Enhancing Georeferencing of IFC Models through Surveyed Points Integration

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Abstract

The integration of geoinformation with Building Information Models (BIM), termed GeoBIM, has garnered significant attention across academic and non-academic sectors due to its potential for analyzing the reciprocal impacts of new designs on their environment. However, achieving integration between 3D city models and BIM necessitates ensuring consistency and alignment between their respective features and specifications. Georeferencing, a fundamental task in GeoBIM, involves establishing a connection between digital models and the Earth's surface through coordinate transformations. Despite its importance, accurate georeferencing of BIM models has often been overlooked, resulting in challenges for integrating BIM models and geographical data. To address this gap, our study proposes a novel approach to enhance the georeferencing accuracy of BIM models by integrating surveyed points, considering the varying levels of georeferencing precision applicable to Industry Foundation Classes (IFC) models. We explore the potential benefits and challenges associated with this integrated surveyed point methodology, providing insights to improve georeferencing within the GeoBIM framework.

1. Introduction

The integration of geoinformation with Building Information Models (BIM), known as GeoBIM, has become a prominent topic of interest because it allows the study of the impact of new designs on their environment and vice versa. GeoBIM has drawn attention from a wide range of academic fields such as geoinformation, geomatics, construction, architecture, and urban planning, as well as from non-academic sectors including the building sector and governmental organizations.

3D city models and BIM have different purposes and features (e.g. level of detail, geometries, different semantic objects). To achieve a successful integration for any application, it is crucial to ensure that the features of both models are consistent and aligned. This means that all data should meet the specifications of either the 3D city model, the BIM model, or a different set of specifications if a third-party use case is defined (Noardo et al., 2020).

The geometric context of a BIM model is generally regarded as a localized, three-dimensional Euclidean space, wherein objects situated on the construction site are represented utilizing a Cartesian coordinate system with an origin in the project site and axes usually aligned with the features in the model (Jaud et al., 2020). In recent research developments, there have been notable updates to the open, international BIM standard, named Industry Foundation Classes (IFC), that have enabled the representation of models using a projected coordinate referencing system (CRS). This advancement is particularly beneficial for larger projects, such as infrastructure, because of the distortions that can occur when geographic coordinates are projected into Cartesian space or vice versa (Jaud et al., 2022).

In a general context, the process of georeferencing an object includes the transformation of its geometric coordinates in a manner that guarantees precise placement at the correct geographical location on a map, while also achieving congruence with other features existing within the map's framework (Snyder, 1987). Georeferencing in GeoBIM is a major base task for many use cases that acquire, manage, analyze, or visualize the geometric information of buildings (BIM) and 3D city models (from GIS) as combined or linked information. Georeferencing is performed through coordinate operations (ISO19111, 2019) from one coordinate system to another. A building model can be georeferenced if enough meta information (ISO19115-1, 2014) is given to apply a coordinate transformation from the coordinate reference system of the building or construction site to a target CRS like a map or a national grid.

Georeferencing within BIM creates a connection between the digital model and the Earth's surface through coordinates. While its functionality is present in BIM software tools, the effective utilization demands expert knowledge, a skill set often not readily possessed by BIM modelers and architects. This lack of expertise has led to inconsistencies and irregularities in the integration of geospatial data across various BIM models. Thus, for most of the models to be effectively utilized within a GeoBIM framework, improvements in georeferencing are required.

The study presented in this paper introduces a novel approach for enhancing the georeferencing accuracy of BIM models through the integration of surveyed points. This proposed method takes into account the diverse degrees of georeferencing applicable to IFC models, as we aim to explore and elucidate the potential benefits and challenges associated with the deployment of this integrated surveyed point approach.

The paper is structured as follows. Section 2 first gives a further explanation of coordinate systems as used in BIM. Then the Level of Georeferencing (LoGeoRef) framework by Christian et al. (2019) is introduced since our georeferencing methodology relies on this framework to increase the LoGeoRef of IFC models. Then, the use of common points and the Helmert transformation are explained, as incorporated into our methodology (Section 4). Our methodology to improve the georeferencing of IFC models is detailed in Section 5. We have developed and

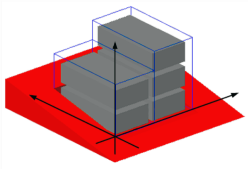


Figure 1. Cartesian coordinate system used in a BIM model.

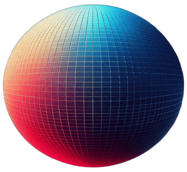


Figure 2. Ellipsoid mathematical model of the earth

utilized the IfcGref software for computing georeferencing values, the details of which are provided in Section 6. Our methodology is applied to case studies in Section 7. The paper concludes with a discussion of the results and conclusions.

2. Background

A coordinate reference system (CRS) serves as a foundational framework facilitating the measuring and communicating of points on the Earth's surface through a specified set of coordinates. In the majority of BIM models, a Cartesian coordinate system is employed (see Fig. 1). This system is designed for a confined space, often a specific engineering project, over which the curvature of the Earth can be safely approximated as flat without significant distortion.

The diverse array of CRS types is contingent upon how the Earth is conceptualized and the methodology employed for coordinate measurement. One prominent CRS variant is the geographic coordinate system (GCS), employing a three-dimensional spherical or geodetic surface (see Fig. 2). The GCS relies on angular units, a designated prime meridian, and a datum to pinpoint locations, expressed in terms of longitude and latitude (Campbell and Shin, 2011).

Alternatively, a projected coordinate system (PCS) utilizes a two-dimensional plane, underpinned by a map projection, transforming the Earth's surface into a flat grid (ISO19111, 2019). The PCS encompasses an origin point, a linear unit of measure, and additional parameters to define projection orientation and scale, referencing points through x and y coordinates on the grid. While CRSs are indispensable for geospatial analysis, facilitating data comparison, integration, distance measurement, and spatial operations, their utilization introduces distortions as approximations of the Earth's actual shape and size (ISO19115-1, 2014). Consequently, the judicious selection of an appropriate CRS for each geospatial task is imperative, accompanied by an awareness of inherent limitations and trade-offs associated with different CRS choices (Stal et al., 2022).

Most BIM projects define a reference point that is linked to the Earth's coordinate system by specifying its longitude, latitude, and elevation. The True North direction of the project is also associated with this reference point, which is essential for accurate solar analysis, shadow studies, and alignment with other BIM models and disciplines.

True North and Grid North (or Map North) apply to distinct principles in GCS and PCS. True North points toward the geographic North Pole along the Earth's surface, aligning with the rotational axis and serving as a reference for navigation, astronomy, and global mapping. In contrast, Grid North (or Map North) indicates the North arrow's direction on a map projected from a three-dimensional Earth to a two-dimensional surface. It aligns with the vertical grid lines on the map and is commonly used for local navigation in projected coordinate systems for mapping. The distinction between True North and Grid North arises from distortions introduced during map projection, transforming the curved Earth surface into a flat map with distortions in angles, distances, or areas (Yang et al., 1999).

When mapping the Earth's curved surface onto a flat map using a PCS, distortion inevitably occurs, affecting the map's scale. The scale factor, representing the ratio of map distance to ground distance, varies based on location, measurement direction, and projection type. In a PCS, the scale factor varies depending on the location and direction of measurement and type of map projection (Yang et al., 1999). Comparatively, a Cartesian coordinate system provides a constant scale factor of 1, making it a uniform but less accurate representation of the Earth's curved surface.

Understanding CRSs is crucial for accurate georeferencing in BIM. By combining geospatial and BIM principles, professionals can incorporate real-world spatial data, ensuring accurate alignment between BIM models and geographical information. This alignment improves project coordination, facilitates informed decision-making, and optimizes various tasks like building rules checking, urban planning, and environmental analysis. Georeferenced BIM data empowers stakeholders to visualize, analyze, and optimize projects with increased accuracy and efficiency.

3. Level of Georeferencing (LoGeoRef)

Incorporating the Level of Georeferencing (LoGeoRef) framework proposed by Christian et al. (2019) provides a structured approach for assessing the quality of georeferencing in building models using Industry Foundation Classes (IFC). This framework offers a range of levels, from basic postal address integration at LoGeoRef 10 to advanced Projected Coordinate Reference System implementation at LoGeoRef 50, catering to varying degrees of geospatial precision and data integration requirements (See Table 1).

As highlighted in Table 2, LoGeoRef 50 emerges as the optimal level for accurately georeferencing BIM models, given its comprehensive inclusion of all necessary parameters crucial for the process. The condition for calculating the rotation values within LoGeoRef 30 and LoGeoRef 40 relies on the absence of distortion between the True North direction and the PCS North direction, which is the specified target coordinate reference system (CRS).

4. Surveyed Points Integration

Common points, in the context of georeferencing and spatial data integration, refer to identifiable locations or reference points that are shared between different coordinate systems or datasets. These points serve as key markers for aligning and transforming spatial data from one coordinate system to another (Hackeloeer et al., 2014).

LoGeoRef	Attributes Needed
LoGeoRef 10	IfcPostalAddress (address lines, postal code, etc)
LoGeoRef 20	IfcSite (RefLatitude, RefLongitude, RefElevation)
LoGeoRef 30	IfcLocalPlacement object (for direct location storage)
LoGeoRef 40	IfcGeometricRepresentationContext
LoGeoRef 50	IfcMapConversion and IfcProjectCRS

Table 1. IFC attributes needed for each Level of Georeferencing (LoGeoRef) (Christian et al., 2019)

LoGeoRef	Translation	Rotation	Scale
LoGeoRef 10	No	No	No
LoGeoRef 20	Yes	No	No
LoGeoRef 30	Yes	Conditional	No
LoGeoRef 40	Yes	Conditional	No
LoGeoRef 50	Yes	Yes	Yes

Table 2. Availability of sufficient information for calculating georeferencing parameters for each LoGeoRef

A surveyed point is a location on the Earth's surface whose geographical coordinates have been accurately measured and documented through a surveying process using a variety of surveying instruments and techniques in the field (Brinker and Minnick, 2012). In GeoBIM, a surveyed point measured in the PCS can act as a common reference point if its corresponding position in the BIM model is also determined.

4.1 Helmert Transformation

For building-scale projects where dimensions are less than 1 square kilometer, Helmert transformations remain dependable for coordinate transformations, despite their limitations. The linear assumption inherent in Helmert transformations is more likely to remain valid in smaller areas, and it is feasible to achieve higher control point densities, enhancing accuracy. This is why we use the Helmert transformation in our methodology.

Utilizing the Helmert transformation method involves employing a set of equations to accurately convert coordinates between different spatial reference systems. Equations 1, 2, and 3 represent the transformation process, where X', Y', Z' denote the target map coordinates, and X, Y, Z correspond to the coordinates within the BIM environment. The transformation incorporates a scale factor and translations in each direction (E, N, H), alongside a counterclockwise rotation (θ) in the x-y plane. In Equation 1 and 2, the trigonometric functions $\sin(\theta)$ and $\cos(\theta)$ facilitate the rotation, while $Scale$ adjusts for scale differences between the coordinate systems. This methodology ensures accurate alignment and integration of spatial data.

$$X' = Scale.[(cos(\theta).X) - (sin(\theta).Y)] + E \tag{1}$$

$$Y' = Scale.[(sin(\theta).X) + (cos(\theta).Y)] + N \tag{2}$$

$$Z' = (Scale.Z) + H \tag{3}$$

where X, Y, Z = BIM coordinates
X', Y', Z' = target map coordinates
E, N, H = translations in each direction
θ = counterclockwise rotation on the x-y plane

5. Methodology

Our methodology for accurately georeferencing BIM models adopts the Level of Georeferencing (LoGeoRef) framework as a methodological foundation for enhancing the georeferencing accuracy of BIM models using the options offered by IFC. The framework describes the progression of each level, reaching LoGeoRef 50 ultimately, which is identified as the most accurate representation of georeferencing within BIM environments.

The proposed methodology differs depending on the LoGeoRef of the input data and the steps for each LoGeoRef are described below.

5.1 Enhancing LoGeoRef0 and LoGeoRef10

IFC models in this category lack geoinformation essential for computing georeferencing values. Therefore, all necessary data must be derived from the common points information. As previously outlined in Equations 1, 2, and 3, there are five variables (three translations, one rotation, and one scale) that need to be computed. While one common point provides three equations, which is still insufficient, two common points offer the minimum information required for calculating these parameters.

This system of equations becomes nonlinear due to the presence of trigonometric terms, adding complexity to its solution. To address this, our developed IfcGref software tool employs the least squares method, a mathematical approach aimed at identifying the optimal curve or line that best fits a given set of data points. This method achieves this by minimizing the sum of squared vertical distances between the data points and the curve or line.

The presence of more common points can significantly improve the accuracy of the solution. With more common points available, the system becomes over-determined, meaning there are more equations than unknowns. This redundancy allows for a more robust estimation of the parameters, as it helps to mitigate the positional errors of the common points and uncertainties in the data.

5.2 Enhancing LoGeoRef20

IFC files possessing this level of georeferencing already include an origin point containing its longitude, latitude, and elevation. By converting this point from EPSG 4326 to the target CRS, we can utilize its coordinates as a shared reference for computations. Thus, the inclusion of just one more common point will offer the essential minimum data for calculations (Table 3). Adding more common points enhances the solution's accuracy and allows for a more reliable estimation of the parameters, reducing positional errors and data uncertainties.

5.3 Enhancing LoGeoRef30 and LoGeoRef40

Assuming alignment between the project's North direction and that of the map allows for the utilization of either the TrueNorth attribute's direction (LoGeoRef40) or the LocalPlacement's rotation value (LoGeoRef30) as the rotation parameter. Like LoGeoRef20, the presence of an origin point with fundamental geoinformation simplifies the georeferencing process, necessitating just one common point for calculation. However, in this scenario, the absence of rotation calculation renders the system of equations linear.

LoGeoRef	Number of Points	System of Equations
LoGeoRef 0	2	Nonlinear
LoGeoRef 10	2	Nonlinear
LoGeoRef 20	1	Nonlinear
LoGeoRef 30	1	Nonlinear/Linear
LoGeoRef 40	1	Nonlinear/Linear

Table 3. Minimum number of common points required for calculating each LoGeoRef and the corresponding system of equations

The inherent advantage of this approach is its potential to simplify and streamline the georeferencing process through alignment assumptions and reduced computational complexity.

The main advantages of this approach are its potential to simplify and streamline the georeferencing process through alignment assumptions and reduced computational complexity. However, it faces possible distortion regarding the North direction between the BIM model and the map. Therefore, the rotation data provided in the IFC model may not be sufficiently accurate to be employed for the calculation of georeferencing parameters. Given the potential problems associated with ensuring the availability of reliable rotational data, there is a practical preference to follow the methodology adopted for LoGeoRef20 and ignore the rotational data available in the models in these LoGeoRefs. This approach overcomes the complexities and uncertainties surrounding rotational data, thereby offering a reliable and consistent framework for georeferencing operations at these levels as well.

6. Implementation: IFC georeferencing Tool (IfcGref)

IfcGref (Hakim, 2024) is developed to discover the current georeferencing status of IFC files, with a focus on IFC4 and subsequent versions. It implements our methodology to accurately georeference these files to the highest level. The tool examines the geo-information in the existing BIM model and updates the IFC file based on the surveyed points' information and their corresponding coordinates in the BIM model as provided by the user. A pivotal feature of IfcGref is its integration of the least squares method, which is based on the SciPy library (Virtanen et al., 2020) in Python. This optimization algorithm is adept at solving nonlinear least-squares problems with bounds on the variables, making it an essential component for accurate georeferencing.

Additionally, IfcGref utilizes the pyproj library (Snow et al., 2024) to enable transformations between different projected and geographic CRSs. This integration allows IfcGref to manage a wide range of geospatial data, thereby enhancing the reliability of the updated georeferencing information in IFC files.

Notably, the updated IFC files can be visualized on a map through the visualization component of the software. The solution is web-based, offering a professional and accessible platform for effective georeferencing management.

7. Case Studies

Three distinct case studies involving different BIM models and locations are examined for validation of the methodology. All cases utilize the Cartesian Coordinate System as the source system for BIM coordination. Depending on their respective locations and countries, distinct projected CRS will be employed as the target CRS for each case. The cases are situated in the Netherlands, Portugal, and Germany respectively (Fig. 3, 4, and 5).

Each model will be inspected on its existing LoGeoRef to discover the required data necessary for the computation of georeferencing parameters and advancing to LoGeoRef 50. The IFC files for each level will be updated and visualized on the target map using a web-based tool (to be described in the next section).

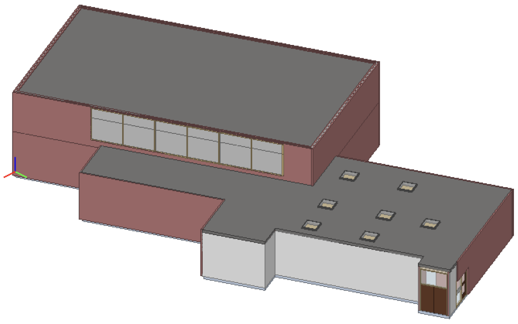


Figure 3. Model view of BIM case study located in Den Bosch, The Netherlands

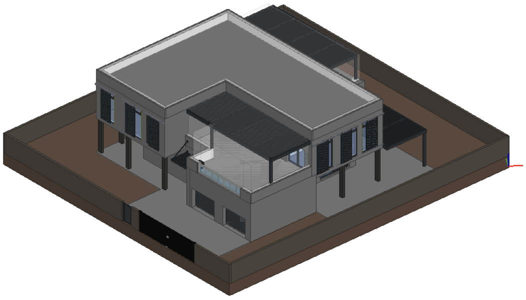


Figure 4. Model view of BIM case study located in Vila Nova de Gaia, Portugal (data source CHEK project)

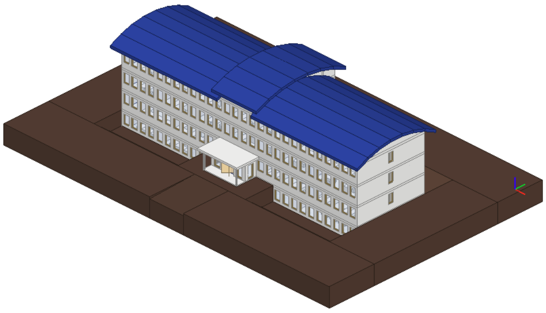
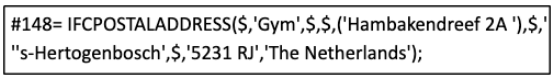


Figure 5. Model view of BIM case study located in Neuenburg, Germany

7.1 Building in Den Bosch, The Netherlands (LoGeoRef 10)

Within this IFC model, only an IfcPostalAddress is present (Fig. 6), lacking additional metadata required for georeferencing. To address this, two surveyed points in EPSG 28992 and their corresponding BIM coordinates (Table 4) were inputted into the IfcGref tool for the computation. With this additional data, the model was georeferenced to LoGeoRef50, as depicted in the tabular results (Table 6) and the visualization of the building's roof outline on the map (See Fig. 7).



```
#148= IFCPOSTALADDRESS($,'Gym',$,$,('Hambakendreef 2A '),$,'
''s-Hertogenbosch',$,'5231 RJ','The Netherlands');
```

Figure 6. Syntactical representation of the IfcPostalAddress entity in Den Bosch model

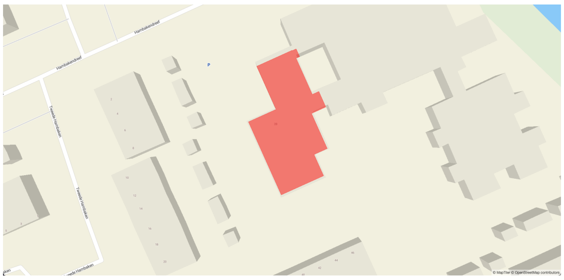


Figure 7. Visualization of the roof outline of updated ’s-Hertogenbosch model using IfcGref

7.2 Building in Gaia, Portugal (LoGeoRef 20)

In this IFC model, the IfcSite object contains attributes for longitude, latitude, and reference elevation, yet lacks information regarding the project’s North direction (Fig. 8). To overcome this limitation, a surveyed point in EPSG 3763 and its associated BIM coordinates (Table 5) were entered into the IfcGref tool for the computation. This supplementary data enabled the model to be georeferenced to LoGeoRef50, as illustrated by the results and the visualization of the building’s roof outline on the map (See Fig. 9).

7.3 Building in Neuenburg, Germany (LoGeoRef 40)

In this model, essential georeferencing data are stored within the IfcSite object. This data includes information such as longitude, latitude, and reference elevation, providing a solid foundation for georeferencing tasks. Additionally, details about the project’s North direction are also available within the model (as seen in Fig. 10).

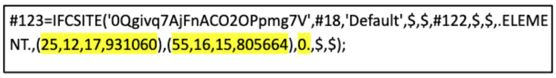
To enhance the accuracy of georeferencing in the model, a surveyed point specified within the EPSG 25832 coordinate reference system (CRS) was identified, along with its corresponding Building Information Modeling (BIM) coordinates (Table 5). These data points were added to the IfcGref tool. The result of the georeferencing process is shown in Fig. 11 and Table 6.

8. Conclusion

In this study, we have proposed a novel methodology for enhancing the georeferencing accuracy of BIM models (in IFC)

		Point 1	Point 2
IFC coordinates:	X	0	4098
	Y	0	39225
	Z	0	100
	unit	mm	mm
Map coordinates:	X’	149626.315	149630.414
	Y’	413717.684	413756.909
	Z’	249.378	249.476
	unit	m	m
	EPSG	28992	28992

Table 4. Coordinates of common points used for Den Bosch case study



```
#123=IFCSITE('0Qgivq7AjFnACO2OPpmg7V',#18,'Default',$,$,#122,$,$,.ELEME
NT.,(25,12,17,931060),(55,16,15,805664),0.,$,$);
```

Figure 8. Syntactical representation of longitude, latitude, and elevation in IfcSite in Gaia model

Figure 9. Visualization of the roof outline of updated Gaia model using IfcGref

		Gaia	Neuenburg
IFC coordinates:	X	22.753	30
	Y	-7.112	20
	Z	-0.10	0
	unit	m	m
Map coordinates:	X’	-39018.047	481127.434
	Y’	413717.684	413756.909
	Z’	151891.0198	5445056.828
	unit	m	m
	EPSG	3763	25832

Table 5. Coordinates of common point used for Gaia and Neuenburg case studies

```
#60=IFCDIRECTION((0.,1.));
#62=IFCGEOMETRICREPRESENTATIONCONTEXT($,'Model',3,1.0000000000E-5,
#59,#60);
```

Figure 10. Syntactical representation of TrueNorth attribute available in IfcGeometricContext in Neuenburg model

Figure 11. Visualization of the roof outline of updated Neuenburg model using IfcGref

	Den Bosch	Gaia	Neuenburg
Translation X	149626.316	-39040.799	479338.601
Translation Y	413717.684	151898.131	5444142.430
Translation Z	249.37	0	0
Rotation (degree)	0	0	44.47
Scale	0.001	1	0.999

Table 6. Georeferencing Values Computed: Analysis Outcome

through the integration of surveyed points. Georeferencing plays a crucial role in the integration of geospatial information with BIM, known as GeoBIM, facilitating the analysis of the reciprocal impacts of new designs on their environment. Despite its significance, georeferencing in BIM has often been overlooked, leading to challenges in integrating geospatial data across different BIM models.

By leveraging the Level of Georeferencing (LoGeoRef) framework and employing the Helmert transformation method, we have outlined a systematic approach for georeferencing BIM models at various levels of georeferencing. Our methodology considers the varying degrees of georeferencing available in IFC models and utilizes common points and the least squares method to compute the necessary georeferencing parameters to improve the LoGeoRef of IFC files.

Through three case studies situated in Den Bosch, The Netherlands; Gaia, Portugal; and Neuenburg, Germany, we have demonstrated the effectiveness of our approach in enhancing the georeferencing accuracy of BIM models. By integrating surveyed points and leveraging existing georeferencing metadata within the IFC models, we were able to achieve the highest level of georeferencing (LoGeoRef 50), ultimately enabling accurate spatial integration and analysis within the GeoBIM framework.

Furthermore, the implementation of our methodology in the IfcGref tool provides a practical solution for verifying and modifying IFC files to ensure adherence to georeferencing standards. The integration of this tool with web-based visualization capabilities enables users to visualize the georeferenced BIM models on a map, enhancing accessibility and usability for practitioners in the field.

Our methodology enhances the accuracy of georeferencing by aligning with real-world coordinates, thereby improving spatial analysis and visualization accuracy essential for various applications like urban planning, infrastructure management, and environmental analysis. Better interoperability facilitates data exchange among stakeholders, boosting collaboration and workflow efficiency. Accurate georeferencing supports informed decision-making across the asset life cycle, from design to maintenance, thereby enhancing planning and management.

Several challenges accompany the integration of surveyed points into BIM models. Obtaining accurate surveyed points, especially for large projects, can be resource-intensive and time-consuming due to challenges like accessibility issues or environmental constraints. Ensuring alignment between surveyed points and BIM models demands meticulous data validation and quality control to rectify inconsistencies and discrepancies in coordinate systems. Such inconsistencies and discrepancies can impact the accuracy and reliability of spatial analysis results.

On the other hand, the systematic methodology streamlines workflows, reducing manual errors and increasing efficiency in geospatial data integration and analysis tasks. Regardless of the complexity or scale of a BIM model, this approach can be adapted and applied effectively across a broad spectrum of projects.

This study analyzed the minimum number of surveyed points required for computing georeferencing values effectively. The IfcGref tool can function with a minimum set of points, but integrating additional surveyed points enhances the accuracy of georeferencing values. The incorporation of more surveyed points provides the tool with additional reference data, reducing potential errors, and improving the precision of georeferencing. Therefore, while the tool can function with a minimal set of surveyed points, it is recommended to integrate as many surveyed points as possible to ensure the highest level of georeferencing accuracy in BIM models.

There are several exciting avenues for future research to improve the integration of surveyed points into BIM models, which can lead to enhanced georeferencing accuracy. By investigating automated surveying techniques, refining data validation and quality control processes, and exploring real-time data integration like IoT sensors, we can continue to advance the alignment between BIM models and real-world coordinates. Additionally, expanding the case studies to more diverse geographic regions, enhancing the user interface and accessibility features of IfcGref, and determining optimal surveyed point requirements can contribute to the broader applicability and usability of our georeferencing methodology. Pursuing these directions can strengthen the GeoBIM framework, and empower stakeholders with more accurate spatial analysis and decision-making capabilities across a wide range of applications.

9. Acknowledgement

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