© 2022 Society of Photo-Optical Instrumentation Engineers.
One print or electronic copy may be made for personal use only. Systematic reproduction and distribution, duplication of any material in this paper for a fee or for commercial purposes, or modification of the content of the paper are prohibited.

Multisource-Data-Fusion for the Digitization of Critical Infrastructural Elements

S. Stemmler*[a,b], T. Kaufmann[c], M.J. Bange[e], D. Merkle[a,b], A. Reiterer[a,b], K. Klemt-Albert[f], S. Marx[d,e];

[a]Fraunhofer-Institute for Physical Measurement Techniques IPM, Freiburg, Germany; [b]Department of Sustainable Systems Engineering INATECH, Albert-Ludwigs-University Freiburg, Germany; [c]Kaulquappe GmbH, Germany; [d]MKP GmbH, Hannover, Germany; [e]Institute of Concrete Structures, Faculty of Civil Engineering, TU Dresden, Germany; [f]Chair and Institute of Construction Management, Digital Engineering and Robotics in Construction, RWTH Aachen University, Germany;

ABSTRACT

Due to the relatively high average age of the rail infrastructure in Germany and the thus often historic plans, as-built documentation has a very high priority at Deutsche Bahn AG. The inventory and updating of existing plans represent an enormous challenge for the operator, DB Netz AG. More than 4.6 million inventory plans must be continuously checked to ensure that they are up to date,correct,adjusted and supplemented as necessary. The most fragile structures are railroad bridges. These are the focus of this paper. For now, all information of bridges such as planning documents, statics, status reports of bridge examination, etc. are collected in decentral locations of the owner or operator. The existing information is available in a wide variety of formats, e.g. pdf files, plans on paper, scanned paper plans, digitally created plans, SAPdata and photos. We tackled this problem of non-uniform and decentralized data management within the mdfBIM project.

Within the scope of this project, a process model was developed that describes the merging of the various data sources in the planning process and attempts to identify the primary data source in each case. The validation and adaptation of this model was carried out continuously after it had been set up based on a railway bridge in Hannover, Germany. We used machine learning algorithms to enable an automated object classification for the most common objects to derive the highest possible degree of automation. Another important step towards automation was the consolidation of the numerous data sources. This existing, inhomogeneous data was homogenized in a defined process. During this homogenization, the data sets - ranging from existing as-built plans, photo documentation, maintenance and conversion reports, SAP extracts, construction books and construction plans to the newly recorded laser point cloud - was evaluated.

In this paper; the complete process chain and the first results are presented. Furthermore, an outlook is given on further research tasks and the further development of the elaborated process chain.

Keywords: UAV, LiDAR Multi-Sensor Fusion, Infrastructure Monitoring

1. INTRODUCTION

A modern integrated transport system is a central point to ensure a well-functioning infrastructure. Therefore, it is not only important to plan new parts of the infrastructure with modern technology, but also to digitalize existing infrastructure elements, like bridges.

For now, all information of bridges such as planning documents, statics, status report of bridge examination, etc. are collected in decentral locations of the owner or operator. The existing information is available in a wide variety of formats, e.g. pdf files, plans on paper, scanned paper plans, digitally created plans, SAP data and photos (on paper or in digital format). For a comprehensive effective planning of repair work, maintenance, predictive maintenance and for condition assessment over the life cycle of an existing bridge, all information must be considered. This information includes

in: Erbertseder, T.; Chrysoulakis, N.; Zhang, Y.; Society of Photo-Optical Instrumentation Engineers – SPIE: Remote Sensing Technologies and Applications in Urban Environments VII. Proc. SPIE 12269, Paper 1226905 (2022); doi: 10.1117/12.2634711

geometry, used materials during the building phase, static boundary conditions assumed during the building phase, static recalculations, repair work already carried out and incidences which affect the static behavior. It is currently customary to collect this information atdifferent locations and often important details are missing. In addition, existing information must be rated on their actuality, because old plans often do not represent the current situation of the bridge. A digital building model is used to bring together varied levels of information based on an object-based and geometric model, which is enriched by semantic information [1]. Digital building models based on open BIM are not limited by file formats. Thus, they can be used as a central database for target-oriented maintenance and operative phases of infrastructure [2], [3].

A central collective digitized infrastructure enables:

- Central database
- Maintenance and updating of the building data over the entire life circle
- Planning security for maintenance measures
- Digital building model-based predictive maintenance
- Bundled maintenance measures
- Ensuring functioning infrastructure without major restrictions on usability
- Extending the life of the structure
- Optimization of maintenance investments
- Planning security for replacement
- Model-based deconstruction planning
- Deconstruction and waste management

To take advantage of a digitizedinfrastructure, digitalization needs to be an efficient process. Therefore, we analyzed within the mdfBIM project, the process of creating a digital model regarding automation potential. To ensure that the digital model depicts the current situation, the process of creating such a model includes a 3D capture of the geometry, based on laser scanning and photogrammetric methods. The 3D geometry model can be used to rate the existing documents of the bridge. If the topicality of these documents is sufficiently confirmed, they can be used to enrich the 3D geometry out of the laser scanning process by additional geometry, which could not be captured by laser scanning (e.g. founding) and by semantic information (e.g. used materials). The main challenge of this process is to merge the multi-source data into one model and to make this process efficient. The feasibility study of mdfBIM could already prove that parts of this process can be automated. Undoubtedly, a partially automated process to create digital models of bridges, as components of the infrastructure, supports the digitization of infrastructure efficiently.

2. MATERIAL AND METHODS

To achieve maximum data yield, the following systems were used to digitize the demonstrator structure:

- Aerial survey with LiDAR system [4]
- Aerial survey with drone-based cameras [5]
- Recording of the underside of the bridge with a system camera to calculate photogrammetric point clouds

Within the project mdfBIM we choose a bridge in Hannover, Germany. As a first step we planned the flights path for the LiDAR and camera drones. In this process, the terrain to be flown over is defined and divided into flight strips, as shown in figure 1. The flight time for this bridge was determined by the size of the area, the desired overlap of the data and the flight speed. For this flight of approx. 1 ha, an overlap of the image data of 80 % along the flight axis and 60 % transverse to the flight axis was selected [5]. This resulted in a flight speed of 3 m/s corresponding to 10 km/h. Based on this flight plan, all the necessary permits for the flights were obtained.

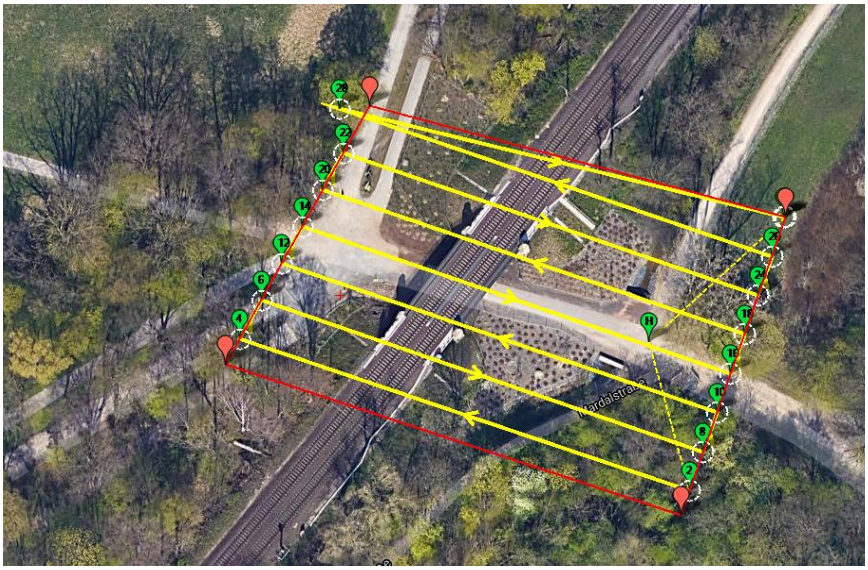

Figure 1.: Flightpath of the UAVs at the bridge at Herrman-Löhns Parc, Hannover, Germany.

This flight planning was used both for the flights with the LiDAR-system and for the flight with the camera drone. In order to be able to merge the point clouds of the LiDAR system and the photogrammetric point clouds, ground control points (GCP) were laid out and measured using differential GNSS. Using the GCP, it is possible to merge and homogenize both point clouds and georeference them in the same step [6].
The Fraunhofer IPM LAP system uses an integrated GNSS system for referencing and provides 3D data directly in LAS format. The positional accuracy was improved again by using the GCP. Agisoft Photoscan was used to calculate the point clouds from the acquired image data [7].
Some of the image data was also used to train a rudimentary neural network to automatically segment the images. The following elements were trained: tracks, vegetation, sky and railings. This neural network was tested with the image data not used in the training. The results of the automated segmentation were then projected onto the point clouds [7].

Geometric modeling is performed based on the evaluated point cloud, with the help of the total point cloud and the existing as-built documents. It has been found that all these sources of information are necessary for a full-fledged modeling and there is currently no technical possibility to geometrically record above-ground components as well as hidden and below-ground components.
Based on the recorded and homogenized laser point clouds, geometric modeling was performed in parallel with automated object recognition. Using the modeling software Autodesk Revit, the point cloud could be directly imported and cleaned up. The individual separated points were then used to identify geometric objects and overlay them with model objects. In this way, almost all near-surface objects could be modeled, but for some objects, information from the associated as-built documents had to be consulted. Subsurface, interior or hidden components had to be added entirely based on the as-built documents. For the pilot structure, parameters were integrated in the modeling for this purpose, which allow a statement to be made about the origin of the necessary geometric information.
During geometric modeling, semantic information defined for the respective use case is added via attributes on the individual objects. In addition, specific information can be assigned to each object, which on the one hand describes the object in its basic condition, and on the other hand also contains information relevant to operation, such as maintenance intervals and the most recently determined state of corrosion.
Checking algorithms can be used, to automatically compare whether all necessary information is available on all relevant components. The model is then imported into a central data platform via the open data exchange format .ifc. Via this platform, plant managers or other stakeholders can gain access to the geometric and semantic information of the as-built model. Other documents, reports and photos relevant to the structure can now also be referenced.

3. RESULTS

It was identified that it is necessary to define use cases for the digital inventory model, in order to subsequently derive information requirements. On this basis, the following geometric modeling and semantic attribution must be adapted and designed. It was possible to record initial requirements from the perspective of a structure inspector, an asset manager and a planning engineer and consolidate them with the standardized BIM use cases from the field of transport infrastructure in Germany.

- Use for operation & maintenance
- Use for dimensioning and verification
- Use for monitoring, diagnostics & as-built investigations
- Use for deconstruction planning for new construction
- Use for replanning & rehabilitation

Each of these use cases defines different information and accuracy requirements for the digital as-built model. These requirements were further analyzed and could be clustered and defined in a comprehensive table along the main component groups for bridge structures.
To illustrate the complexity of these definitions, two examples are shown below:
For the documentation of structural inspections, it is necessary that detected damages can be stored in the model in a clearly locatable way. For this purpose, a relatively exact geometry with individual objects is necessary.
However, as a basis for a structural analysis of the main structure, it is not necessary to model equipment components with geometric accuracy. These are only considered as loads; the geometry is secondary for this use case. The semantic information is the focus here since it provides information about the material of the main structure and its condition and thus contributes an essential role to the structural analysis.

Existing information of bridges not only differs in formats, but also in quality. The quality of the plans depends on the type of creation and the year of creation.
The as-built plans of the examined sample route are either drawn by hand or with an CAD software. The quality and quantity of the existing planning documents from one of the 18 buildings examined was very low.
In fact, that means that one of a total of 415 plans examined was of such poor quality that a partially automated readout is probably not feasible.
Even if individual plans have to be read out and interpreted with an engineering understanding, the quality of the plans is sufficient to implement a partially automated readout.

The following results, also shown in figure 2, can therefore be derived from the manual modeling:

- It is not possible to create a fully-fledged model solely from aerial survey data, since a drone does not capture interior, hidden and concealed components, which, however, are often of great interest in this context.
- Since only surfaces are reached with the laser scan in the course of an aerial survey, information about the geometric depth is missing for numerous objects.
- For object-based modeling, several data sources (at least aerial survey data, floor plans and sections) are necessary.
- Modeling based solely on plan documents proves to be difficult. The point cloud provides information that can be used to make modeling much more efficient.
- The use of a point cloud is particularly suitable as a real reference for checking the component dimensions, the component distances, as well as the component position in the overall model.
- The quality and reliability of point cloud data is crucial for the modeling of detailed components.
- The referencing of image data of complex building areas and components in the point cloud is recommended.

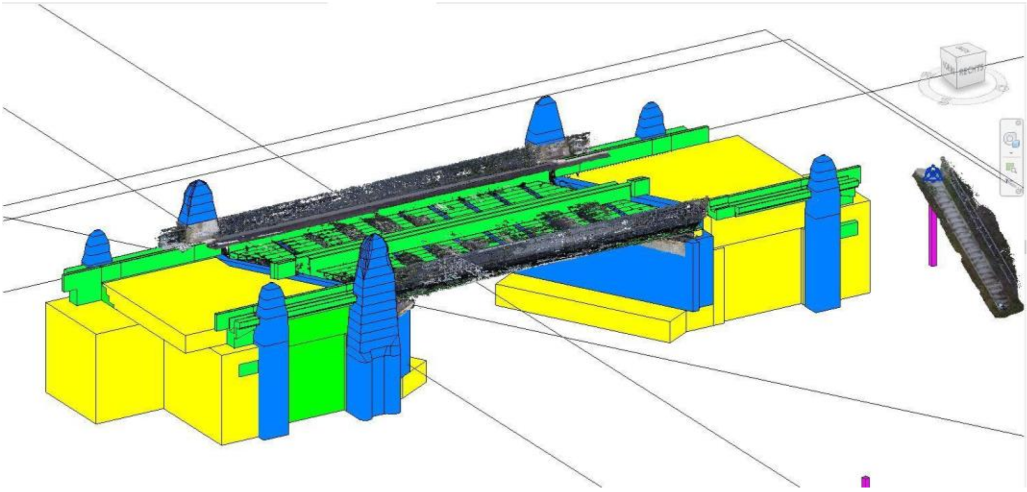

Figure 2. Modeled bridge with color differentiation of information origin. The colors refer to the origin of the information as follows: Blue: point cloud; Yellow: as-built documents; Green: mix of point cloud and as-built documents.

4. CONCLUSION AND OUTLOOK

Through the project, work numerous process steps could be identified that have a great potential for automation. Computer-based or computer-assisted evaluation and analysis processes using machine learning and artificial intelligence can be used to search existing inventory documents for relevant information much more efficiently. The flying of structures with drones is already partly automated and thus enables very effective flight planning. In the course of post-processing, numerous steps are already carried out by neural networks, so that there is further potential here, especially in decoding and cleaning and, above all, in segmenting and object recognition of the point clouds.

The automated modeling of the geometric inventory model is still a great challenge, but partial successes with the automated object recognition and subsequent transformation into standardized geometric objects are already possible. The final quality assurance is already carried out by software-supported inspection algorithms, but the evaluation and correction are mostly still done manually. Due to the high potential of this process chain, the project will be continued within the framework of the project mdfBIM+. In this project, we planto further automate the presented project chain by using AI and VR/AR.

ACKNOWLEDGEMENT

We would like to thank the German Federal Ministry of Transport and Digital Infrastructure BMVI (mFUND, Modernitätsfonds) for funding the project mdfBIM in the framework of which this work was carried out.

REFERENCES

[1] Klemt-Albert, K. (2018): Building Information Modeling. In: Schneider, K.-J., Goris, A., Albert, A. (Hg.): Bautabellen für Ingenieure. Mit Berechnungshinweisen und Beispielen. 23. Auflage. Köln: Bundesanzeiger Verlag.

[2] Hartung, R., Naraniecki, H., Klemt-Albert, K., Marx, S. (2020): Konzept zur BIM-basierten Instandhaltung von Ingenieurbauwerken mit Monitoringsystemen. In: Bautechnik 97 (12), S. 826–835.

[3] Grabe, M., Ullerich, C., Wenner, M., Herbrand, M. (2020): smartBridge Hamburg – prototypische Pilotierung eines digitalen Zwillings. In: Bautechnik 97 (2), S. 118–125.

[4] Becker, D., Stemmler, S., Reiterer, A. (2020). Entwicklung und Evaluierung eines kompakten Multisensorsystems für den Einsatz auf Drohnen. In: Ingenieurvermessung, 20, 99-108.

[5] Frey, J., Kovach, K., Stemmler, S., Koch, B. (2018). UAV photogrammetry of forests as a vulnerable process. A sensitivity analysis for a structure from motion RGB-image pipeline. In: Remote Sensing, 10(6), 912

[6] Stemmler, S., Wiedenmann, D. (2021): Multi-sensor data acquisition for assessing the condition of vegetation. In: Remote Sensing for Agriculture, Ecosystems, and Hydrology XXIII (Vol. 11856, pp. 111-118). SPIE.

[7] Zhan, Qingming, Yubin Liang, and Yinghui Xiao (2009): Color-based segmentation of point clouds. In: Laser scanning 38.3 (2009): 155-161.