Change toolkit for digital building permit

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Contents

1. Executive Summary

In the context of integrating Building Information Models (BIM) and city models within the CHEK project, a critical challenge arises in ensuring consistency between the localized, three-dimensional, Cartesian coordinate system of BIM models and the projected coordinate system of city models. Georeferencing becomes a fundamental task, requiring the transformation of coordinate systems to facilitate integration and decision-making during the digital building permit process.

To address the georeferencing challenge, the IfcGref Web-Based Application has been developed. This Flask-based tool, accessible at https://ifcgref.bk.tudelft.nl, provides a comprehensive solution for designers, engineers, and software developers. IfcGref supports georeferencing operations starting from IFC 4, ensuring backward compatibility with earlier versions. The tool utilizes IfcMapConversion, incorporating attributes like SourceCRS, TargetCRS, and other key parameters to enable precise coordinate transformations.

The workflow of IfcGref involves a user-friendly interface for file upload and verification. Georeferenced files are promptly confirmed, while non-georeferenced files undergo a guided process, including EPSG code selection, optional surveyed points input, and visualization. The tool employs scientific computing libraries to ensure optimal solutions for coordinate operation values. A visualization feature allows users to observe the real-world impact of georeferencing on the IFC model's geometry and where it is located on the map. For software developers, a dedicated section allows HTTP requests for IFC files, streamlining the management of files and providing prompt responses regarding their georeferencing status.

IfcGref stands as a principal solution within the CHEK project, contributing to the integration of BIM and city models through effective georeferencing, ultimately improving compatibility between building and city information.

2. Introduction

The aim of WP3 is to integrate geographic information with BIM models to streamline the permit approval process, to improve decision-making, and to enhance collaboration among stakeholders during the DBP process. 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 correctly positioned with respect to each other.

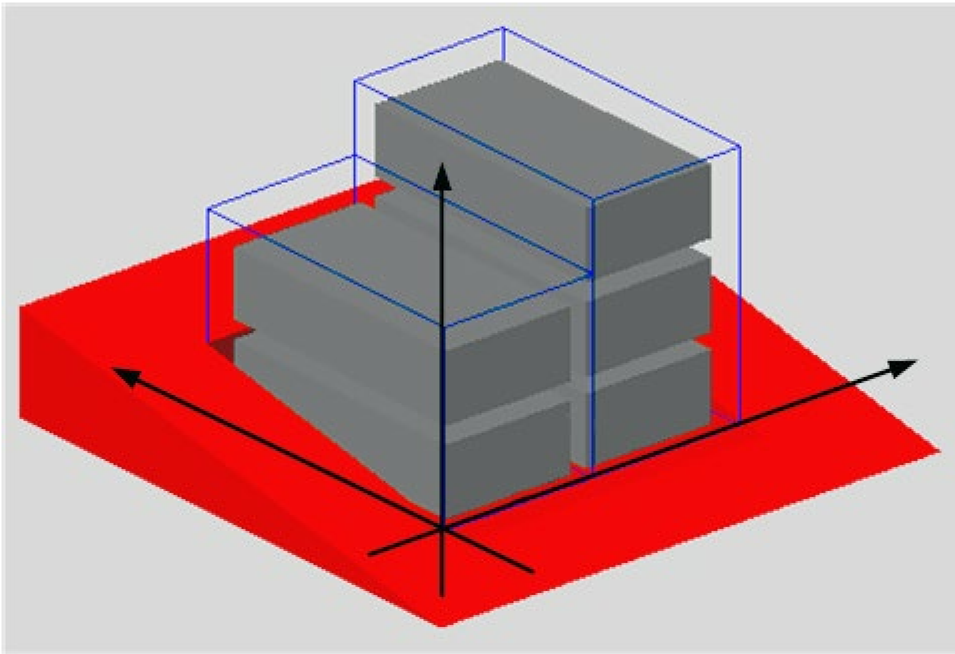

Figure 1 Cartesian coordinate system used in a BIM model.

The geometric context of a BIM model in DBP is a localized, three-dimensional Euclidean space using a Cartesian coordinate system aligned with features on the construction site. City models, however, utilize different coordinate systems called projected CRS, employing a two-dimensional plane with a map projection to represent a specific section of the Earth's surface as a flat grid.

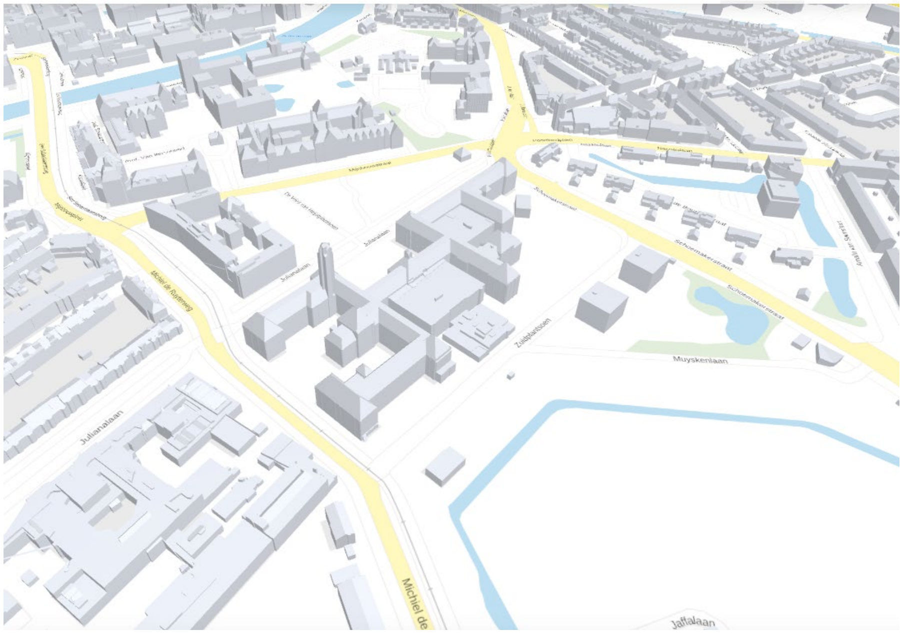

Figure 2 Example of 3D city model utilized a projected CRS (EPSG 7415)

Georeferencing plays a crucial role in CHEK, serving as a fundamental task for various scenarios involving the integration or connection of geometric data from buildings (BIM) and city models (GIS). This process involves coordinate operations, as defined by ISO19111 (Geographic information Spatial referencing by coordinates), facilitating the transformation from one coordinate system to another. An IFC model, as the open and international BIM standard, is considered georeferenced when sufficient metainformation is provided to execute an accurate coordinate transformation from the building or construction site's coordinate reference system to a target CRS, such as a map or national grid.

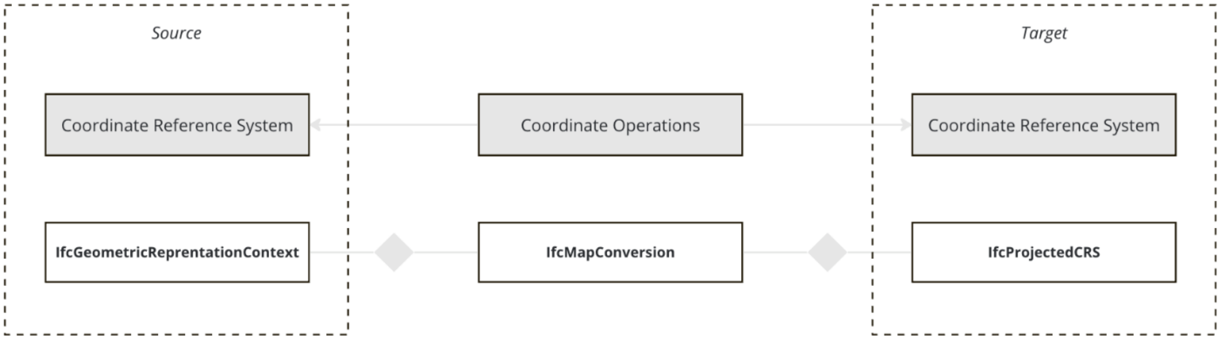

Figure 3 Coordinate Operations in CHEK

3. IfcGref Web-Based Application

To address the challenge of catering to users on various platforms, including those without the possibility to install software locally, a web-based application named IfcGref is developed. This allows accessibility through a URL (https://ifcgref.bk.tudelft.nl), accommodating designers, engineers, and software developers.

The Flask-based application is designed to fulfill the function of georeferencing IFC. It utilizes the IfcMapConversion entity present in IFC4, streamlining the process of updating data and converting from a local Coordinate Reference System (CRS), commonly known as the engineering coordinate system, to the coordinate reference system of the underlying map (Projected CRS). The result will be an updated IFC file with sufficient georeferencing information.

The source code is openly accessible on GitHub (https://github.com/tudelft3d/ifcgref).

3.1 Supported IFC versions

Coordinate operations become accessible starting from IFC 4. Consequently, for earlier versions, such as the widely used IFC2x3, Property sets (Pset) are employed to facilitate georeferencing. The following is a table of the supported versions:

Table 1 Supported IFC versions.

Version	Name
4.3.2.0	IFC 4.3 ADD2
4.0.2.1	IFC4 ADD2 TC1
4.0.2.0	IFC4 ADD2
4.0.1.0	IFC4 ADD1
4.0.0.0	IFC4
2.3.0.1	IFC2x3 TC1
2.3.0.0	IFC2x3

3.2 Metadata source

The operation of coordinate transformation in CHEK is based on IfcMapConversion, which bridges the local CRS of a BIM model and the Target CRS of the city model (See Figure 3). The following are the attributes involved in IfcMapConversion and their roles in the operation:

Table 2 IfcMapConversion Entity in IFC4

#	Attribute	Type
1	SourceCRS	IfcCoordinateReferenceSystemSelect
2	TargetCRS	IfcCoordinateReferenceSystem
3	Eastings	IfcLengthMeasure
4	Northings	IfcLengthMeasure
5	OrthogonalHeight	IfcLengthMeasure
6	XAxisAbscissa	OPTIONAL IfcReal
7	XAxisOrdinate	OPTIONAL IfcReal
8	Scale	OPTIONAL IfcReal

- Translation:

It refers to the operation of relocating a geometric object from one position to another. In the context of georeferencing, the terms Easting, Northing, and Orthogonal Height denote the displacement in each respective direction (x, y, and z) based on the map grid.

- Rotation:

Rotation entails changing the angular orientation of a geometric object to align it with the desired geographic or map orientation. This involves rotating the object around the Z (up) axis. The rotation is determined based on the values of XAxisAbscissa and XAxisOrdinate.

- Scale:

The term indicates the proportional adjustment of the size or dimensions of a geometric object. In georeferencing, it includes unit conversion and addresses proportion differences due to varying coordinate reference systems, caused by factors like distortion.

3.2.1 IFC supporting entities

In the BIM industry, most IFC files contain some fundamental geoinformation that can be utilized for computing georeferencing values. Entities such as RefLatitude, RefLongitude, and RefElevation in IfcSite are optionally available. The application verifies their presence as a potential input source.

Table 3 IfcSite attributes definition

#	Attribute	Type	Cardinality
10	RefLatitude	IfcCompoundPlaneAngleMeasure	?
11	RefLongitude	IfcCompoundPlaneAngleMeasure	?
12	RefElevation	IfcLengthMeasure	?
…	…	…	…

Another entity that can be leveraged in order to compute rotation values is the True North Direction. This is also optionally accessible in the IfcGeometricRepresentationContext.

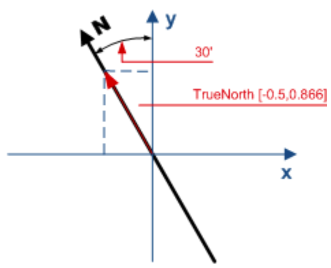

Figure 4 True North direction as seen in BIM

3.3 Workflow

The initial step for users to use the application involves the user uploading an IFC file, followed by a verification process to determine whether it is georeferenced. In the event that the file is georeferenced (IfcMapConversion is accessible), the user will receive a confirmation comment indicating its georeferenced status along with IfcMapConversion attributes. Subsequently, the user can visualize the roof print of the uploaded file on the map.

In cases where the file is not georeferenced, the user is prompted to select their desired EPSG code as the target Coordinate Reference System (CRS). The entered code undergoes validation to ensure it corresponds to a projected CRS. If the validation is successful, the IFC file is examined for the presence of the Reference Longitude, Latitude, Elevation, and True North Direction values. The user is notified if these are available. Additionally, users have the option to input surveyed points for improving precision in the calculation of IfcMapConversion parameters. If the provided metainformation is sufficient, IfcMapConversion values are computed, displayed, and the user is informed. Following this, the georeferenced file can be downloaded, and users can visualize it on the map using the visualization feature.

The process involves the assessment of IFC file entities and attributes, target EPSG code selection, and optional surveyed points input.

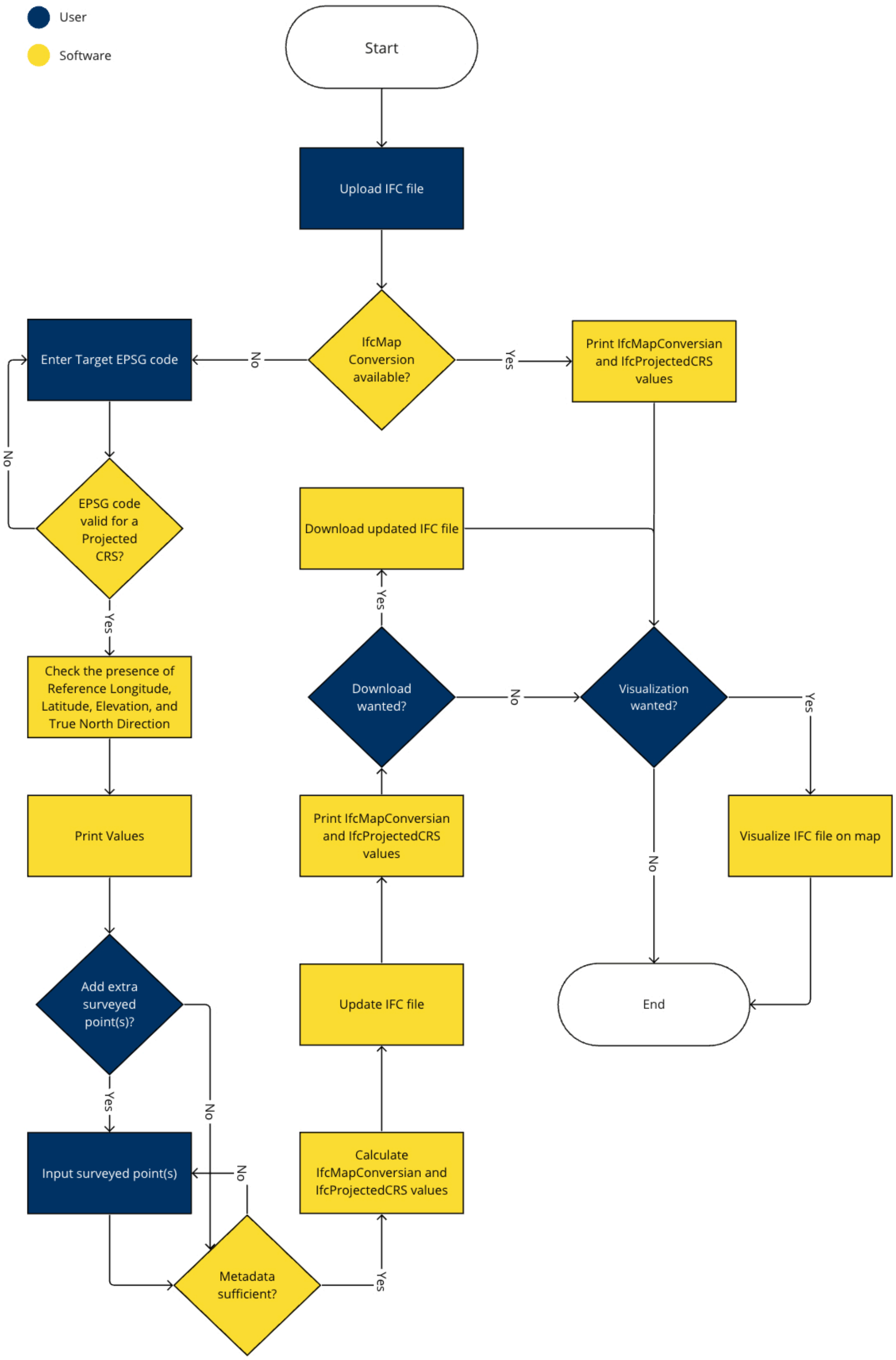

Figure 5 Workflow of the IfcGref tool.

3.3.1 Surveyed points input

While it is feasible to compute translation values using a single point, as is commonly found in IFC files, incorporating additional survey points can make it possible to compute the rotation and scale, as well as to enhance the precision of these calculations. The angle of rotation can be inferred from the True North direction in BIM models, if it is present. However, discrepancies may arise between the True North direction in the Geographic Coordinate System (GCS) and on a map (Projected Coordinate System - PCS) due to distortions and other assumptions of the map. Therefore, it is advisable to calculate this factor using multiple survey points. The scale factor cannot be determined from the BIM model and must be computed using at least two georeferenced points. With more surveyed points, the process of optimizing and calculating the conversion values described in the following section can be more thorough and accurate, with an increase in precision.

For this reason, there is a part dedicated to adding sets of surveyed or georeferenced points to the application.

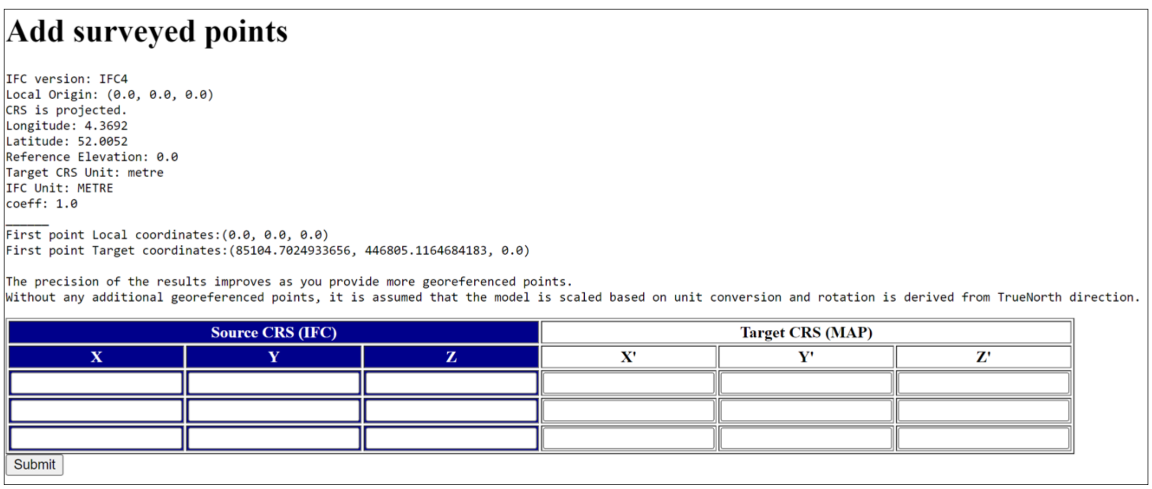

Figure 6 User interface of IfcGref tool for adding surveyed points information.

3.3.2 Calculation

In the context of map conversion, we are presented with a complex equation for the coordinate conversion. This equation is characterized by its non-linearity and the presence of multiple variables. See below:

$$
\boxed{\begin{aligned}
X' &= (A \times X) - (B \times Y) + Eastings \\
Y' &= (B \times X) + (A \times Y) + Northings \\
Z' &= (Scale \times Z) + OrthogonalHeight \\
A &= Scale \times cos(\theta) \\
B &= Scale \times sin(\theta) \\
\theta &= atan2(XAxisAbscissa, XAxisOrdinate)
\end{aligned}}
$$

Figure 7 Map conversion equation

To tackle this complexity, we have chosen to employ the `scipy.optimize.least_squares` function. It is a function in the SciPy library, which is a scientific computing library for Python. This function is used for solving nonlinear least-squares problems with minimizing the sum of squares of a set of nonlinear equations.

This method is particularly suited for the CHEK needs, as it is designed to find the optimal solution by systematically minimizing the difference between the observed and predicted values in order to minimize geometric distortions when the data is used as input for automated rule checking further in the process.

Through this approach, we have been able to effectively address the inherent non-linearities in the coordinate conversion equations. Consequently, we have obtained the most suitable solution for the coordinate operation values in IfcMapConversion. This method has proven to be an effective strategy in our ongoing efforts to improve the accuracy and reliability of the processes.

3.3.3 Visualization

To provide a visual understanding of how georeferencing values impact the IFC model geometry on a map, we have incorporated a visualization feature. Users can select the 'Show on Map' option to view the roof-print (2D projection of the roof from above) of the IFC model. This roof-print, represented as a polygon, is rendered on the map directly beneath the model, allowing users to see the real-world implications of their georeferencing values.

The visualization component leverages support from another project managed by TU Delft in CHEK, known as IfcEnvelopeExtractor, which can generate the roof-print of the 3D BIM model in the process of extracting its outer shell.

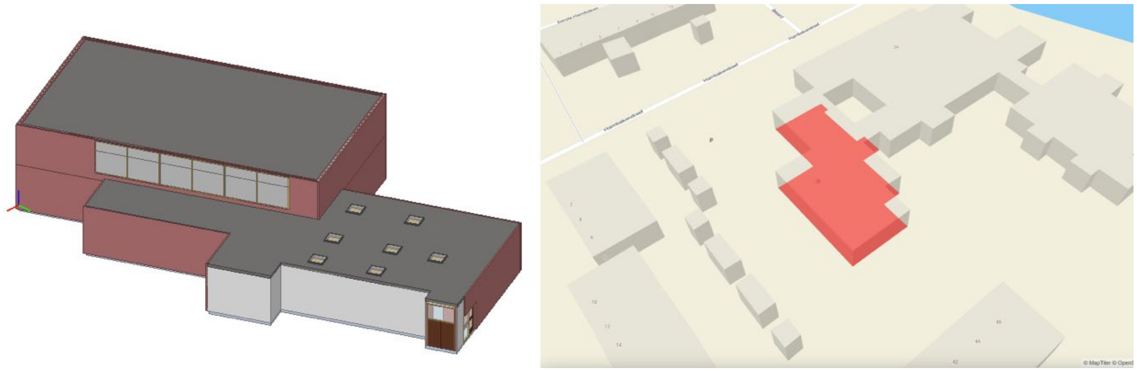

Figure 8 3D view of a georeferenced BIM model (left) and its visualization on the map (right)

3.4 HTTP request

To simplify the management of received IFC files for software developers, controlling whether they are georeferenced or not, a dedicated section named "devs" (https://ifcgref.bk.tudelft.nl/devs) is provided. Developers can interact with this section by making an HTTP request with the IFC file, and in return, they receive a response from the server.

```python
import requests

url = 'https://ifcgref.bk.tudelft.nl/devs'
file_path = './00.ifc'


data = {
    'file': ('00.ifc', open(file_path, 'rb'))
}


# Make a POST request to the /devs route with the data
response = requests.post(url, files=data)

# Print the response content
print(response.text)
```

Figure 9 Sample of HTTP request from the devs section using a python script.

```
Filename: 00.ifc
Georeferenced: YES
IFC version: IFC4
IFC file is georeferenced.
IfcMapconversion:

           property                                                                                       value
0                id                                                                                      259882
1              type                                                                            IfcMapConversion
2         SourceCRS  [None, Model, 3, 1e-05, [[(0.0, 0.0, 0.0)], [(0.0, 0.0, 1.0)], [(1.0, 0.0, 0.0)]], [(0.0, 1.0)]]
3         TargetCRS                                              [EPSG:25832, None, None, None, None, None, None]
4          Eastings                                                                               479338.600506
5         Northings                                                                              5444142.430127
6   OrthogonalHeight                                                                                        0.0
7      XAxisAbscissa                                                                                       0.85
8      XAxisOrdinate                                                                                      0.758
9             Scale                                                                                         1.0
TUD501276:venv shakim$
```

Figure 10 Sample of IfcGref HTTP response to a georeferenced file.

The "devs" section is designed for developers to check the georeferencing status of the IFC files. In order to modify or visualize the files, they need to use the web-based application.

3.5 Refinement and Collaboration

In addition to multiple Work Package 3 meetings, a pivotal session with industry experts outside of CHEK was conducted at TU Delft. These collaborative engagements not only exposed valuable insights into users' specific needs but also delved into potential enhancements for the IfcGref Web-Based Application. This dialogue, spanning designers, engineers, and software developers, aligned with the CHEK project's primary goals. The refinements made during the application's development extended beyond addressing user interface needs to include strategic upgrades and solutions to potential issues, such as security of file sharing. These proactive measures not only ensure the tool's accessibility but also underscore its commitment to meeting the diverse and evolving requirements of stakeholders within the GeoBIM area.

3.6 License

4. Conclusion

The development of the IFC georeferencing tool represents a key advancement in the CHEK project, effectively tackling the critical challenge of transforming coordinate systems between Building Information Models (BIM) and city models. To cater to a diverse user base, including designers, engineers, and software developers on various platforms, a web application has been developed and is accessible through a specific URL.

While map coordinate operations were initially introduced in IFC 4, the tool accommodates users of earlier, widely used versions by implementing property sets based on the standards of newer releases. The streamlined workflow, from file upload to visualization, confirms whether the file is georeferenced or guides users through an interactive georeferencing process. The optional addition of surveyed points enhances precision in the translation calculations, contributing to georeferencing accuracy. Leveraging the SciPy function optimize.least_squares effectively addresses non-linearities in the map projection equations, ensuring optimal solutions for the transformation of coordinate values. The visualization feature allows users to observe the real-world impact of georeferencing on the IFC model's geometry. For software developers, the dedicated "devs" section provides a streamlined approach for managing IFC files through HTTP requests, showcasing the tool's adaptability for diverse user needs.

It is important to note that the IfcGref Web-Based Application is one of the main tools of the CHEK project to assist in the integration of BIM and city models for improving collaboration and decision-making processes. This will enable the integration of geospatial data into building permits, as well as provide a basis for analysis and regulatory checks related to DBP.

5. References

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List of used abbreviations

BIM - Building Information Modeling

DBP - Digital Building Permit

CRS - Coordinate Reference System

GCS - Geographic Coordinate System

GIS - Geographic Information System

PCS - Projected Coordinate System

Pset - Property set

WP - Work Package