6326 Shades of Georeferencing BIM - Low distortion projections (LDP) for the German Railway

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Abstract

Beside smart Information Management, Building Information Modeling (BIM) focuses on three-dimensional planning and model coordination. However, 3D CAD/BIM software does not conceptualize geodetic coordinates, which causes systematic deviations between geospatial surveys and 3D BIM Model. In local projects, the use of Cartesian coordinates (not curved geodetic coordinates!) is indispensable, due to the high precision demands in computational geometry. The solution is to convert geodetic coordinates into an optimized coordinate reference system. This procedure has been standardized and implemented for 6,326 traffic stations of the German Railway, minimizing systematic deviations and using the DB REF geodetic datum for consistent referencing the alignment of the railway tracks. The developed approach enables the precise use of geometric models (CAD/BIM, high quality 3D point clouds, measured surveys) less than 5ppm, facilitates conversion to other coordinate reference systems using GIS-standard tools, and allows construction projects to be directly staked out from the BIM-model.

1. Introduction

Beside smart Information Management, Building Information Modeling (BIM) focuses on three-dimensional planning and model coordination. However, 3D CAD/BIM software does not conceptualize geodetic coordinates, which causes systematic deviations between geospatial surveys and 3D BIM Model. In local projects, the use of Cartesian coordinates (not curved geodetic coordinates!) is indispensable, due to the high precision demands in computational geometry in CAD. The solution is to convert geodetic coordinates into an optimized coordinate reference system. This procedure has been standardized and implemented for 6,326 traffic stations of the German Railway (German: Deutsche Bahn, DB), minimizing systematic deviations and using the DB_REF geodetic datum for consistent referencing the alignment of the railway tracks.

The German Railway normally operates with a Transversal Mercator projection (3°-meridian stripes, Bessel-ellipsoid; Gauß-Krüger, EPSG:5682-EPSG:5685), realized in the DB_REF reference frame of an overall absolute 1-σ-accuracy of $<$ 1cm. Despite such an accurate realization, the Gauß-Krüger-Projection (GK) results in a project scale up to 150ppm, due to map projection and height above the ellipsoid.

The newly developed approach of a *Low Distortion Projection* (LDP) enables the precise use of geometric models (CAD/BIM, high quality 3D point clouds, measured surveys) less than 5ppm, facilitates conversion to other coordinate reference systems using GIS-standard tools, and allows construction projects to be directly staked out from the BIM-model.

1.1 Motivation

In recent years, the barrier-free renovation of railway passenger stations has gained considerable momentum and is continuing at a high level. To ensure the efficient implementation of the measures, the use of Building Information Modeling (BIM) in passenger station projects has been mandatory since January 1, 2017. The German government will invest an additional €100 billion in infrastructure between 2025 and 2028, leading to a sharp increase in construction activity. Digital methods, in particular BIM, are used to accelerate planning and construction. BIM is also a mean to anticipate and prepare the operation of stations, tracks, tunnels and bridges as digital twins.

Alongside information management, three-dimensional planning and model coordination of spatially federated sub-models and thematically separated specialist-models are key elements of Building Information Modeling (BIM). Three-dimensional surveying of the existing building portfolio forms the basis for three-dimensional modeling. However, the 3D authoring and coordination software used in the BIM method does not work with geodetic coordinates, which are required for alignment, track planning and in Geoinformation Systems (GIS). With "normal" Cartesian coordinate systems, to put it bluntly, "BIM software thinks the earth is flat". The systematic deviations from DB_REF/GK of up to 15 cm per 1 km (150ppm) currently arise because 3D planning software does not take the curvature of the earth into account.

In the local area, however, for example when planning construction work at passenger stations or a bridge, it is essential that Cartesian coordinate systems are used because these form the basis of the planning software used by architects and civil, electrical, and mechanical engineers. It cannot be assumed that the parametric solid modeling, as key feature for efficient CAD/BIM software will be able to be modeled mathematically correctly with curved geodetic coordinates, such in the future.

The task is therefore to convert the necessary geodetic view for qualified alignment for high-speed train operations (DB_REF; GIS systems) into the equally necessary Cartesian view of the planning (3D; CAD systems) for locally limited structures.

The solution lies in transforming the geodetic coordinates in such a way that the systematic deviation between 3D planning and surveying is minimized by the optimal definition of a coordinate reference system (CRS). A systematic, standardized procedure has been developed and tested for this conversion, which is useful in principle for all traffic facilities (VA).

Using this new uniform and standardized procedure, a local CRS was created for all 6,326 traffic stations and made available as a database on the web. This type of CRS is called the local coordinate system for passenger stations (VA system for short). The conversion of the local DB_REF/LDP systems to DB_REF/GK is easy to implement with GIS and CAD software and is based on common IT standards.

With the new standardized procedure, the geometric information can continue to be used correctly even years after planning, and can be transferred to other CRSs and merged. Furthermore, this standardized procedure will enable the construction project to be staked out directly from the model in the future.

1.2 Research Questions

This paper summarizes the results of a comprehensive study for German Railway (Deutsche Bahn). The study answers the following research questions:

1. How large are the systematic deviations (scale in ppm) in locally limited BIM projects resulting from cartographic mapping reduction (Transversal Mercator) and height reduction (0 m to 1000 m above MSL)?

2. With which concepts (datum, geoid, reference frame) and based on which data (position of the stations, DTM) can locally adapted cartographic low-distortion-projections (LDP) be developed for each passenger station in Germany?

3. How can the results be made available in a standardized way for all construction projects? Which IT standards are suitable for the roll out?

4. What implications do the new distortion-minimized coordinate reference systems have for the practical tasks of alignment, surveying documentation, 3D modeling, setting out and asset management done by the German Railway and all sub-contractors?

2. Related Work

Geo-referencing 3D-BIM Models is a hot topic for applied sciences, as the latest meta study by (Azari et al., 2025) shows. The specific problems that arise when global CRS are used for 3D modeling of elongated structures (railways) are discussed in (Jaud et al., 2020), among others. The authors specifically address the scale problem and also show how incorrectly interpreted coordinates affect volume calculations, for example of earth masses. Some specific investigation had been made on the IFC Schema by (Jaud et al., 2022), focusing in IFC entities for geo-referencing and addrsing CRS that are specified as WKT but not with a EPSG-code.

The canonical british snake-grid approach (Iliffe et al., 2007) was not suitable for this study, because a snake grid only works for peer-to-peer railway connection. However, the scientific and technical literature contains numerous methods for local CRSs, all of which aim to minimize distortions due to the curvature of the Earth locally. (Dennis, 2016) shows how different projection types affect *Low Distortion Map Projections*. Other authors, e.g. (Baselga, 2021), develop complex methods for high-altitude areas by adjusting the ellipsoid dimension (a, b) for local measurements. An overview of the different concepts of ellipsoid adjustment is provided by (Rollins and Meyer, 2019). Further publications compare possible calculation surfaces for surveying practice with the aim of developing clear terminology (Billings, 2013). Important arguments for considering elevation in CRS design are described in older studies on the required elevation accuracy for determining the scale factor k_0 by (Burkholder, 2004).

When it comes to standardized concepts and IT deployment of georeferencing, the international standards ISO19111 *Geographic information — Referencing by coordinates* (ISO 19111, 2019) and ISO19162 *Geographic information — Well-known text representation of coordinate reference systems* (ISO 19162, 2019) are authoritative. For reliable formulas and implementation through programming, the compendium *Coordinate Conversions & Transformations including Formulas* (International Association of Oil & Gas Producers (IOGP), 2025) is a reliable standard work. The practical implication, when applying LDP Systems to railway stations, have been discussed in (Kalantari et al., 2024) and are the basis for Section 4 in this article.

3. Solution for an automated Workflow

3.1 Specification of requirements for the LDP database

The parameters in the LDP-system database parameterize an automated transformation of DB_REF coordinates to the local system and back. The transformation of the coordinates can be performed with standard software (GIS/CAD). The transformation parameters (table 1) were calculated under the following premises:

- The parameters describe a compound 2D+1D coordinate reference system (CRS) consisting of horizontal position and vertical height.

- The geodetic datum of the DB_REF (vector frame and ellipsoid dimension) remains unchanged. No geodetic datum transformation takes place.

- Only the (cartographic) projection is adjusted. The central meridian Λ_0 of a transverse Mercator projection runs through the given geographical coordinates of the traffic station (fig. 1). Thus the distortion Δs is minimized.

- The origin of the projection is defined by latitude and longitude Φ_0, Λ_0. The local LDP system coordinates are given a supplement in the east direction fE = 5000m and in the north direction fN = 10000m to avoid negative coordinate values in the measure area.

- The scale $k0$ of the Mercator projection is optimized so that the difference between the measured horizontal distance and the distance calculated from the coordinates in the projection plane is minimized locally. The only influencing quantities for k_0 are the ellipsoidal height h_0 taken from the digital terrain model (DTM), of the train station surroundings and the earth-radius R_0 at that

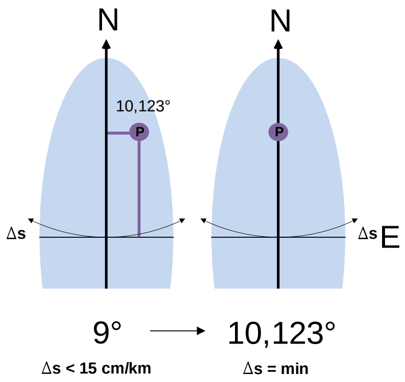

Figure 1. The transverse Mercator projection runs through the given geographical coordinates of the traffic station, adapted from (Clemen et al., 2023)

- The heights of the LDP system are nearly identical to DB_REF2016, using the German Combined Quasigeoid 2016 (GCG2016). This keeps the heights equal to the state and national surveys.
- A folder is created for each LDP system containing the parameters according to ISO 19162 (Well-known text representation of coordinate reference systems, (ISO 19162, 2019)) in the syntactic dialects for GDAL, ESRI, Proj, GML, and a special Autodesk xml format, among others.

These premises achieve the goal of minimizing systematic deviations between surveying and 3D software. If the survey models (fixed points, topographic survey, 3D point cloud) are available in the LDP system, they can be used directly by 3D BIM software. To put it bluntly, the earth can remain a disc for BIM.

3.2 Projected or Topocentric-Cartesian CRS?

The study numerically compared two possible approaches for local coordinate reference systems. The coordinates are given in the DB_REF/GK system. These are transformed in each case as examples.

Variant 1 3D. A local, topocentric 3D CRS as *Engineering Coordinate Reference System*

Variant 2 2D+1D. A compount system, with a locally projected 2D CRS and separate 1D vertical component: *Projected 2D CRS + Vertical CRS*

In purely geometric terms, variant 1 corresponds to 3D modeling in CAD/BIM software without Earth curvature, while variant 2 corresponds to geodetic surveying practice. The surveying instruments total station, level, and 3D laser scanner realize a horizontal plane that is horizontal at the respective instrument position each time they are set up.

In a small area, less than 1000 m, the differences between variant 1 and variant 2 in the horizontal coordinates are negligible. The column Δd of Table 2 shows that the horizontal distance differences up to a distance of $1\,\mathrm{km}$ are less than $0.1\,\mathrm{mm}$. The situation is different with height. The reason for the large difference Δz is that the topocentric 3D system defines an x,y plane that is horizontal only at the origin of the coordinates. Due to the curvature of the Earth, the divergence between the perpendicular line and the surface normal of the x,y plane increases with the distance from the projection center.

Column	Feature
`Station_ID`	the station ID (+ revision number, if applicable)
`Station_Name`	the station name
`Station_Category`	the station category
`lat0`	original latitude of the projection in DB_REF
`lon0`	Central meridian of the projection in DB_REF
`fE`	false easting
`fN`	false northing
`k0`	Scale factor at the origin of the projection
`h0`	Ellipsoidal height used for the scale
`H0`	Normal height of the center or median of the area
`Undulation`	Geoid undulation in the center or median of the area
`ppm_Max`	Maximum scale deviation due to height difference
`ppm_Range`	Range of scale deviation due to height difference
`ppm_Avg`	Mean value of scale deviation due to height difference
`ppm_StdDev`	Standard deviation of the scale deviation due to height difference
`East_GK`	Gauß-Krüger Easting of the origin
`North_GK`	Gauß-Krüger Northing of the origin
`Meridian_conv`	Meridian convergence in the origin

Table 1. Structure and content of the csv-file for all 6326 station. The ppm Meta-Information is only calculated for larger stations

Most applications in the GIS field allow conversion to projected systems using standardized and easily accessible methods, such as Proj strings. Due to the elevation problem with topocentric coordinates, the LDP system uses variant 2, i.e., a projected coordinate system for the location and the official elevation system for the elevation (2D+1D).

For comparison in Table 2, the following projection pipeline was used and executed with standard software:

```
+proj=pipeline +ellps=bessel +step +proj=tmerc
+lat_0=50.7692 +lon_0=6.0916 +k=1.0000287
+x_0=5000 +y_0=10000 +inv +step +proj=cart +step
+proj=topocentric +lat_0=50.7692 +lon_0=6.0916
+h_0=183.0 +step +proj=helmert +x=5000 +y=10000 +z=183
```

3.3 Kind of conformal map projection?

To avoid any changes in shape when projecting the coordinates, a conformal projection is used. Conformal projections are for example Transverse Mercator projection and Lambert Conic Conformal projection. Both projections provide almost identical coordinates (within 1/100 mm) for the small area covered by a LDP system. The Transverse Mercator projection had been chosen for the LDP system because it is likely to work well in all (German) software applications and contains fewer configuration parameters. A conformal projection guarantees correct conversion of measured and calculated horizontal directions. The minimal but unavoidable distance distortions at distances

locally projected			topocentric			difference	
x [m]	y [m]	H [m]	x [m]	y [m]	z [m]	Δd [mm]	$\Delta z - H$ [mm]
5000.0000	10000.0000	183.0000	5000.0000	10000.0000	183.0000	0.00	0.00
5000.0000	10500.0000	183.0000	5000.0000	10500.0000	182.9804	-0.01	19.61
5000.0000	11000.0000	183.0000	5000.0000	11000.0000	182.9215	-0.01	78.45

Table 2. Example comparison of projected (2D+1D) to topocentric (3D) with given DB_REF/GK and a height of 40m

from the projection center of the Transverse Mercator projection are easy to handle using formulas. Since the LDP system is only used locally in the measurement area < 1 kilometer, these distortions are negligible in practice.

3.4 H or Z? - Interpretation of height

The study investigated the consequences of equating the Cartesian height Z (3D modeling) and the normal height H (surveying). In absolute height, the difference at a distance of 1000 m from the project base point is approximately 7.8 cm (see Figure 2).

We recommend using the normal height H as the height Z in the modeling software so that ...

- Measurement and modeling can use the same height values without conversion.
- The heights between 3D modeling and routing are comparable without conversion.
- Horizontal components are actually marked out horizontally.

The deviations due to the (very slight) curvature of approx. K=1/6380000 m of the xy planes can be neglected in component-structured modeling, as shown in the example in Figure 2.

3.5 Optimal Scale Factor k0?

The scale factor k_0 is part of the definition of the LDP system. It must be defined in such a way that the difference between the locally measured distances and the distances in the LDP system is minimized. The only influencing factor for k_0 is the height above ellipsoid. The reference height h_0 for determining the scale factor k_0 is defined using the DTM heights in the wider (larger stations category 1-3) or nearby (small stations category 4) surrounding of the coordinate origin (λ_0, ϕ_0).

The scale factor is generally calculated using the formula:

$$k_0 = \frac{h_0 + R_0}{R_0} = 1 + \frac{h_0}{R_0}. \quad (1)$$

However, the ellipsoidal height $h_0^{DB\_REF}$ can only be calculated iteratively because, at the time of calculation, the DTM (10m) and the quasi-geoid model (GCG2016) were only available in the European datum ETRS89, not in the datum of the German railway DB_REF.

The ellipsoidal height $h_0^{DB\_REF}$ is calculated using:

- Determination of the normal height $H_0^{DHHN2016}$ in DHHN2016 at the location $\left(\lambda_0^{ETRS89}, \phi_0^{ETRS89}\right)$ from input data H_0 and eight neighboring points in the DTM. In order to not be dependent on a single elevation value at the center coordinate when determining the height of the system, the elevations of the 8 DTM neighboring points are determined in addition to the elevation of the center point. The median of the 9 heights determined is then used as the height H_0.
- Determination of the quasi-geoid undulation $\zeta_0^{ETRS89/GCG2016}$ at the location $\left(\lambda_0^{ETRS89}, \phi_0^{ETRS89}\right)$. The values can be obtained, for example, via the free BKG web service.
- Determination of the ellipsoidal height h_0^{ETRS89} with quasigeoid undulation $\zeta_0^{ETRS89/GCG2016}$.

$$h_0^{ETRS89} = H_0^{DHHN2016} + \zeta_0^{ETRS89/GCG2016} \quad (2)$$

- Datum transformation to DB_REF with the transformation steps

$$\left(\lambda_0^{ETRS89}, \phi_0^{ETRS89}, h_0^{ETRS89}\right) \mapsto \left(X^{ETRS89}, Y^{ETRS89}, Z^{ETRS89}\right) \quad (3)$$

$$\left(X^{ETRS89}, Y^{ETRS89}, Z^{ETRS89}\right) \mapsto \left(X^{DB\_REF}, Y^{DB\_REF}, Z^{DB\_REF}\right) \quad (4)$$

$$\left(X^{DB\_REF}, Y^{DB\_REF}, Z^{DB\_REF}\right) \mapsto \left(\lambda_0^{DB\_REF}, \phi_0^{DB\_REF}, h_0^{DB\_REF}\right) \quad (5)$$

- This gives $h_0^{DB\_REF}$.

The Earth radius R_0 must approximate the curvature of the ellipsoid at the position $\left(\lambda_0^{DB\_REF}, \phi_0^{DB\_REF}\right)$ as accurately as possible, which is why the radius of the Gaussian sphere is used when calculating k_0 of the LDP systems. The Earth radius at the origin of the local LDP system can be calculated from the semi-major axis a, the semi-minor axis b of the Bessel ellipsoid, and the latitude ϕ_0:

$$R_0 = \frac{a^2\, b}{\sin^2 \phi_0\ (b^2 - a^2) + a^2} \quad (6)$$

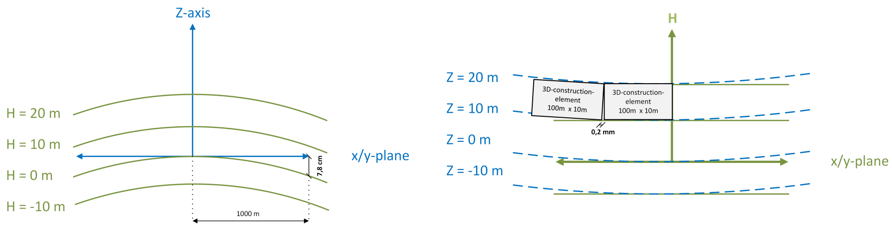

Figure 2. Due to the curvature of the Earth (and the Earth's gravitational field), the planes Z=const and H=const differ. At 1000 m, the difference is approximately 7.8 cm. Setting the surveying H and Cartesian Z equal results in only very minor deviations for object-structured building modeling. For example, for a component with dimensions of 10 m height x 100 m length, the joint difference between the top and bottom would only be 0.2 mm.

The accuracy of the input parameters radius R_0 and height h_0 are determined by the desired accuracy of the projected coordinates. With a maximum area of $1\,\mathrm{km}$ and a required accuracy of $1\,\mathrm{mm}$, the scale factor must be determined to at least the sixth decimal place, i.e. $1\,\mathrm{ppm}$. According to linear error propagation, the error ϵ_{k_0} of the scale is composed of the error of the height ϵ_H and the radius ϵ_{R_0} as follows:

$$\epsilon_{k_0} = \frac{1}{R_0} \cdot \epsilon_{h_0} + \frac{h_0}{R_0^2} \cdot \epsilon_{R_0} \tag{7}$$

If the value of the radius is set to $6381\,\mathrm{km}$, then the height must be determined to an accuracy of better than approx. 6m.

At the highest point in Germany ($2962\,\mathrm{m}$), the Earth's radius is required with an accuracy $13\,\mathrm{km}$. In Germany, the radius for the GRS80 ellipsoid can be in the range of $6358\,\mathrm{k}$ to 6399 kilometers, so a separate radius R_0 must be calculated for each traffic station.

Since the height has a major influence on the horizontal scale, it is better to use the robust median value of several altitudes (grid) of a defined area instead of a single point in the center for larger facilities. For stations with a large area (station categories 1 to 3), additional heights are derived from the DTM around the center point in order to better adapt the scale k_0 to the terrain. This was done for the LDP database as follows:

1. Calculate an approximate value for k_0 using the normal method, equations 1 to 5.
2. Generate a local $500\,\mathrm{m}$ x $500\,\mathrm{m}$ grid with a point spacing of $50\,\mathrm{m}$ and the projection center $\left(\lambda_0^{ETRS89}, \phi_0^{ETRS89}\right)$ as the center point.
3. Determination of the grid point heights in ETRS89 using DTM.
4. Back-transformation of the individual grid points with the heights h_i into the DB_REF system, taking into account the quasi-geoid undulation and datum definitions.
5. Formation of the median value $\bar{h}_0$ of the calculated ellipsoidal heights h_i.
6. Determination of the scale factor k_0 from the median value $\bar{h}_0$ as in Equation 1.

Finally, a figure showing the scale deviations at the individual grid points is generated (see Figure 3) and stored in the LDP system database for clarity and documentation.

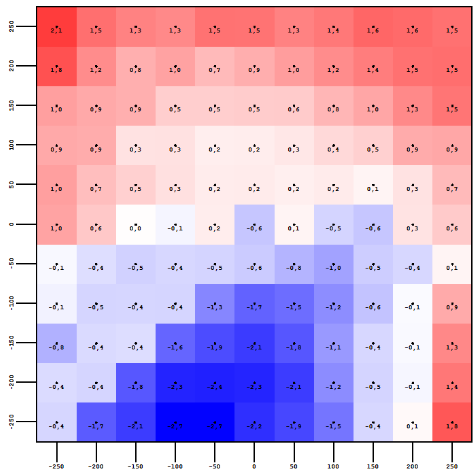

Figure 3. Graphical representation of (small) scale deviations [ppm] due to the terrain in the area of measures.

4. Practical Implications of the LDP-approach for Engineers

4.1 Workflow of surveying work - When to convert?

In order to minimize systematic deviations between surveying and 3D modeling, this study recommends transforming the DB_REF $\mapsto$ LDP system coordinates between regional network densification and surveying in the area of construction side (passenger station).

1. **Consolidation of the DB_REF geodetic network.** Network consolidation is carried out in accordance with all quality specifications and procedural requirements of German Railway, and the points are marked and documented at their locations.
2. **Conversion of DB_REF $\mapsto$ LDP system**. The control points are automatically converted to the LDP system of the traffic station. For this purpose, the LDP system database provides parameters for all traffic stations of the German Railway.
3. **Project-related densification of the fixed point field.** Network densification is carried out in accordance with engineering geodetic requirements in a scale-free LDP system; the points are marketed and documented in the locality.
4. **Measuring object points.** The coordinates of the object points are measured or scanned in the LDP system. The

points describe the structure and form the basis for modeling in CAD, GIS, and BIM. There are **no systematic differences between surveying and modeling** in 3D software. The influence of the Earth's curvature can be neglected due to the transformation.

4.2 BIM Project Management - Project base point always 5000-10000)

Because the entire process of local, distortion-minimized georeferencing is standardized and automated, there is a nice side effect for BIM management. For BIM authoring systems, such as Autodesk Revit, uniform project templates can be created for georeferencing. These always have Easting = 5,000 m and Northing = 10,000 m as the project base point and the north direction 0.000°. If topographical site plans, processed geodata or 3D point clouds have been created in the LDP or transformed there, the models can be easily imported into the 3D software without manual interaction.

4.3 Parameterization in Software

The use of DB_REF-LDP system is mandatory for new BIM projects. This leads to changes in the surveying and BIM modeling processes. The contracting entity, German Rail (DB, Deutsche Bahn), has therefore produced a number of software guides for contractors that demonstrate, that parameterization in the LDP system is not complicated in practice, especially when geo-software like QGIS, ArcGIS, Civil3D or the German Railway-CAD-Systems Korfin, ProVI and card_1 are used. Most CAD vendores or reseller in Germany have already have integrated LDP systems programmatically into their software and graphical user interfaces.

4.4 Meridian convergence for turning back true north

Railways are national, sometimes transnational networks. However, the LDP-solution is aimed at individual construction measures on an engineering structure or a station building. This duality has consequences for georeferencing. When it comes to the large-scale network, the railways, routing, tracks, switches, and signals, the DB_REF/with the Gauss-Krüger projection must be used. Locally, the LDP system is used. Therefore, it may also be necessary to transform the 3D model (not just points) between the two cartographic representations. This may be necessary, for example, in a large-scale 3D-BIM coordination model or for the visualization of routes and many traffic stations. For this reason, the meridian convergence and the center point of the LDP projection in the Gauss-Krüger projection were calculated and published for each station. These three parameters are sufficient to convert a 3D model, for example in Autodesk Revit, from the local to the regional map projection.

5. Limitations and Discussion

The approach developed is ideal for locally limited BIM projects because it minimizes geometric deviations between the 3D model and geospatial data. Perfect mathematics is one thing—change management in construction practice is another. The mandatory introduction of LDP projection is therefore accompanied by comprehensive training materials and one-day workshops for German Railway engineers and BIM managers.

Regardless of the mathematical description, the real world changes. Every year, new traffic stations are created and must be entered into the database. This requires rigorous management. In particular, when recalculating the database, the transformation parameters that have been published must not deviate — not even in the last decimal place. This is because construction is a fragmented economic sector with a large number of companies and software systems. A numerical update would not be implemented consistently across all systems.

One crucial conflict has not yet been conclusively resolved. The alignment, i.e. the parametric representation of the track axis with the alignment elements straight line, circle, clothoid, gradient, and lateral inclination, cannot be transferred from one cartographic projection to another without mathematical compromises. Critical factors include nominal radii, continuity requirements, kilometer marking, and the associated railway regulations. Since tracks and engineering structures are often planned in parallel, there are currently coordination challenges between traditional georeferencing with meridian strips of 3°, 6°, 9°, 12°, and 15° and the 6326 shades of georeferencing in BIM.

At the same time, the introduction of LDP systems has led to an increase in the awareness and appreciation of precise surveying and semantically rich geospatial data in BIM projects.

6. Acknowledgment

The study on the introduction of LDP systems for every passenger station in German was financed by Deutsche Bahn. Partial results and the graphs shown were published in German in the industry magazine *Der Eisenbahningenieur* (Clemen et al., 2023) and as a practical example in the international textbook *BIM and 3D GIS Integration for Digital Twins* (Kalantari et al., 2024).

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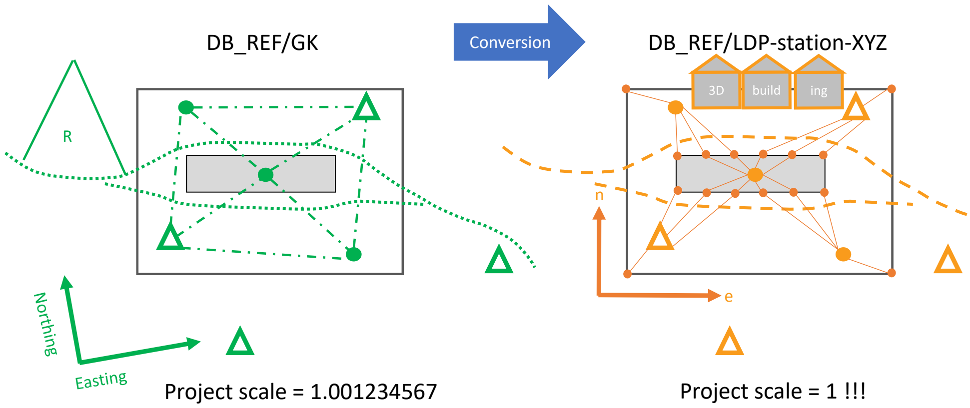

Figure 4. The higher-level network densification and routing take place in DB_REF. The control points are then automatically converted into the LDP system. For local densification, object surveying, and modeling, no geodetic corrections are necessary due to the scale: The LDP system has a scale = 1, , adapted from (Kalantari et al., 2024)

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