa}{IfcMapProjection{::}XAxisOrdinate}\right)$

With these classes and the relationships between them we can model the shift from Earth's irregularities to geodetic global and local CRSs which in turn set the BIM-global CS used by *IfcProject* and further by individual elements (see Figure 7). However, this is true only for simple cases, where the local CRS can be defined with the parameters of the simplified Helmert transformation from Equation (4). Should the coordinates be defined with a project-specific CRS (e.g., spanned with a NTv2 dataset), the existing entities do not suffice.

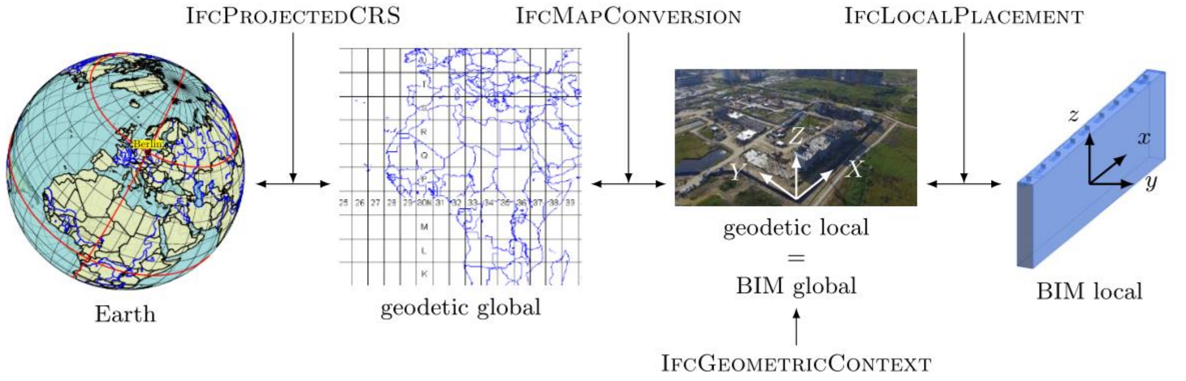

Figure 7. An overview of positional referencing within IFC and the corresponding CSs.

5. PROPOSAL

Both projects described in Section 3 cannot be georeferenced with the current IFC schema, as both use project-specific geodetic CRS which are not listed in the EPSG database and thus cannot be referenced with *IfcProjectedCRS*. This is a major drawback, since exactly such projects (state funded and/or international) call for open competition among the firms and thus demand a well-defined non-proprietary data format for neutral data exchange. In order to incorporate support for such cases, an extension of the schema is necessary.

To allow for exchange of such projects, the grid shift transformation parameters described in Section 2 need to be included in the IFC file and thus added to the IFC schema. We propose to add an additional class deriving from *IfcCoordinateOperation* following the object hierarchy in the schema. We name this class *IfcBilinearConversion*. There are two possibilities of how to define this class and fill it with data.

1. It includes an array of tuples of triplets $(((E_1,N_1,H_1),(X_1,Y_1,Z_1)),((E_2,N_2,H_2),(X_2,Y_2,Z_2)),...)$ which represent the link between the coordinates in the geodetic CRS defined with *IfcProjectedCRS* and the corresponding coordinates used in the BIM model. For this, a new class *IfcGeodeticPoint* should be defined to semantically separate it from the Cartesian point already defined in the schema as *IfcCartesianPoint*.

2. Some of the existing NTv2 datasets are already included in the EPSG database, e.g., EPSG:15948 – the *BeTA 2007* data set for the transformation DHDN to ETRS89. Instead of specifying all parameters, a reference to the EPSG code could suffice, similarly to the EPSG code in the *IfcProjectedCRS::Name* attribute.

Either of these options is equally correct, so we propose to make them both optional and induce a rule, where only one of them must be provided in order to avoid inconsistencies.

6. DISCUSSION

At the beginning of any construction project, the state of the surroundings is acquired, either by querying an existing database or by recording it anew. In both cases, one must pay attention in which CRS the geospatial data is provided, if one does not want to violate compulsory points or prefabricate an element of false dimensions.

The problem of distorted coordinates and dimensions was not getting the necessary attention in the past as the difference between distorted and non-distorted distances was negligible or was hidden in the building projects. There, the precision error at construction time is greater than the distortion due to the projection occurring at such small dimensions. However, when designing and constructing an infrastructure facility (e.g., a 40 km highway) these distortions cannot be omitted.

Many times, it is beneficial to define a construction site's own, local (Cartesian) CRS without any distortion (buildingSMART, 2017; Kaden & Clemen, 2017). This CRS is seen as local in the geospatial domain and as global in the BIM domain, as every building belongs to a construction site, which is the uppermost element in the spatial hierarchy. An element on the site (for example, a floor slab) may then define its own, BIM-local CRS, e.g., with the help of Equation (1) in *IfcLocalPlacement*. With that, every coordinate is provided relative to a local point of origin and thus the magnitude of coordinates drops and simplifies the handling of numbers on the site. Software specialized for detailed design of elements near one another can still work on the data and ignore the geospatial reference.

Nevertheless, the problem still persists if distorted geospatial data (usually originating from a geographic information system) is included in such a project without back transformation to the local CRS and is used as the basis upon which the engineer plans and designs. A fundamental discussion should happen at model setup and a consensus of all stakeholders should be sought for (buildingSMART, 2017).

7. CONCLUSIONS

Building Information Modelling (BIM) has been getting increasingly adopted in the infrastructure domain. As such, an influx of new concepts has been added to the BIM data format Industry Foundation Classes (IFC). One of the new chapters is georeferencing and positioning of the asset on Earth which must be included in the model itself and considered during all planing phases. A correct understanding of geodetic Coordinate Reference Systems (CRS) has become of utmost importance among all project stakeholders, especially if parts are to be prefabricated from the BIM model.

The project basis point and the direction vectors in the model define the construction site's local Cartesian CRS which needs to be transformed back to the Earth's surface when constructing. The parameters are provided in *IfcMapConversion* and *IfcProjectedCRS* which define the geodetic and vertical datum as well as the projection and a simplified Helmert transformation of the local CRS with Equation (4).

However, we provide two examples of real-world infrastructure projects where these two entities do not suffice. We propose new entities in Section 5 which cover these cases by allowing to include the grid shift parameter data sets in the IFC file (e.g., National Transformation version 2 (NTv2)). With that, coordinate transformations with empirically derived and location dependent transformation parameters are adequately modelled.

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REFERENCES

Barazzetti, L. and Banfi, F. (2017). *BIM AND GIS: WHEN PARAMETRIC MODELING MEETS GEOSPATIAL DATA.* ISPRS Annals of Photogrammetry, Remote Sensing & Spatial Information Sciences 4.

BBT SE (2018). *Brenner Basis Tunnel: Project's official website.* https://www.bbt-se.com/en, accessed on January 21, 2018.

Borrmann, A., König, M., Koch, C. and Beetz, J. (2015). *Building Information Modeling: Technologische Grundlagen und industrielle Praxis. [Building Information Modeling - Technological foundations and industrial practice]* VDI-Buch, Springer Fachmedien Wiesbaden.

Borrmann, A., Amann, J., Chipman, T., Hyvrinen, J., Liebich, T., Muhič, S., Mol, L., Plume, J. and Scarponcini, P. (2017). *IFC Infra Overall Architecture Project: Documentation and Guidelines.* Retrieved from buildingSMART website: https://buildingsmart.org/wp-content/uploads/2017/07/08_bSI_OverallArchitecure_Guidelines_final.pdf, accessed on January 12, 2018.

buildingSMART. (2017). *Model Setup IDM, Vol I: Geo-referencing BIM.* Retrieved from buildingSMART website: http://buildingsmart.org.au/wp-content/uploads/Vol-1-Geo-referencing-BIM_v1.2.pdf, accessed on January 12, 2018.

Del Giudice, M., Osello, A. and Patti, E. (2014). BIM and GIS for district modeling. *Proceedings of the 10th European Conference on Product & Process Modelling 2014 Conference*, Vienna, Austria.

Donaubauer, A. and Kolbe, T. H. E. (2017). *Leitfaden Bezugsystemwechsel auf ETRS89/UTM: Grundlagen, Erfahrungen und Empfehlungen. [Guide for reference system change to ETRS89 / UTM: Fundamentals, experiences and recommendations]* Retrieved from Rundertisch-GIS website: https://rundertischgis.de/publikationen/leitfaeden.html, accessed on January 12, 2018.

Heunecke, O. (2017). Planung und Umsetzung von Bauvorhaben mit amtlichen Lage- und Höhenkoordinaten. [Planning and implementation of construction projects with geodetic coordinates] *zfv* 142, pp. 180–187.

ISO 16739:2013 (2013). *Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries.* Standard International Organization for Standardization Geneva, CH.

ISO 19111:2007 (2007). *Geographic information – Spatial referencing by coordinates.* Standard International Organization for Standardization Geneva, CH.

Kaden, R. and Clemen, C. (2017). Applying Geodetic Coordinate Reference Systems within Building Information Modeling (BIM). *Technical Programme and Proceedings of the FIG Working Week 2017*, Helsinki, Finnland. ISBN: 978-87-92853-61-5.

MSB (2007). *Magnetschnellbahn Ausführungsgrundlage: Fahrweg, Teil V, Vermessung. [Transrapid Execution Plan: Track, Part V, Surveying]* MSB Fachausschuss Fahrweg.