DEVELOPMENT OF A WEB PLATFORM TO VISUALIZE PS-INSAR DATA IN A BUILDING INFORMATION MANAGEMENT SYSTEM

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ABSTRACT:

Building Information Modeling (BIM) is a widely used approach in construction project management, providing a detailed and integrated view of a building's physical and functional characteristics. However, BIM models can be further improved by incorporating data from remote sensing techniques such as Persistent Scatterer Interferometry (PSI), which provides information on ground deformation and movement. In this paper, we present a methodology for integrating PSI data into BIM models using the industry foundation class (IFC) format and presenting it in a custom web platform. We use SAR data and PSI processing to obtain deformation information, generate an IFC compatible model, cluster PS points, and create a custom web platform for data presentation. The proposed approach has the potential to improve construction project management by providing a more comprehensive understanding of a building's behavior and enabling stakeholders to make informed decisions based on remote sensing data.

1. INTRODUCTION

Building Information Modeling (BIM) has gained widespread recognition in the construction industry due to its ability to provide a detailed and integrated approach to construction project management. BIM models can provide insights into the physical and functional characteristics of a building, enabling stakeholders to make informed decisions throughout the project's lifecycle. However, BIM models can be further enhanced by incorporating data from other sources, such as the remote sensing technique Persistent Scatterer Interferometry (PSI).

PSI can provide information on ground deformation and movement, allowing for the identification of potential hazards and risks that could impact a building's structural integrity (Crosetto et al., 2016). By combining PSI data with BIM models, construction professionals can gain a more comprehensive understanding of a building's behavior and make more informed decisions about its design and construction. BIM models, represented in the industry foundation class (IFC) format allow the integration of sensor data (Kazado et al., 2019).

Presenting this integrated approach in a web platform is important for enabling wider accessibility and usability of the data by stakeholders from different fields. A custom web platform allows to emphasize the project specific aspects of the BIM data - here the satellite based deformation measurements. This browser based approach also enables the access to the data without specialized software.

In this paper, we present an overview of our methodology for integrating PSI data into a BIM model and presenting it in a web platform. The proposed approach has the potential to improve construction project management by providing a more comprehensive understanding of a building's behavior and enabling stakeholders to make informed decisions based on reliable and accurate data.

Firstly we give an overview over the methods and database, followed by a examples of our web platform in the results section. Finally we discuss the some aspects of the process and give and outlook over potential future improvements.

2. METHODS AND DATABASE

Here we describe the database that was used to create the BIM model the PS points and describe the workflow of how to augment the IFC model with this DInSAR data.

2.1 SAR Data and PSI Processing

The synthetic aperture radar (SAR) data basis for our experiments is a stack of TerraSAR-X images in High-Resolution Spotlight mode (Airbus, 2017), acquired during a 20 month time span over Bochum, Germany (Tab. 1).

Based on the original idea of Persistent Scatterer Interferometry (PSI) (Ferretti et al., 2001), several commercial software solutions are available.

We processed the SAR data with the PS-module in SARscape 5.5 (SARMAP, 2014).

The result from the PS-analysis is an estimated 3d coordinate for each PS-point along with a time series $\mathrm{Def}(t)$ that depicts the line-of-sight (LOS) movement of this point towards the satellite. While the 3d accuracy of the coordinate is usually in the order of meters, the deformation time series for X-band SAR can be in the mm/year scale (Gernhardt et al., 2015, Quin and Loreaux, 2013).

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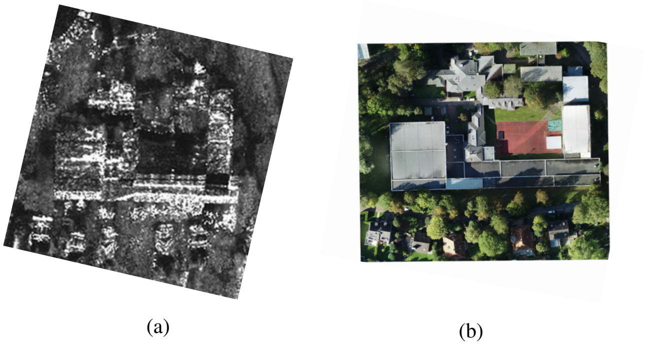
We manually select 7425 PS-points on the building of interest. An amplitude image of the study site, next to an orthophoto is shown in Figure 1.

Platform	TerraSAR-X
Wavelength	31mm (9.6 GHz, X-Band)
Acquisition Mode	High Resolution Spotlight
Orbit Direction	Descending
Resolution: Range × Azimuth	0.6 m × 1.1 m
Number of Images	28
Time interval	07.02.2018 - 05.10.2019
Repeat Time	11 Days
PS-Algorithm	L3 SARscape 5.5
Coherence Threshold	0.7

Table 1. SAR Data acquisition and processing parameters.


(a)

(b)

Figure 1. (a) Amplitude SAR image of the building of interest. (b) An orthophoto of the same scene.

2.2 Study Site

The study site for this project is a large building complex (Fig. 1b) with an expansion of 50m by 100m, that has undergone some minor deformations due to post coal mining subsidence in the Ruhr area in Germany. The site was chosen for several reasons, including the availability of high-resolution TerraSAR-X data from the DLR archive and the building administrator's interest in the project, which allowed us to survey the indoor and outdoor areas of the building to create an as-built BIM model as an accurate representation of the building's current state.

2.3 Representation in industry foundation class (IFC)

The IFC data model is the international convention for Building Information Modeling (BIM) (Vanlande et al., 2008, Laakso et al., 2012). It defines a standard schema for the description of the geometry and metadata of building objects. The geometry of the building components can be represented as triangulated surfaces or as boundary representation (BREP) solids. The IFC data model has a rich set of attributes for describing the geometry of the building components. For example, there are attributes for defining the wall thickness, the exact 3D shape of the wall, the material properties of the wall, etc. The IFC schema is designed to be independent of any particular software or BIM system.

We use the IFC format to model the structural elements of a building. Structural elements in a building include walls, floors, columns, beams, slabs, and roofs.

2.4 Generation of IFC Compatible Model

For the generation of the "as-build" BIM Model, we relied on orthophotos, drone flights with optical and thermal cameras Additionally the digital terrain models, city model and orthophotos from the "geobasis NRW" portal was used. An on-site walk-through of the building gave us useful information about the position of the beams and columns. In addition, construction plans and knowledge of the building operators were included. This workflow is depicted in Figure 3.

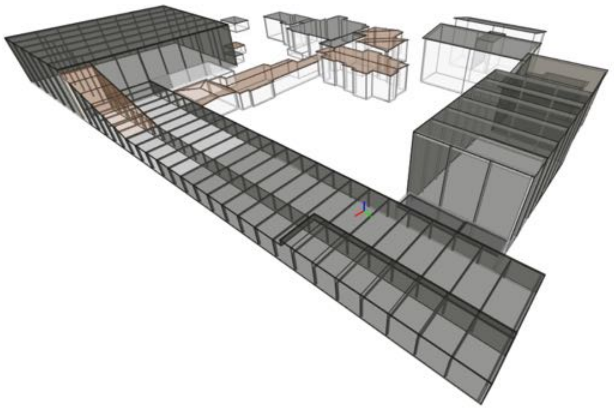


Figure 2. Transparent BIM

The modeling was execute in the industry standard software "revit". This labor intensive work was carried out fully manualy, since every structural part had to be included in the model.

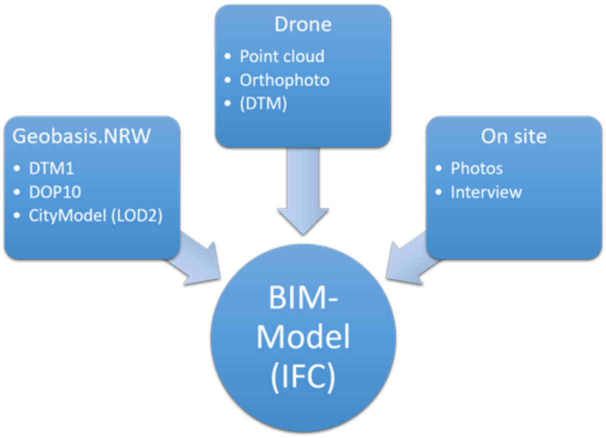


Figure 3. Data modalities that where used for the generation of the "as-build" BIM

2.5 PS- Point clustering

We treat the deformation history of each PS point as a point in a high-dimensional space, with a dimension for each acquisition date.

We use a hybrid distance metric to embed PS points and cluster as described in (Schneider and Soergel, 2021a).

The assumption is that points that lay on a rigid structure show similar deformation behavior and therefore form clusters in this deformation space. Clustering directly in this high-dimensional space goes along with the various curse of dimensionality problems (Allaoui et al., 2020). Figure 4 shows this representation in the deformation space schematically.

Instead, we use a non-linear dimension reduction method with a hybrid distance metric followed by a clustering process to

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extract such clusters from the PS-point cloud, as proposed by (Schneider and Soergel, 2021b). That means, we embed the points into a low dimensional space while preserving local neighborhoods, using UMAP (McInnes et al., 2018). The distance of two points is defined by a combination of the Pearson correlation and the Euclidean distance as described by (Schneider and Soergel, 2021a):

After a noise floor estimation by analyzing the Core Distance Graph (Ankerst et al., 1999), DBSCAN (Ester et al., 1996) is used to extract clusters.

Each of the clusters represents a group of PS-points that move in a correlated way and are not too far apart on the building. For each of the clusters, the centroid can be analyzed. If treated as a time series one can derive the mean deformation history for each cluster. In the final web platform only the centroids for the extracted clusters for each building part are shown.

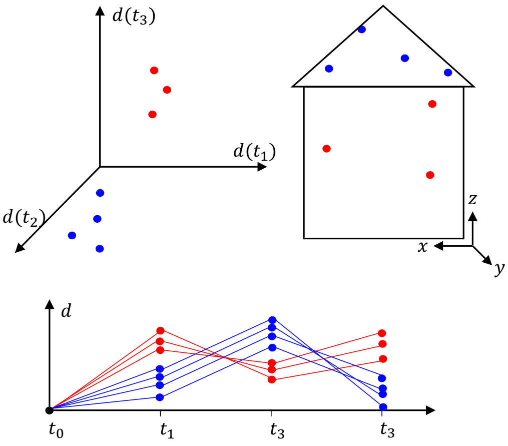


Figure 4. Representations of PS points. **Top right**: On building. **Bottom**: Deformation time series. **Top left**: In deformation space. The assumption is that points that lay on a rigid structure (e.g. the roof) show similar deformation behavior and therefore form clusters in deformation space.

2.6 Combination of PS-Groups with Building Model

We combine the groups and building parts as described in (Schneider and Soergel, 2022). Hereby we use an adapted Kuhn–Munkres algorithm (Kuhn, 1955) to find the optimal assignment of many building parts to each one PS group. Figure 5 shows this exemplary and Figure 6 shows the results for the study site. This approach also allows for a quality metric that describes how good the association for each part is.

To process the IFC File, we use the *ifc open shell* (https://ifcopenshell.org/) suite of developer libraries and utilities to manipulate OpenBIM data.

We create a new *property set* that includes the derived deformation information and meta data for each part. All properties are listed in Table 2.

Property (data type)
Mission name (string)
Acquisition mode (string)
Wavelength (mm)
Start and end dates (date)
PSI processing algorithm (string)
Valid data flag (boolean)
Line-of-sight direction (angles)
Velocity (LOS) (mm/year)
Deformation history as time series (table of mm)
Quality metric (float)
Cluster and PS IDs (list of integers)

Table 2. Data fields of the property set for DInSAR Data in the IFC file

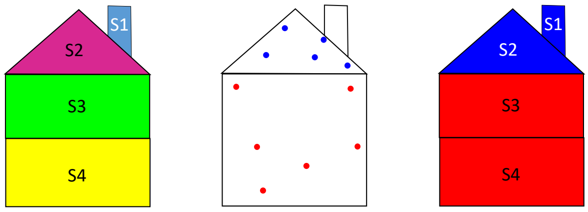
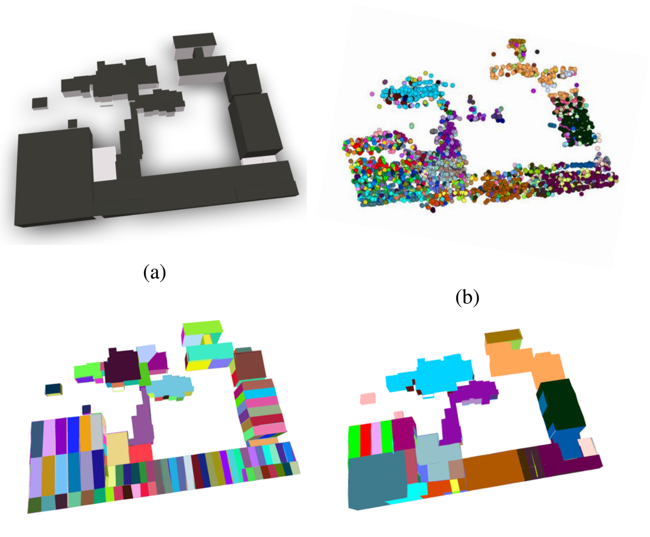


Figure 5. An example for the PS points clusters to building segments assignment problem. **Left**: A building with 4 segments. **Middle**: 2 PS Clusters are found on the building. **Right**: The optimal assignment.



(a) (b)

(c) (d)

Figure 6. PS Points on the study site, a large sports facility in Germany. (a) shows the BIM model and (c) the individual segments. (b) shows the PS clusters and (d) the assignment to the segments.

2.7 Design Aspects of the Platform

Ifc data can be visualized in various industry standard software packets. Though they the lack the ability to highlight and display custom property sets in a suitable fashion. Therefore, we designed a visualization platform (Fig. 7 - 10), which is available online and compatible with all operating systems via a web browser. It provides users tools to monitor the building's health under a flexible 3D view. That means, one can rotate, zoom in and out the BIM model for an intuitive investigation. Each building block contains its own properties like ID, coordinate, timeline, and SAR-derived movement data. These properties can be clearly displayed and updated if necessary. Among them, the step wise movement series and corresponding velocity are crucial signals for building safety. The color of each building block can be switched to different meanings. By default, the color indicates the object; for example, black refers to roof and white to wall. We can also visualize the LOS-velocities by a color bar. Here the positive and negative values mean the movement is away and close to the SAR sensor, respectively. Another display mode shows the PS-groups, each of which features a similar movement behavior shared by the local PS-points. It is important for safety to know if a single object like a roof is affected by variant movements. Last but not least, we created a filtering to highlight those building blocks, whose movement exceed a defined range. They can be then further checked to see if a potential risk exists.

The web platform was developed with standard web tools such as html, javascript and css and hosted at a our server. It processes the IFC file on the client site using *ifc.js* (https://ifcjs.io) at its core.

3. RESULTS

The web platform developed in this study provides an effective tool for visualizing and analyzing monitoring data from an IFC file. The platform allows for the selection of individual structural elements, such as walls, beams, slabs, and parts of the roof, and displays the associated data from the IFC file. Screen prints of the web platform are shown in Figures 7 and 9, which demonstrate the selection of a part of the wall and the associated time series plot showing the movement of the PS group linked to that part.

In addition to individual element analysis, the web platform also enables more complex analysis and visualization, as shown in Figures 8 and 10. These figures demonstrate the color-coded display of LOS velocity for each part and the ability to visualize sections of the complete building, respectively. This feature allows for the investigation of otherwise hidden parts, such as beams and columns, and the roof.

Overall, the web platform developed in this study provides an effective tool for visualizing and analyzing monitoring data from an IFC file. The ability to select individual elements and perform more complex analysis and visualization provides valuable insights into the behavior of the building and can inform maintenance and repair decisions.

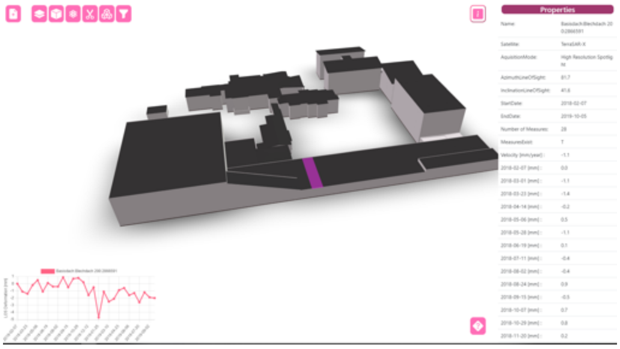


Figure 7. A web portal to visualize an IFC file with monitoring data from PSI. Single structural elements, like walls, beams, slabs, and parts of the roof can be selected. The associated data from the IFC file is displayed. Here the selected part of the wall is highlighted pink. The time series plot shows the movement of the PS group that is linked to this part.

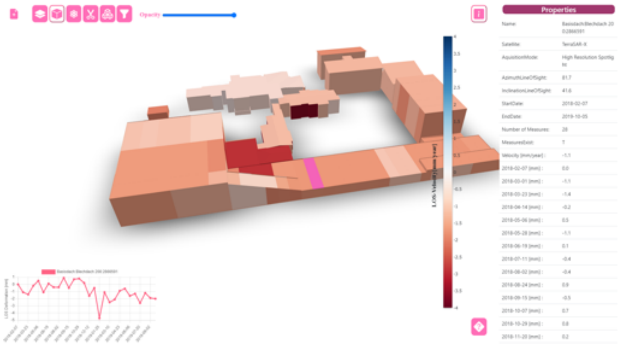


Figure 8. The web portal allows also for more complex analysis and visualization. The LOS velocity is color coded for each part. The user can visualize sections of the complete building. This allows for investigation into otherwise hidden parts, like the beams and columns and the roof.

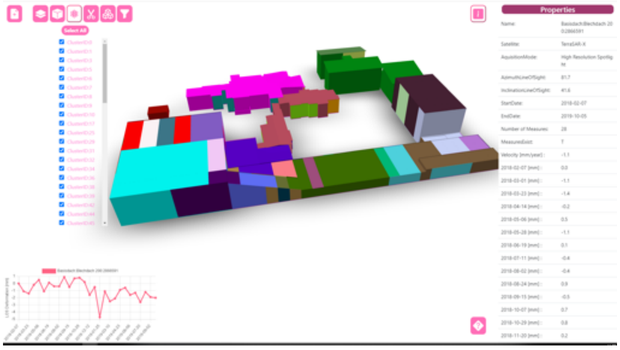


Figure 9. A web portal to visualize an IFC file with monitoring data from PSI. Single structural elements, like walls, beams, slabs, and parts of the roof can be selected. The associated data from the IFC file is displayed. Here the selected part of the wall is highlighted pink. The time series plot shows the movement of the PS group that is linked to this part.

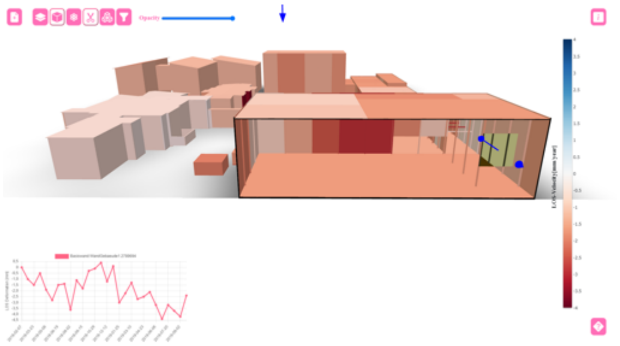


Figure 10. The web portal allows also for more complex analysis and visualization. The LOS velocity is color coded for each part. The user can visualize sections of the complete building. This allows for investigation into otherwise hidden parts, like the beams and columns and the roof.

4. CONCLUSION AND OUTLOOK

In this paper, we presented a methodology for integrating PSI data into a BIM model and presenting it in a web platform. Our approach can provide construction professionals with a more comprehensive understanding of a building's behavior by incorporating ground deformation and movement information obtained from remote sensing.

We demonstrated the potential of our approach through a case study in Bochum, Germany, where we manually selected 7425 PS-points on the building of interest, generated an as-built BIM model using a combination of orthophotos, drone flights, and on-site inspections, and clustered the PS-points based on their deformation history. We presented the results in a custom web platform that allowed stakeholders to view the building's deformation behavior over time.

Our approach has the potential to improve construction project management by providing accurate and reliable data for decision-making, risk management, and hazard identification.

Future work could focus on improving the accuracy of the as-built BIM model by using 3D laser scanning technology and automating the process of extracting structural elements from point clouds. Additionally, incorporating other data sources such as temperature and humidity sensors, wind sensors, and occupancy sensors into the BIM model could provide further insights into a building's behavior.

Overall, we believe that the integration of PSI data into BIM models and the presentation of the results in a custom web platform has the potential to revolutionize the construction industry by providing stakeholders with more comprehensive and accurate information for decision-making.

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