Applying Geodetic Coordinate Reference Systems within Building Information Modeling (BIM)

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Key words: Coordinate Reference System, Building Information Modelling, Georeferencing, GIS, Surveying

SUMMARY

Within this paper, the differences between the understanding of coordinates in the domain of architecture/engineering/construction (AEC) and in the geospatial domain are discussed in detail. Since the Building Information Modeling (BIM) method is originated in the AEC domain and the topographic modeling methods in surveying and GIS systems are originated in the geospatial domain, the spatial integration requires detailed knowledge of the characteristics of the coordinates. In the geospatial domain, mainly global Coordinate Reference Systems (CRS) including a map projection are used whereas in the AEC domain, mainly local Project Coordinate Systems (PCS) are used. It is explained, which properties characterize these coordinate systems and which differences must be considered when integrating GIS and surveying data with BIM data. For the spatial integration, methods and models for georeferencing the BIM project using the proprietary software Autodesk Revit 2016 and the open standard Industry Foundation Classes (IFC) are tested and discussed. These methods was primarily developed to georeference planned buildings (as-planned) within a BIM project. In addition, also a numerical example of georeferencing an existing building (as-built) using the Revit functionalities is shown in detail. This paper aims to be a guide for persons in charge working with BIM in the AEC and the geospatial domain to increase the awareness of the characteristics of coordinate systems, in order to guarantee a correct spatial integration of BIM with surveying and GIS systems.

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1. INTRODUCTION

In the field of architecture and civil engineering, digitalization has been developed from a 2D geometry representation to an object oriented 3D information modeling, called Building Information Modeling (BIM). The scope of BIM is the continuous use of digital building models within all phases of a building life cycle, from the planning phase through the operation phase to the final demolition phase. The so called BIM method is coming more and more into practice and leads thereby to a comprehensive change of working techniques and working methods within the building industry. In Germany, the Government acknowledged BIM as a major step towards utilizing the opportunities presented by digitalization. In December 2015, Alexander Dobrindt, Federal Minister of Transport and Digital Infrastructure, officially announced that the use of BIM will be mandatory for all transportation projects by the end of 2020 (BMVI, 2015). Especially for large, elongated projects such as roads and railways but also for ordinary building projects, the characteristics of projected geodetic Coordinate Reference Systems (CRS) cannot be ignored by architects and civil engineers. Especially in the design phase, GIS data and location plans serve as a basis for BIM projects and must be integrated correctly (Clemen and Manthe, 2016). Also surveyors will have to deal more and more with BIM data, e.g. deliver BIM conformable as-built models, location plans or extracting set-out coordinates from BIM projects during the construction phase.

2. COORDINATE SYSTEM PARADIGMS

In the past, many different coordinate systems has been defined and applied within the different technical domains such as the mechanical engineering, computer graphics, geospatial, facilities management and architecture/engineering/construction (AEC) domains. The different coordinate definitions follow different paradigms in accord with the requirements of each particular domain and lead to a different understanding of coordinates. However, due to the digitalization of work processes in the AEC domain, e.g. by using CAD or BIM methods, digital topographic and building data need to be integrated during the planning and construction phase of buildings and structures. GIS data and survey plans represented in geodetic coordinates flow into the BIM and survey stake-out data need to be exported. The common used coordinate systems within the geospatial domain and the AEC domain are now explained.

2.1 Coordinate Reference Systems (CRS) in the Geospatial Domain

During the last decades, a number of software systems has been developed to manage, store and represent geo data, i.e. geodetic CAD and GIS systems. A common Coordinate Reference System (CRS) used in the geospatial domain consists of two components, a physical part which is the geodetic datum and a mathematical part which is the coordinate system, shown in figure 1 (ISO19111, 2007).

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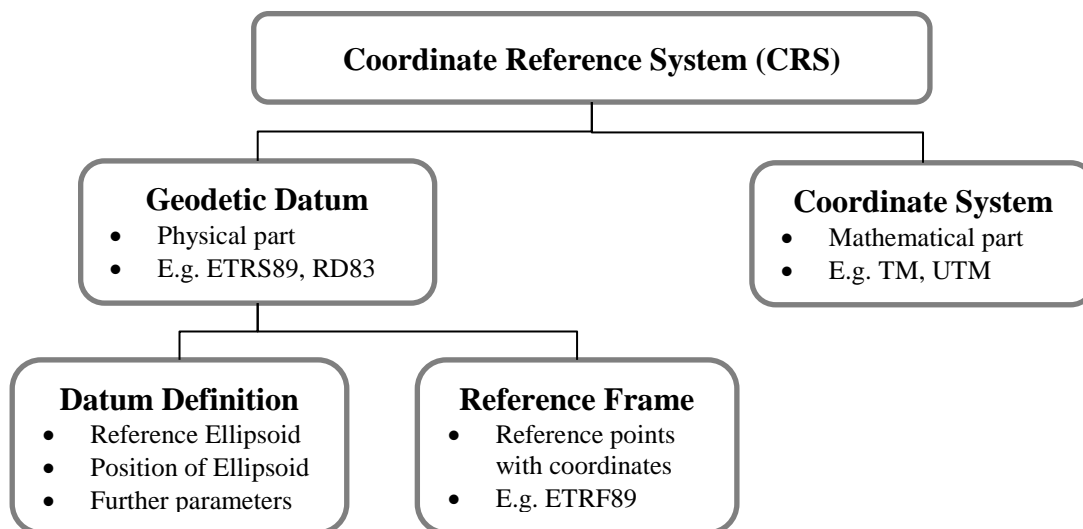Helsinki, Finland, May 29–June 2, 2017

Fig. 1: Components of a Coordinate Reference System (CRS) in the geospatial domain

A geodetic datum describes the exact position, the extent and the orientation of a reference ellipsoid within the body of the earth, using data and a set of parameters consisting of fixed points and their coordinates. Worldwide, many different definitions of ellipsoids exist as mathematical substitute figures for the earth. While a local reference ellipsoid is best fitted to a specific region or country, the global ellipsoid represent the entire body of the earth. In Germany, the geodetic datum is based on the ellipsoid developed by Bessel, which defines the Potsdam datum (PD). The 1984 World Geodetic System (WGS84) describes a global reference system. In order to unify the various systems, the European Terrestrial Reference System (ETRS89) has been defined using the ellipsoid Geodetic Reference System (GRS80). For the conversion from a former German coordinate reference system based on the Potsdam Datum, e.g. RD83, to UTM coordinates, based on the European Terrestrial Reference System, a datum change from PD to ETRS89 is necessary. To determine real locations on the Earth surface, reference points must be defined. They form the reference frame and link the coordinates with actually measured positions on the earth.

In order to quantify positions on the earth with respect to the reference ellipsoid, a coordinate system has to be defined. A coordinate system is a mathematical-geometric arrangement system to facilitate referencing of geographic data. This can be realized by global ellipsoidal (latitude, longitude) or global Cartesian coordinates (X,Y,Z) as well as by a projection of the global coordinates to plane coordinates (projected coordinates). The advantage of using projected coordinates are that the axes are right-angled and with a uniform metric division (Cartesian systems) so that the Euclidean metric can be applied in the horizontal plane. Commonly used coordinate systems in geodesy and GIS are the Transverse Mercator (TM) or the Universal Transvers Mercator (UTM) projection, shown in figure 2.
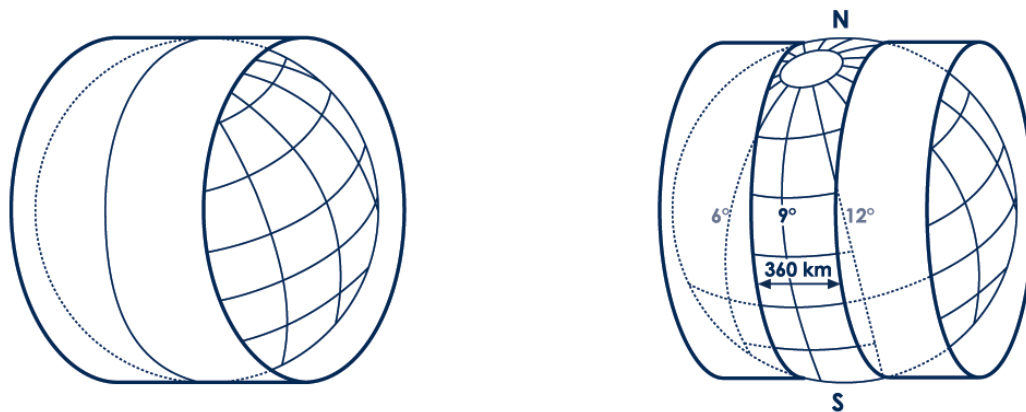
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Fig. 2: Cylindrical Transverse Mercator (left) and the Universal Transverse Mercator (right) projection (GeoBremen, 2015)

Both the Transverse Mercator and the Universal Transverse Mercator are planar and angular conform projections which can be visualized by using a cylinder placed around the earth. The Gauss-Krueger TM projection uses a cylinder touching the earth along a central meridian, where the circumference of this cylinder is equal to the circumference of the central meridian. Along this meridian, the image is length-preserving, however, with increasing distance from the meridian, the distance distortion is increasing. The German distortion tolerance is reached 1.5 degrees west or east of the central meridian, so 3 degree of strip width is used. In order to be able to map the whole earth, this cylinder is moved systematically by 3 degrees so that 120 strips of 3 degrees each are defined. The UTM projection uses a cylinder with a scale factor of 0.9996 at the central meridian and divides the Earth into 60 zones, each 6 degrees in width. The origin of the coordinate systems is the intersection of the central meridian with the earth's equator. In order to prevent negative coordinates west of the central meridian, the value 500 km is added to the easting from the center of each zone.

2.2 Project Coordinate Systems (PCS) in the AEC Domain

During the last decades, a number of software systems has been developed in the AEC domain, i.e. CAD/CAAD and BIM systems. A CAD system is used to model the actual objects in a system that is independent from the Earth's surface. In this system design intent and geometric accuracy and not the actual geographical position in a local or global context are the primary focus.

Software systems such as MicroStation and AutoCAD use Cartesian coordinate systems in 2D and 3D to locate data by fixed coordinates. X, Y, and Z coordinates of the so called World Coordinate System (WCS) or Project Coordinate System (PCS) are not real geographic positions, instead, they are positions relative to an arbitrary geometrical origin (0,0,0). The X axis can be seen as the east value direction and the Y axis as the north value direction, but they are not necessarily coincident to the grid directions in geo data. Although it is possible to create CAD data that matches the X,Y coordinates of a projected Coordinate Reference System (CRS), most CAD data is created without this consideration. Typically, positions of features are defined by measured distances relative to other features at the local terrain height.

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Moreover, linear units in a CAD file are not dependent on or defined by the coordinate system of the data. Drawing units are defined by the authors before they begin creating the data. As a general rule, CAD drawings (or models) are drawn in full scale (1:1). A drawing unit can be any linear unit of measurements, e.g. millimeters, meters or feet. The decision depends mostly on the level of detail, e.g. the interior of a building is often drawn in millimeters and drawing of a survey or a landscape plan is more likely drawn in meters.

2.3 Important CRS and PCS Properties for Integrating GIS and BIM

The common Coordinate Reference Systems (CRS) in the geospatial domain facilitate the representation of the entire earth whereas local Project Coordinate Systems (PCS) in the AEC domain aim to represent a specific object, independent from other features. For this reason, the linear unit of the coordinate values in a geodetic/GIS system depends on the underlying geodetic CRS and is defined – for the common used TM and UTM coordinate systems in Europe – in meters. Drawings in CAD or BIM systems may base on arbitrary linear units, e.g. millimeters or meters, depending on the level of detail and the choice of the author of the drawing.

In the geospatial domain, objects like buildings, streets and any other topography can be geographically referenced and spatially associated to each other, anywhere on earth. However, due to the limitation of distance distortions for TM and UTM projections, the coordinate system strips mentioned above are given unique zone numbers for the representation of geo data. This need to be considered in case of using GIS data in CAD or BIM projects for the planning of elongated infrastructure projects which straddle different zones. Therefore, coordinates need to be transformed into one common zone first.

Since the geodetic CRS are global systems, the coordinate values are large numbers, e.g. for UTM coordinates seven or eight digits before and two or three digits after the decimal point. For example, the UTM coordinates of the city center of Dresden are Easting: 33411491.73 and Northing: 5656189.12. The easting coordinate starts with the zone number 33, which is not a metric component, followed by the metric value and the northing value is the metric distance from the earth equator.

Due to the projection of the curved earth surface into the plane by the TM or UTM projection, distances and areas are distorted in the projection, shown in figure 3 (left). For example in UTM, a measured distance of about one kilometer between two points close to the central meridian on the earth surface is about 40 centimeters longer than the calculated distance between the same points in a GIS. Especially for elongated projects like streets or long bridges, this projection distortion needs to be considered when using geo data within CAD or BIM projects as well as for survey work in the field.

Another distortion of distances is due to the height different between the earth surface and the projection surface which is the reference ellipsoid, shown in figure 3 (right). The higher the earth's surface above the reference ellipsoid (e.g. in mountainous areas), the greater will be the distortion of distances and areas. For example, a bridge of about one kilometer which is planned at a height of about 500 meters above sea level is about 8.5 centimeter longer than the surrounding topography in

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a GIS. Hence, this distortion has to be considered as well during the planning and construction phase using a BIM.
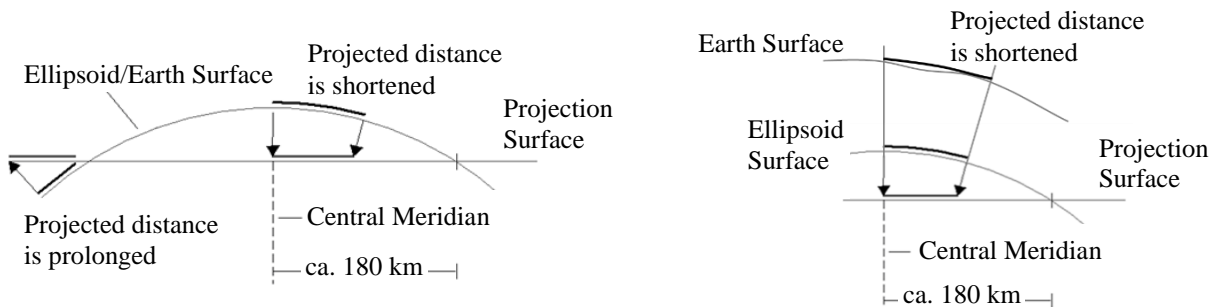

Fig. 3: Distortions due to UTM projection (left) and height (right)

The distortions due to projection and due to height can be corrected using the following formulas for UTM (GeoBremen, 2015). The correction values need to be applied when transforming between geo data using a geodetic CRS with a UTM projection and local coordinates on the earth surface resp. construction/planning site.

Height correction:
$$S_{ell} = S_{meas} \cdot \left(1 - \frac{h_{ell}}{R_m}\right)$$

Projection correction:
$$S_{UTM} = S_{ell} \cdot 0{,}9996 \cdot \left(1 + \frac{(E_m - 500\,km)^2}{2R_m^2}\right)$$

Combined height and projection correction:
$$S_{UTM} = S_{meas} \cdot 0{,}9996 \cdot \left(1 - \frac{h_{ell}}{R_m} + \frac{(E_m - 500\,km)^2}{2R_m^2}\right)$$

Where:
S_{meas} ...*Measured horizontal distance on earth surface*
S_{ell} ... *Horizontal distance on reference ellipsoid*
S_{UTM} ... *Horizontal distance in UTM projected CRS*
H_{ell} ...*Height of earth surface resp. construction/planning site above reference ellipsoid*
E_m ...*Mean easting value of the construction/planning site*
R_m ...*Mean radius of osculating sphere: 6383 km*

Table 1 summarizes and compare important properties of the CRS in the geospatial domain and the PCS in the AEC domain, which must be considered when integrating GIS data and location plans into BIM projects or when extracting set-out coordinates from BIM projects.

Table 1: Comparison of important properties of the CRS and the PCS

	CRS (e.g. ETRS89/UTM)	PCS (e.g. local WCS)
Linear Unit:	Meter	Arbitrary
Scale/Coverage:	World	Local (limited)

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Zone Limitations:	Yes, by fixed zones	No
Number of Digits:	Large numbers (7-8 before and 2-3 after decimal point)	Small numbers (Origin close to the project site)
Projection Distortion:	Yes (up to ~ 400ppm)	No (1:1)
Height Distortion:	Yes	No

3. GEOREFERENCING BIM PROJECTS

In order to spatially integrate a BIM project with GIS data, the BIM project must be georeferenced correctly. This is also important when extracting correct set-out coordinates from the BIM project during the construction phase. Within this chapter, the proprietary BIM software Autodesk Revit 2016 and the open standard Industry Foundation Classes (IFC) are tested and discussed. These methods was primarily developed to georeference planned buildings (as-planned) within a BIM project. In addition, also a numerical example of georeferencing an existing building (as-built) using the Revit functionalities is shown.

3.1 Autodesk Revit 2016

Autodesk Revit 2016 is one of the most frequently used BIM software for the planning and construction of buildings and infrastructures. Although, Revit was developed for the AEC domain working with local project coordinates, there are possibilities to georeference the project coordinates to a geodetic CRS. However, there is no standardized procedure to uniquely identify the coordinate system within the project by using a so called Spatial Reference System Identifier (SRID). A SRID is a unique value used to unambiguously identify projected, unprojected or local spatial coordinate system definitions and is used in GIS software. That means, that all involved stakeholders and operators working with a BIM project must be informed about the CRS definition, in order to be able to locate the project on its true position on the earth. There are three methods to georeference a BIM project in Revit, which are from a geodetic point of view more or less practicable and partially reliable.

3.1.1 Georeferencing using the Revit Survey Point and Project Base Point

For georeferencing in Revit 2016, the survey point and the project base point can be used. For this purpose, coordinates are assigned to either a Local Surveying Coordinate System (LSS) or a geodetic CRS.

The project base point defines the origin of the Project Coordinate System (PCS). The PCS is defined automatically when a project is created and is used to relatively model the building elements with measures. Object coordinates that reference the PCS are displayed relative to the project base point. The project base point can be either located anywhere in the project geometry or – in case of georeferencing the project in a higher coordinate system like a LSS or a CRS – any logical point, e.g. the intersection of grid lines or a specific building corner with known coordinates in the higher system. The project base point is symbolized as a blue-circle with cross symbol (Baldacchino, 2013).

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The survey point allows the definition of the higher coordinate system like a LSS or a CRS. It represents either the origin or a physical survey point close to the project site in the LSS or CRS. It is symbolized as a blue triangle labeled with "Survey Point". The three parameters of its location in the higher coordinate system (northing, easting, azimuth) are shown as attributes at the project base point.

The survey point and the project base point are visible in the site view. To enable visibility in other views, the visibility must be activated in the corresponding views. Both, the survey point and the project base point can be clipped or unclipped, which affects the behaviour of the these points with respect to the coordinates when moving them in a view (Autodesk Revit Help, 2017).

For georeferencing a project in Revit using these points, different workflows can be carried out. One is to unclip the survey point and assign the CRS coordinates either of the origin (0,0,0) or of a known survey point close to the project site. Enter the coordinates by clicking Apply. The survey point moves to this position in the view. The fixation must then be activated again. Thereafter, the project base point must be unclipped and moved to an identifiable control point within the project, e.g. a building corner, with known coordinates in the CRS. Now, the project base point must be clipped and the coordinates of the control point can be assigned and confirmed. Additionally, the rotation of the project coordinate system to the geodetic CRS has to be assigned by entering the angle to the project base point properties. After defining the survey point and the project base point, the annotations of coordinates can be displayed either with respect to the local project coordinate system or to the geodetic CRS.

3.1.2 Georeferencing using coordinates from linked CAD data set

A second method to georeference a Revit project is to use coordinates of a CAD data set like a DWG or DXF file. Location plans of the planning sites from surveyors are usually based on an official CRS, e.g. ETRS89, which can be adopted for the project within Revit. Therefore, the CAD file can be linked to a Revit project. The coordinates of the linked project become the shared coordinates of the Revit project, based on the position of the linked project instance in the Revit project. However, there is no change to the internal coordinates of the Revit project. Furthermore, the Revit project also acquires the true north information (azimuth angle) from the linked CAD project. The origin of the coordinates of the linked project becomes the origin of the shared coordinates within the Revit project.

When a Revit project acquires coordinates from a linked DWG file, the World Coordinate System (WCS) of the selected linked DWG file becomes the shared coordinate system of the Revit project. Therefore, the DWG file should be linked to the Revit project by using the function "Auto - Center to Center" or "Manual - Center" in order to place the DWG close to the Revit project. Afterwards, the DWG file geometry has to be placed on its right position in the Revit project by moving and rotating. The coordinates of the DWG file can now be acquired by using the function "Acquire Coordinates", which can be found at the Manage tab, Project Location panel and Coordinates (drop-down). Other linked models which share coordinates with the Revit project acquires the new coordinates as well. The project base point displays the new CRS coordinates (Autodesk Technical Specialists, 2016).

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3.1.3   Georeferencing using two control points

From a geodetic point of view, the third option is the most native way to georeference a Revit project. Two control points, e.g. building corners, with known coordinates in the higher coordinate system are used to transform the Revit project geometry into a CRS or LSS. However, this function is only available within the Autodesk Point Layout (APL) Plug-In, which is for acquiring stake out data for surveyors.

The tools can be found in the Autodesk Point Layout tab, Set up panel and Coordinates. Using this tool, two control points can be selected within the graphic and assigned with appropriate coordinates of the target system. After defining the coordinate units, the tools ask for selecting the control points and the related coordinates in the higher system. It is possible to enter two or three dimensional coordinates. If the difference of the distances between the assigned coordinates and the project coordinates is too large, an error message is displayed showing the deviation. The deviation can be the result of a systematic scale difference, e.g. if the target coordinate system is a projected CRS, the result of random measurement errors or the result of a misidentification of one or both of the control points. Overriding the error message should not be done ligtly. If the error message was confirmed and the new coordinate system named, the coordinates will be adopted to the Revit project.

3.2 Industry Foundation Classes (IFC)

The Industry Foundation Classes (IFC) standard is an open standard coming from the AEC domain for the digital representation of Building Information Models (BIM). The IFC standard is defined by buildingSMART International, which emerged from the Industrial Alliance for Interoperability (IAI). Moreover, IFC was adopted as an international standard by the ISO 16739 and is available in release 4. Using IFC, logical building structures such as window→wall→story→building with its associated properties (attributes) and optional geometries can be represented. This allows to transfer complex 3D planning data including building elements and descriptive attributes between AEC software systems.

In order to understand how project coordinates can be georeferenced, it is first necessary to consider the placement concept of geometries in the IFC scheme. Following the inheritance hierarchy in the IFC model, all objects which have a spatial context are derived from the element IfcProduct. This class has two attributes, which are required for the placement and geometry presentation. The ObjectPlacement attribute uses the IfcObjectPlacement element to establish the relationship to the different object placement options in the model. A placement can be absolute, relative or in a defined grid. In the IFC model, absolute placement does not mean that the geometry is placed using a geodetic CRS, rather it is placed w.r.t. the project World Coordinate System (WCS), which is defined within the IFC file using the element IfcGeometricRepresentationContext. A relative placement of an object refers to a placement of another object, usually a superior object, e.g. the placement of a wall is relative to the coordinate system of the respective story and the story is again placed relative to the coordinate system of the building.

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Regarding to the IFC specification, the most superior object in the project, e.g. the spatial element IfcSite, should be placed absolute w.r.t. the project WCS. A site is a defined area of land, such as a property or a construction site. In addition, the IfcSite element can be georeferenced using a single reference point with WGS84 coordinates (Longitude, Latitude and Elevation). This point defines the origin (0,0,0) of the LocalPlacement of the IfcSite object. All other objects, which are hierarchically below, e.g. IfcBuilding, then follow the relative positioning w.r.t. the local system of the site element, in which it is included. For georeferencing the IFC model to any other CRS (other than WSG84), the IFC elements IfcCoordinateReferenceSystem and IfcMapConversion have to be used.
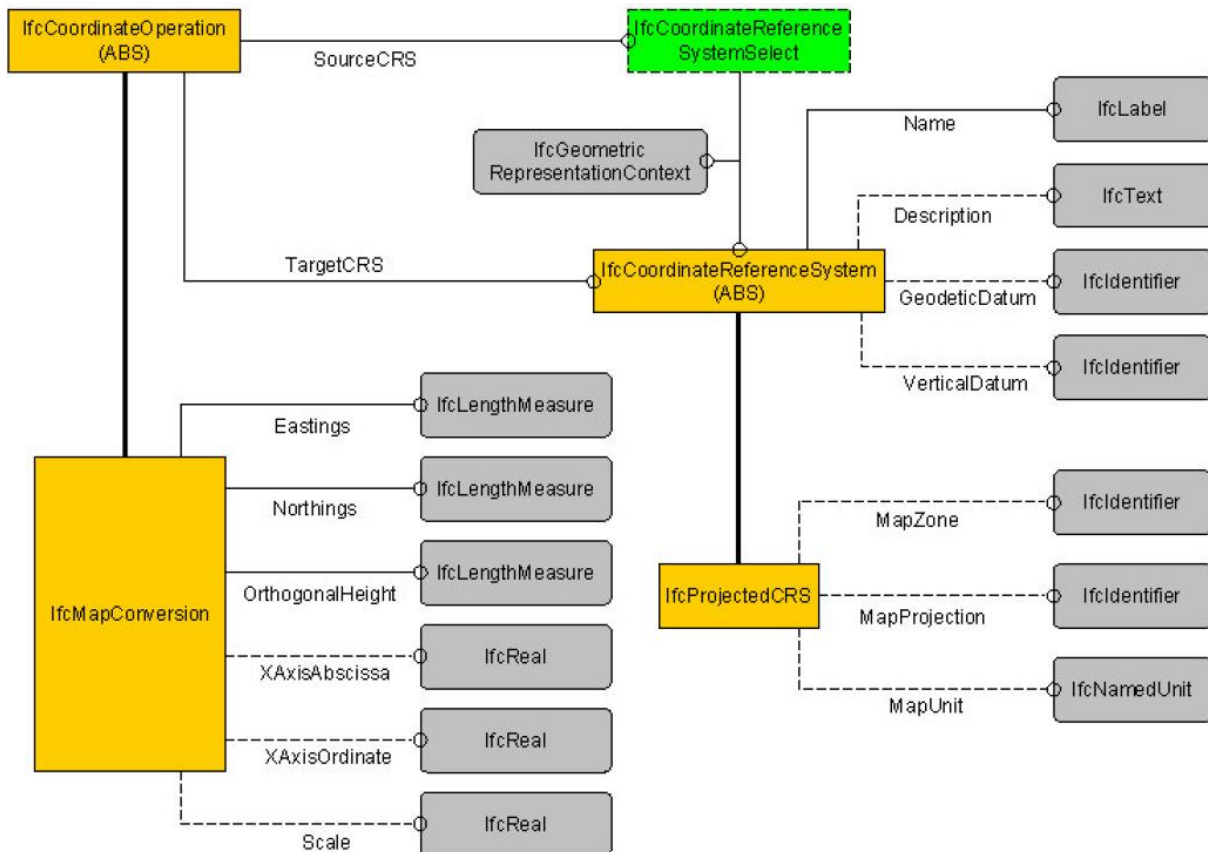

Fig. 4: EXPRESS-G Diagram of the IFC coordinate operation model (Görne, 2016)

As shown in figure 4, the abstract IfcCoordinateOperation element is the root for the coordinate operations that can be provided in the IFC model. The class consists of two attributes referring the source and target coordinate systems of the coordinate operation. Using the selection type IfcCoordinateReferenceSystemSelect, the source coordinate system can be either the project WCS or – in case the project WCS is already coherent to a CRS – a geodetic CRS. The defined parameters for the project WCS are derived from the class IfcGeometricRepresentationContext. This class describes the context of representation for the 3D model and the mapped 2D plans.

The target system of the coordinate operation as well as for the source system, a CRS can be defined. Since the class IfcCoordinateReferenceSystem is abstract, only its child class

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IfcProjectedCRS can be instantiated. Thus, only a projected CRS can be defined as a target system by attributes of both classes. According to the IFC specification, the attribute Name is mandatory and should represent a Spatial Reference System Identifier (SRID) according to the European Petroleum Survey Group (EPSG) code. However, the definition of the CRS using an EPSG code is not explicitly defined in IFC. Depending on the author of the IFC file, the attribute Name can include "EPSG:1234", "1234" or "*Name* EPSG:1234". Moreover, if the optional attributes are used as well, redundancy or even inconsistencies may occur. This may lead to conflicts, if IFC files are to be imported into GIS systems. If no EPSG code is available, a CRS can be specified using the optional attributes Description, GeodeticDatum, VerticalDatum, MapZone, MapProjection and MapUnit.

The coordinate operations between the source and the target coordinate system are defined within the subclasses of IfcCoordinateOperation. Currently, there is only one operation implemented by the IfcMapConversion element. It allows the positioning of the origin of the source coordinate system within the target system using the mandatory attributes Easting, Northing and OrthogonalHeight as well as a rotation in the X,Y plane using the optional attributes XAxisAbscissa and XAxisOrdinate (ISO16739, 2013).

Currently, the buildingSMART community is working together with the Open Geospatial Consortium (OGC) to develop further coordinate operations, such as a transformation between different datums (buildingSMART International, 2016).

3.3 Georeferencing an Existing Building (HTW Dresden Mensa BIM Project) – A Numerical Example

In this example, an Autodesk Revit BIM project of the university cafeteria and laboratory building (Mensa building) is given. The BIM project has been modelled based on construction plans of the building and survey data captured by a total station and a laser scanner (Stieler, 2013). As explained before, the Revit BIM model is based on a Project Coordinate System (PCS). The aim of this sample project is to properly georeference the BIM model and valuate the different methods in Revit explained in chapter 3.1. It is to be shown, how 1.) parameters for the transformation from the PCS to a higher coordinate system can be determined and 2.) to set the parameters in the BIM Software.

In this sample project, an intermediate coordinates system between the BIM Project Coordinate System (PCS) and the national Coordinate Reference System (CRS) has been introduced. It is named as Local Surveying Coordinate System (LSS). The LSS provides a common reference system and frame with scale=1 and short coordinate values. It allows to integrate multiple BIM projects (e.g. Mensa building, Building A, Building B) and to carry out precise engineering/construction surveys, i.e. setting out building elements. The LSS is than georeferenced to a national CRS, as shown in figure 5.

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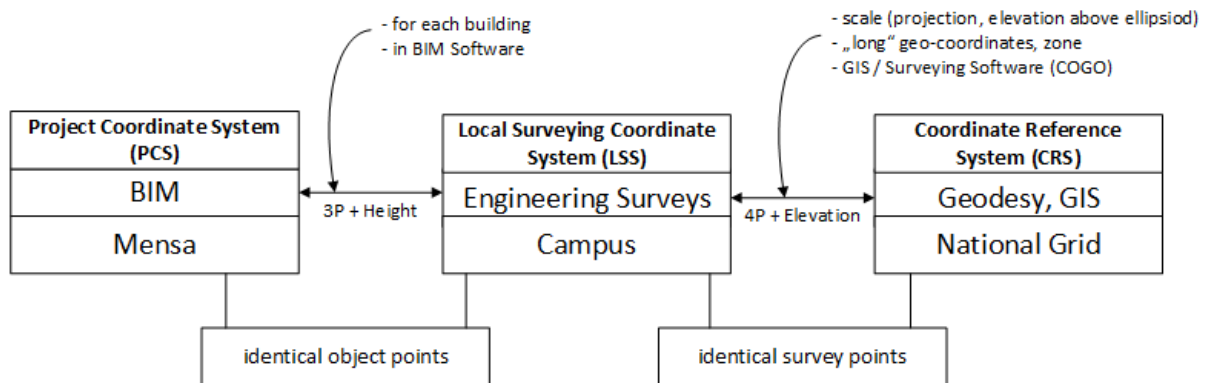Helsinki, Finland, May 29–June 2, 2017

Fig. 5: Overview on coodinate systems applied in the numerical example HTW Dresden Mensa

The survey reference points of the LSS were first measured using the total station Leica TS15 and then properly adjusted as 3D network using the Software "Java Graticule 3D" (JAG3D, 2016). The transformation parameters to the national CRS (here ETRS89/UTM, DHHN) have been determined using four control points points as part of the network. Figure 6 shows the surveying network of the LSS and the Revit BIM model of the Mensa building.
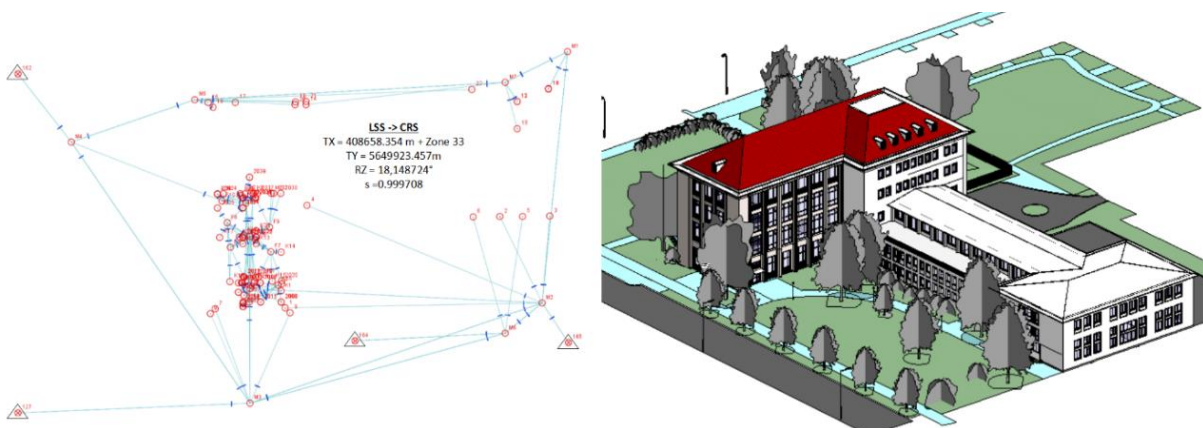

Fig. 6: Surveying Network (left) and BIM model of the HTW Dresden mensa building (right)

In order to spatially link the LSS and the PCS of the BIM model, a set of identical points was defined and measured. This control points are specified in the BIM model and as natural targets of the engineering survey outside and inside the building. The location plan in figure 7 shows the Mensa building with the surrounding topography. The control points are mainly significant building corners but also unique points within the building. Unfortunately, preliminary analysis of the given BIM model with measured control points of the building has shown that the geometry is not as precise as it was expected. This is due to the fact that the BIM model was partially created using construction plans of the building (as-planned).

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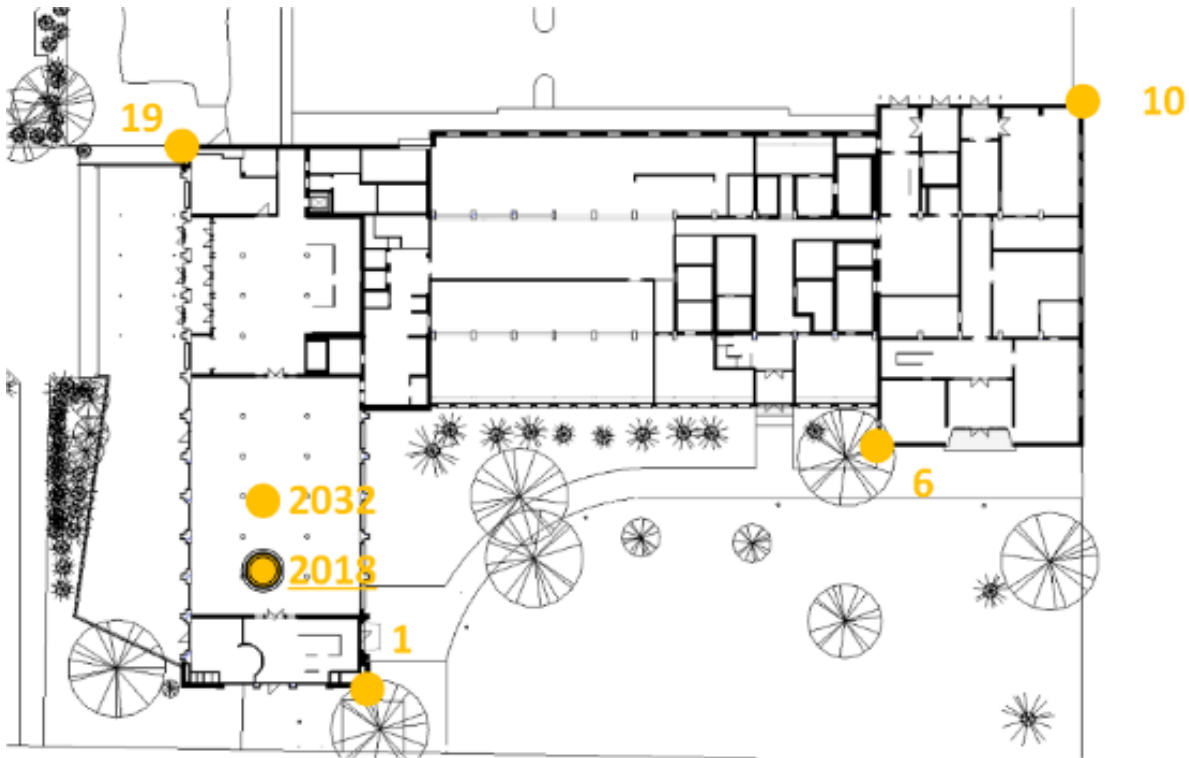Helsinki, Finland, May 29–June 2, 2017

Fig. 7: Location plan with defined and measured control points

Using the measured set of identical points, the above mentioned methods to achieve a georeferenced BIM model in Autodesk Revit 2016 have been carried out and analyzed. Since an Autodesk Revit BIM model is able to store more than one "shared coordinate system", it is possible to work with a LSS and a CRS at the same time. In this numerical example, the BIM model was referenced to the LSS.

3.3.1   Transformation using the Project Base Point

As explained in chapter 3.1.1, a BIM model can be georeferenced by moving the project base point to a control point with known coordinates in the higher-ranked system and then rotating the system manually. Therefore, the first step was to unclip and move the project base point to the well identifiable corner within the building model which corresponds to the pre-measured control point #2018 using the point snapping function. Afterwards, the project base point must be clipped again and the LSS coordinates of the point #2018 was assigned to the Project Base Point properties. Additionally, the azimuth angle of 359.5° was estimated manually in order to get an approximation for the rotation. Figure 8 shows the project base point with the assigned coordinate and azimuth values.

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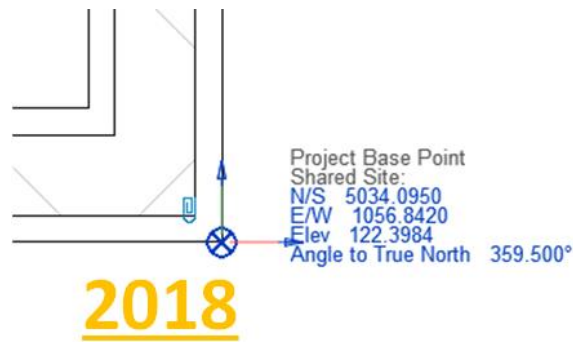Helsinki, Finland, May 29–June 2, 2017

Fig. 8: Revit project base point (blue circle) coincides with control point #2018

The upper section of table 2 shows the result for the first approximation. Point #2018 and #2032 do not fit due to the differences between as-planned and as-built/measured. By comparing the azimuth from #2018 to any other control point, a systematic error of 0.13° is found. By changing the northing coordinates of #2018 of about 8cm and applying an azimuth of 359.4° the results of the fitting could be improved, shown in the lower section of table 2.

Table 2: Residuals in the identical points of the BIM model and the measured LSS

	BIM Method 1 (manually, PBP), azimuth 359,5°				
	LSS:Campus (BIM, Shared Coordinate System)		dx [m]	dy [m]	d_azim. [°] to #2018
#2018	5034,095	1056,842	0	0	-
#1	5026,340	1067,170	0,027	0,067	0,27
#10	5081,445	1133,450	0,046	-0,038	0,04
#6	5049,295	1114,500	-0,014	-0,036	0,00
#19	5076,920	1049,140	-0,072	-0,139	0,20
#2032	5054,230	1056,665	-0,098	-0,019	0,06
		Mean: (without 2032)	-0,003	-0,037	0,13

	BIM Method 1 (manually, PBP), azimuth 359,4°				
	LSS:Campus (BIM, Shared Coordinate System)		dx [m]	dy [m]	d_azim. [°] to #1
#2018	5034,015	1056,842	0,080	0	-
#1	5026,365	1067,255	0,002	-0,018	0,00
#10	5081,495	1133,370	-0,004	0,042	-0,03
#6	5049,315	1114,475	-0,034	-0,011	-0,04
#19	5076,820	1049,065	0,028	-0,064	0,04
#2032	5054,150	1056,630	-0,018	0,016	-0,05
		Mean:	-0,005	-0,007	-0,02

The large deviation of more than 5 cm in #19 are due to the difference between the BIM model (as-planned) and accurate survey (as-built/measured). The method of georeferencing a BIM project by moving the project base point and assigning the coordinate and azimuth values is straight forward, however, it takes quite long time to iteratively fit the BIM model to the LSS points by manually

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minimizing the deviations of the control points ("trial and error"). However, the manually adjusted parameters are sufficient in the mean value.

3.3.2 Transformation using a CAD file

As explained in chapter 3.1.2, a BIM model can be georeferenced by acquiring coordinates from a CAD file. In this example, the coordinates of the LSS were assigned to the Revit Mensa building project by using a CAD file containing lines and polygons of the measured building elements. After linking the CAD file to the Revit project, it was placed in the BIM Model graphically, by using the "move" and "rotate" tool. Figure 9 shows the CAD geometry (yellow) graphically adjusted to the BIM model geometry (black).
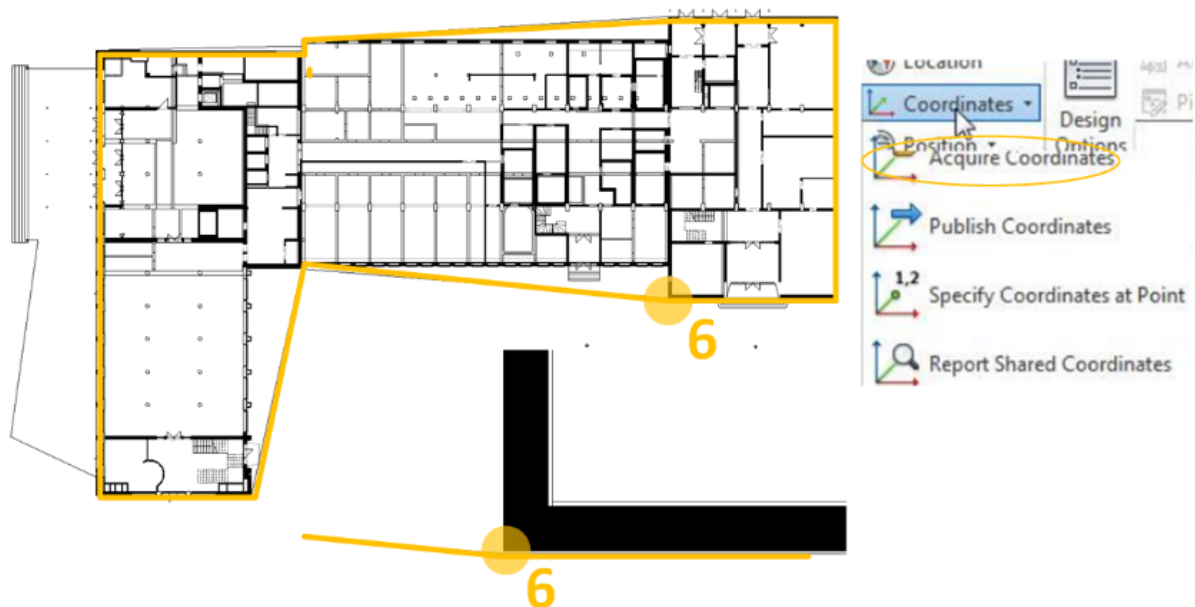

Fig. 9: Integrated CAD geometry with BIM model and "Acquire Coordinates" function assigning the LLS coordinates to the BIM model

Additionally, the "Line Snapping" tool in Revit helps to automatically adjust the CAD geometry to the BIM model geometry using an identical edge. With the Revit tool "Acquire Coordinates", the transformation parameters between the Revit PCS and the LSS are assigned to the Project Base Point. Table 3 shows the results and the deviations of the control point coordinates in the BIM and CAD model.

Table 3: Deviations in the identical points of the BIM model and the measured LSS

	BIM Method 2 (CAD), azimuth 359,421°				
	LSS:Campus (BIM, Shared Coordinate System)		dx [m]	dy [m]	d_azim. [°] to #1
#2018	5034,095	1056,842	0,075	0,012	-
#1	5026,367	1067,237	0,002	-0,003	-
#10	5081,491	1133,412	0,016	0,037	-0,01

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#6	5049,281	1114,464	-0,019	-0,006	-0,02
#19	5076,848	1049,001	0,013	-0,064	0,06
#2032	5054,155	1056,625	0,000	0,000	0,00
		Mean:	0,002	-0,007	0,01

The method of georeferencing a BIM project by moving and rotating linked CAD geometry is straight forward as well. It works purely graphically – control points are only needed in order to find numerical deviations.

3.3.3 Transformation using the Plug-In Autodesk Point Layout

Since CAD and BIM originated in the AEC domain, there is a lack of functionalities which are important for the surveyor's work. In order to bridge the gap, Autodesk provide the plug-in "Autodesk Point Layout" (APL). For georeferencing the Mensa BIM model, the tool "Coordinates" was used to assign the transformation parameters from the Revit PCS to the LSS. First, the desired unit (e.g. meter, millimeter, feet) was selected. However, in the example, it could be recognized that some displayed results are still given in feet, instead of the selected meter. After selecting the unit, the two control points were selected and the corresponding LSS coordinate values was entered. Using APL the azimuth of the transformation was determined by calculation from coordinates – not only by visual adjustment as for the other methods. Using the APL for GIS integration, the BIM model can be georeferenced, neglecting the CRS scale. Table 4 shows the results of the transformation using both methods.

Table 4: Deviations in the identical points of the BIM model and the measured LSS

BIM Method 3 (APL), azimuth 359,428°					
	LSS:Campus (BIM, Shared Coordinate System)		dx [m]	dy [m]	d_azim. [°] to #1
#2018	5034,021	1056,830	0,074	0,012	-
#1	5026,365	1067,240	0,002	-0,003	-
#10	5081,465	1133,380	0,026	0,032	0,00
#6	5049,295	1114,470	-0,014	-0,006	-0,01
#19	5076,840	1049,070	0,008	-0,069	0,06
#2032	5054,155	1056,630	-0,023	0,016	-0,02
		Mean:	0,000	-0,006	0,01
BIM Method 3 (APL-Geo), azimuth 17,576°					
	CRS:ETRS89/UTM (BIM, Shared Coordinate System, scale ignored)		dx [m]	dy [m]	d_azim. [°] to #1
#2018	5654376,621	411229,914	0,071	0,034	-
#1	5654366,042	411237,383	0,002	-0,002	-
#10	5654397,802	411317,413	0,007	0,018	0,00
#6	5654373,104	411289,382	-0,006	-0,028	0,00
#19	5654419,677	411235,778	0,017	-0,062	0,06
#2032	5654395,717	411235,967	-0,033	0,007	-0,01
		Mean:	-0,003	-0,013	0,01

The plug-in was straight forward to use and speeded up the process of georeferencing the BIM model. The numerical results depend on the quality of the two control points. The difference

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between the elevation of the Revit PCS and the LSS or CRS are also part of the property set of the Project Base Point. The elevation can be set manually or within the Autodesk Point Layout plug-in (Schinke, 2017).

4. CONCLUSION

Within this paper, different coordinate systems in the domain of architecture/engineering/construction (AEC) and in the geospatial domain was discussed. Due to this different systems, spatial integration of surveying and GIS data with BIM data requires detailed knowledge of the characteristics of the coordinates. For the spatial integration, methods and models for georeferencing the BIM project using the proprietary software Autodesk Revit 2016 and the open standard Industry Foundation Classes (IFC) was tested and discussed. In addition, also a numerical example of georeferencing an existing building using the Revit functionalities was presented. This paper has shown, that georeferencing BIM projects using the Revit functionalities and the open data model and exchange format IFC is – with a few deficiencies – possible. However, from a geodetic point of view, some enhancements should be make in further versions resp. issues, in order to enable an unambiguous georeferencing.

For example, the definition of the CRS using an EPSG code should be explicitly defined by a specific attribute in IFC. This is essential for a spatially correct integration of IFC files within a GIS system. The "Autodesk Point Layout" (APL) plug-in facilitates georeferencing using two control points and delivers a simple accuracy value in form of the deviation of the distances between the control points (estimated from the BIM model and from the coordinates of the control points). However, in the example, it could be recognized that some displayed results was still given in feet, instead of the selected meter, which may lead to confusions.

REFERENCES

Autodesk Revit Help (2017): Autodesk Revit 2017. Autodesk Knowledge Network, URL: http://help.autodesk.com/view/RVT/2017/ENU/ (15.02.2017)

Autodesk Technical Specialists (2016): Technische Information – Gemeinsam genutzte Koordinaten in Revit, Autodesk Knowledge Network, Issue 01/2016, URL: https://akn-aknsite-article-attachments.s3.amazonaws.com/c35ed8f4-622c-47ac-bf73-e6d19b9fbbe2.pdf (15.02.2017)

Baldacchino, D. (2013): Navigating Through the Storm Using Coordinate Systems in Autodesk® Revit®. In: Autodesk University 2013

BMVI (2015): Stufenplan Digitales Planen und Bauen. Federal Ministry of Transport and Digital Infrastructure, Federal Republic of Germany

buildingSMART International (2016): Industry Foundation Classes Release 4 (IFC4). Add2, Chapter 8.18.3.1, buildingSMART International Ltd, URL: http://www.buildingsmart-tech.org/ifc/IFC4/Add2/html/ (15.02.2017)

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Clemen and Manthe (2016): TLS and Building Information Modeling (BIM) - The BIM Project Central Railway Station Hannover. In: Proceedings of FIG Working Week 2016, Recovery from desaster, Christchurch, New Zealand, ISBN 978-87-92853-52-3

GeoBremen (2015): UTM Abbildung – Informationen und Handlungsempfehlungen. Geoinformation Bremen Landesamt, Hansestadt Bremen, URL: http://www.geo.bremen.de/sixcms/media.php/13/UTM_Abbildung_Info_Handlungsempfehlung_150611.pdf (15.02.2017)

Görne, H. (2016): Building Information Modeling (BIM) – Standards der BIM-Methode für vermessungstechnische Leistungen. Master Thesis, Faculty of Geoinformation, Dresden University of Applied Sciences

ISO19111 (2007): Geographic information - Spatial referencing by coordinates. International Organization for Standardization

ISO16739 (2013): Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries. International Organization for Standardization

Schinke, M. (2017): Building Information Modeling (BIM) für Vermessungsingenieure – Durchführung und Dokumentation einer Absteckung mit offenen Standards (IFC). Bachelor Thesis, Faculty of Geoinformation, Dresden University of Applied Sciences

Stieler, C. (2013): Bauklimatische Untersuchungen zur Mensa Reichenbachstraße auf der Grundlage einer Gebäudemodellierung mit der BIM-Software Revit Architecture. Diploma Thesis, Faculty of Geoinformation, Dresden University of Applied Sciences

JAG3D (2016): Java Graticule 3D. Open Source Geodetic Network Adjustment Sorftware, URL: http://wiki.derletztekick.com/javagraticule3d (15.02.2017)

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