Concept for the integration of BIM and GIS data for monitoring land deformation around an ongoing infrastructure project

Szymon Glinka, Tomasz Owerko

Faculty of Mining Surveying and Environmental Engineering, AGH University of Science and Technology, al. Mickiewicza 30, 30-059 Cracow, Poland, (glinka@agh.edu.pl; owerko@agh.edu.pl)

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ABSTRACT

The BIM (Building Information Modeling) technology, currently being introduced in many countries, and its integration with GIS (Geographic Information System) data within a single CDE (Common Data Environment) platform may allow a more in-depth monitoring of the investment and faster detection of irregularities related to its implementation. Considered separately, each of the above technologies allows different types of analysis, but the synergy effect created by their integration makes it possible to view the problem in a broader perspective and to make the optimal decision. This issue also concerns the analysis of deformations around the erected object, which can be described by GIS data. On the other hand, the object is currently most often represented by a 3D model in IFC format that has the relevant information. The main aspect of this work is to combine these two types of data and analyze such a solution in terms of investment management support. The final result of the work is a description of a BIM and GIS use case for deformation monitoring and the creation of a algorithm for this task including the exchanged information with reference to OpenBIM standards (data exchange format Industry Foundation Classes - IFC, Information Delivery Manual - IDM). The whole work was also considered with reference to risk management during the project.

I. INTRODUCTION

Managing a construction project involves many aspects of risk. Emerging new technologies, allowing the digitization of some construction processes, provide opportunities for greater control of risks associated with, for example, ongoing construction work. One of the representatives of this type of risks may be unexpected or expected, but larger than anticipated, deformations of the ground around the implemented investment. By detecting them more quickly and sending information to site managers, it is possible to reduce the costs associated with delayed action on a given risk or to improve site safety. Moreover, by integrating BIM and GIS technology, it is possible to act before risks materialize.

BIM (Building Information Modeling/Management) is a technology increasingly used in the AEC (Architecture Engineering Construction) industry throughout the life cycle of a building. BIM technology is based on a 3D model and the metadata stored within it. It thus creates a database which is defined in a global or local space. This model can be used in any phase of the life cycle (Eastman *et al.*, 2018). The use of this technology supports decision-making processes related to construction investments. This paper focuses primarily on the construction and operational phases of an infrastructure facility.

On the other hand, GIS (Geographic Information System) are systems or databases responsible for operating on geospatial data, located in the global coordinate system (Thurgood and Bethel, 2003). By using different analytical tools, it is possible to analyze data in terms of many criteria and at different levels of technological advancement. These range from simple operations such as intersecting two layers to the use of complex machine learning algorithms.

By combining BIM and GIS data, synergies are sought (UN-GGIM, WFEO and WGIC, 2020). BIM presents information about the designed or constructed facility, while GIS allows to give context to the model (ISO/TR 23262:2021: GIS (geospatial) / BIM interoperability). This publication focuses on the context concerning the monitoring of an investment through the use of GIS data related to terrain deformation and its recording using a format specific to BIM, namely IFC (Industry Foundation Classes).

A core element of BIM technology, and in particular the idea of openBIM, is the use of an open data exchange format - IFC (ISO - ISO 16739-1:2018 - Industry Foundation Classes (IFC) for data sharing in the construction and facility management industries — Part 1: Data schema) It aims to free itself from native formats and achieve a more efficient exchange of information between stakeholders in the construction process. During research, this schema was used in the proposal of the problem description.

This approach also allows information to be stored and used within a single system, which can be centred on a single CDE - Common Data Environment (ISO - ISO 19650-1:2018) platform. The CDE is the hub for information exchange between stakeholders in BIM-enabled investments. Of course, it is possible to use native formats derived from native software, but this solution is most often inefficient because stakeholders do not work on identical software, and the exchange of native files causes complications such as loss of geometric or informational data.

The aim of the publication is to present the concept of integrating BIM and GIS for the purpose of monitoring terrain deformation during the construction and operational phases of an infrastructure facility. The main focus is on the description of terrain deformation information recording and information flow in the process.

This publication is conceptual in nature and consists of four parts: the first introduces the topic of BIM and GIS, the second presents the background, the third presents a proposal for the integration process and defines a use case for the integration of BIM and GIS for deformation monitoring, then presents conclusions and plans for future work. The publication does not focus on the characteristics of measurement methods that can be used during the implementation of investments, they are only listed and briefly described with reference to the literature, where it is possible to broaden the knowledge on this subject.

II. BIM and GIS integration for deformation monitoring – background

The integration of BIM and GIS technology is a relatively new idea. It emerged with the need for a broader view of the investment. However, due to reasons, different primary applicability of these technologies, some difficulties in their integration exist. The main reasons for these problems are different information records. In GIS, the currently most commonly used open format for exchanging three-dimensional data is CityGML (City Geography Markup Language), while BIM uses the previously mentioned IFC. The detail of the data is also different. GIS usually represents a wide area, but definitely more generalized than in BIM, where the focus falls on a smaller area, but definitely more detailed.

Currently, the integration of BIM and GIS is not fully possible and requires precisely defined requirements for the information to be integrated. The main problems of integration are described among others in (ISO/TR 23262:2021: GIS (geospatial) / BIM interoperability; Liu *et al*. 2017; Song *et al*. 2017).

The GIS data that can support the monitoring of a construction project, and in particular the monitoring of ground deformation, are those acquired from Unmanned Aerial Vehicles (UAVs) and from satellite imagery. This publication is not intended to analyze the measurement methods, so they will only be briefly characterized with reference to the literature. Field measurements using Total Station are difficult to qualify as GIS data, so they are omitted - they are directly geodetic data.

Unmanned Aerial Vehicles allow the use of different types of sensors. The most common are optical and laser sensors. The use of an appropriate sensor depends mainly on the land coverage of the area subject to analysis. In the case of optical sensors, one must take into account the limitations in penetrating vegetation, so the results obtained may be affected by considerable error. Laser sensors, on the other hand, allow to penetrate vegetation by registering many reflections of a given laser beam (echos). This makes it possible to measure below the vegetation and analyze the reflections from the ground. The use of drones for deformation monitoring in the case of mining areas, *e.g*. (Ćwiakała *et al*., 2020), is often found in the literature. A collection of UAV applications in civil infrastructure, including those for deformation monitoring are described in (Greenwood *et al*., 2019).

Another source of data can be satellite data such as InSAR. An example of a system that implements solutions from this field for deformation monitoring purposes is Sille, based on data from the Sentinel-1 mission (Sille). It seems that the application of this type of system for the purpose of deformation monitoring of an infrastructural object can also be applicable, as described among others in (Blasco *et al*., 2019).

An example of a system that integrates BIM data and geodetic survey data for deformation purposes is Trimble Monitoring (Trimble Monitoring). With this type of system it is possible to visualise and control deformation of an object on an ongoing basis, *e.g*. during the construction phase. However, it is mainly based on measurements with Total Stations and GNSS receivers and therefore mainly single point monitoring is possible.

III. Process of integration for deformation monitoring

The process of integration of BiM and GIS technologies should be carried out on the basis of information requirements. The most important elements in BIM technology which define these requirements are:

- IDM - Information Delivery Manual, defines how information should flow throughout the life cycle of an object (or its part)
- IDS - Information Delivery Specification - defines what information should be included in IFC files - assumption of human and machine readability. Currently, this standard is under development and MVD (Model View Definition) is used more often, but it has a lot of limitations.
- OIR/PIR/AIR/EIR - Organizational/Project/Asset/Exchange Information Requirements – accordingly to ISO19650

When used for internal purposes (for example, for a general contractor), integration should take place within the framework of internally defined standards. The process described below relates to a different scenario, *i.e*. one where the appointing party requires the reporting of ground deformation data for project risk management purposes. The algorithm is shown in the figure below (Figure 1).

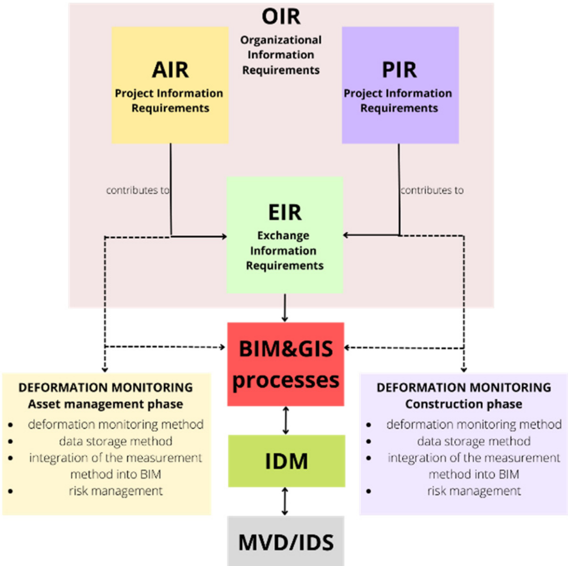

Figure 1. Algorithm for defining Information Requirements for Deformation Monitoring in Construction and Operational (Asset Management) Phase.

The IFC format is used as the basic component for information exchange in BIM technology. In the latest official version, there are difficulties in recording infrastructure information (IFC for infrastructure is expected to be available in 2022 or 2023). However, this does not mean that it is not possible to model components using this format. For this purpose, however, an instance of the IFcBuildingElementProxy class is usually used, which can represent any component not included in the file schema as a separate instance of the class.

The first element of the integration process is the definition of requirements, which was mentioned at the beginning of this section. Considering the integration aspect, the main attention should be paid to the georeferencing of models and unification of coordinate systems used in the project (also for GIS data). The requirements should also include information on the expected resolution of the acquired data and the frequency of its acquisition. The above requirement determines the choice of the measurement method, while the data density - the recording method. The information requirements should also include information about areas that may be particularly susceptible to deformation (places where the contractor or subcontractor should pay special attention).

Another factor is the cyclic measurement of the terrain and the recording of deformation information into an IFC file. For the purposes of this study, three proposals for recording the information were created, as described below.

The first method proposed is to extend the IFC format with classes to record information on terrain deformation. The only classes that currently depict displacement and/or deformation in IFC format (version 4) are IfcStructuralLoadSingleDisplacement and IfcStructuralLoadSingleDisplacementDistortion (IFC Schema Specifications - buildingSMART Technical). These allow the recording of structural displacement due to the application of force. As the focus of this study is on the deformation record relating mainly to the ground surface, this record is not applicable. However, the elements that are possible to use are the attributes of the above classes, shown below in the table (Table 1.).

Table 1. Attributes of the classes responsible for the recording of definitions in the IFC scheme

Attribute name	Type of attribute
Name	IfcLabel
Diplacement X	IfcLengthMeasure
Diplacement Y	IfcLengthMeasure
Diplacement Z	IfcLengthMeasure
RotationalDisplacement RX	IfcPlaneAngleMeasure
RotationalDisplacement RY	IfcPlaneAngleMeasure
RotationalDisplacement RZ	IfcPlaneAngleMeasure

The attributes represent the displacement in each axis and the rotation. The class IfcStructuralLoadSingleDisplacementDistortion can additionally represent deformations using IfcCurvatureMeasure. The above class could serve as a base for writing an object class representing the displacement of control points.

For the first scenario, the information medium would be the IFC model itself, which would write the data using a new type of instance of the IfcControlPoint class. The point would have a property set that would consist of attributes such as those provided in Table 1, and the name of the property set would refer to the date the measurement was taken. In this way it would be possible to store historical and current displacement values.

This type of approach requires editing the IFC class schema, which is a non-trivial and time-consuming process. This solution may also cause difficulties in the exchange of information using the IFC file. To be optimal, the above described class should be implemented in future versions of the format so that it can be used globally. An additional limitation is the ability to store information for single points, so this scenario could only be used for non-densely distributed control points. The advantage of this scenario is that it can be combined with systems that automatically track deformations.

The next two approaches involve acquiring higher density data. The second scenario for recording displacement information concerns the comparison of measurement results from two following ones using an

IFC file. For this purpose it is possible to use the differences between successive records of terrain information. The recording of terrain information in IFC takes place with reference to, depending on the version:

- IFC 2x3 - IFCSite
- IFC 4 - IfcGeographicElement

In the following research, the focus is on IFC version 4.

Terrain geometry can be stored using three classes:

- IfcGeometricCurveSet
- IfcShellBasedSurfaceModel
- IfcTraingulatedFaceSet

A detailed record of the storage capabilities of these classes is shown in the figure below (Figure 2).

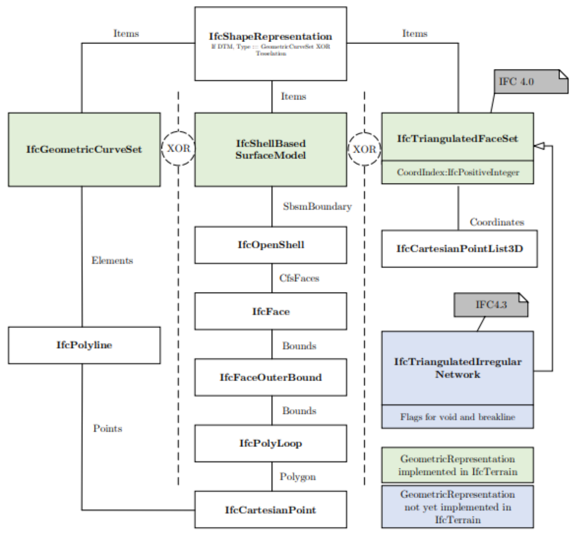

Figure 2. Concepts for Geometric Represenation (Clemen *et al.*, 2021).

In this way, the recorded individual measurement effects or differences between measurements can be combined in a single database or CDE platform and analyzed for risks. This analysis can be performed manually or automatically. In this way, GIS data is converted into BIM formats. A limitation of this method is the much larger disk space needed to store the IFC files, resulting from the storage method of the IFC files (schema). For the conversion of elevation data to IFC format, the open-source software IfcTerrain was developed (Clemen *et al.*, 2021).

The third scenario assumes the use of external structures and their spatial integration within the integration of BIM and GIS technologies. Unlike the first two, in which the information carrier was the IFC format, this scenario assumes the use of bypasses, combining both technologies. The publications identified in section two, that present integration problems, show that it is not a simple process. However, properly modelled, using appropriate IT tools, the process allows additional information to be generated and stored within more efficient structures. Nowadays, database-based solutions are increasingly common, *e.g.* (Wyszomirski and Gotlib, 2020). In this way, it is possible to store information in a structured way. The problem is most often the visualisation of this type of data, as databases need to contain the right methods and class definitions, allowing them to be properly displayed and acted upon within *e.g.* a CDE platform. In the end, they have to be converted into formats characteristic for both technologies (BIM - IFC and GIS - CityGML) anyway. This is most often due to the lack of suitable IT tools for displaying and acting on the data together. Further development of recording techniques can mitigate this problem. An example is the idea of semantic networks, which can serve as a component to draw information from both BIM and GIS and analyze risk within an ongoing construction project (Karan and Irizarry, 2015).

Most importantly, all scenarios described above require a precise definition of information requirements and information flow. The adaptation of the scenario depends on the measurement method used, the frequency of measurement, the object or the deformation predicted.

Finally, the proposed scenarios can be characterised as follows in Table 2.

Table 2. Scenario for the recording of terrain deformation with IFC files

Scenario	Synthetic description
Extension of the IFC format	Adaptation of IFC classes for land deformation monitoring. Recording of displacement information using appropriate classes
Use of IFC files as further results of field measurements	IFC allows information about the terrain to be recorded. Recording consecutive measurements using IFC allows for unified recording and use of the results within one environment. It should be noted, however, that the IFC format is not optimal for recording multiple points
Use of external references	Linking the IFC format to external formats provides the greatest opportunity when considering the area to be analyzed. However, one should bear in mind the limitations resulting from the lack of integration of BIM and GIS technology, which at the moment is not fully coherent

IV. Discussion

The concepts described above aim at a more efficient use of deformation data in the construction process, primarily in the execution phase. The flow of information within a single standardized ecosystem, the role of which is played by the Common Data Environment, provides opportunities for greater control and faster recognition of risks.

It seems that the most efficient of the described scenarios to use at present is scenario three, which allows storage and action on the largest areas. The first scenario requires operating on an IFC file and does not allow dense data to be stored - rather point data of a geodetic rather than GIS nature - but it allows the IFC format to be made more dynamic by providing information to it about the displacement of a control point measured continuously. The second scenario is the easiest technologically but has limitations in the area it can cover - this is due to the method of recording the IFC format.

V. Conclussions

The described concept indicates directions for further work that can be undertaken to develop the use case described in the publication. It is planned to further explore the possibility of recording deformations within the integration of BIM and GIS technologies and to automate this process. It is also possible to use machine learning for this purpose, allowing for more efficient tracking. However, it should be remembered that the proposal is mainly aimed at areas where deformations or land displacement may occur (mainly mining areas or sites of mass movements).

Further work is expected to lead to the creation of a software prototype, which will allow the integration of BIM and GIS technologies for the purpose of terrain deformation monitoring. The creation of such a solution, however, requires standardisation in terms of the unification of data recording in both technologies.

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