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Railway Line Upgrading Project using BIM

Abstract: The study concerns the application of Building Information Modelling (BIM) in the process of railway infrastructure upgrading. The research site was railway line no. 218 Prabuty-Kwidzyn (Poland). The main aim was to verify integration of BIM tools, particularly OpenRail Designer, to enhance the geometric complexity and operational efficiency of railway projects. The methodology included: terrain data acquisition, reconstruction of the existing state, preparation of new project documentation. Upgrading was based on redesigning track alignments, introducing dual tracks, and achieving a target maximum speed of 120 kph, thereby improving both technical and operational parameters. The findings show BIM's potential for interdisciplinary collaboration. Future work suggests integrating train movement simulations to improve the evaluation of modernization benefits.

Keywords: BIM, upgrading, railway line, OpenRail Designer, designing 3D

Introduction

Building Information Modelling is a methodology for managing building information that enables continuous and immediate access to project data, including costs and schedules. The origins of this methodology can be traced back to the early 21st century, and today it is likely

one of the most effective design techniques in general construction. It is no surprise, then, that its adoption is becoming increasingly widespread in the infrastructure industry. BIM has already been applied in numerous road and rail projects worldwide. In Poland, the development of BIM in railway and road construction has not been extensive so far, but recent trends indicate a clear change in mindset within these sectors. It is worth noting that the project requirements for the Central Communication Port (CPK) explicitly include the necessity of implementing investments based on BIM [9]. Moreover, the national railway infrastructure administration, PKP Polskie Linie Kolejowe S.A., has started integrating such guidelines within the organization [10]. Past experiences suggest that the development of the BIM will be crucial for future construction practices.

Literature review

J. Neves, Z. Sampaio, and M. Vilela present an examination of the use of BIM for the upgrade of a roughly 2-kilometer segment of Portuguese railway in article [7]. In order to increase layer separation and stabilize the system, geosynthetics were used in addition to rebuilding the ballast, sleepers, and tracks. The Autodesk Civil 3D and Revit software was used. Using Navisworks, a planning-and-scheduling model for the building process was also produced. The key obstacles were: absence of standard BIM object libraries for transportation infrastructure, restrictions in modelling the intricate physical features of railway tracks and compatibility problems between BIM tools (specifically between Civil 3D and Revit). The benefits that were highlighted included making it easier to plan and schedule building projects, improving the accuracy and visualization of designs, and reducing errors.

A. Matejov and J. Šestáková [6] examined the scope of BIM use in railway infrastructure projects in Slovakia and the Czech Republic concerning especially 5D-models. According to the study, professionals have a comparatively low level of understanding of BIM (63% of respondents had heard of it, but only 29% had actually used it, primarily for 3D models, with less common usage for 4D and 5D). In the case study, OpenRail Designer and Synchro Pro were used to create a 5D BIM model that included details on rail geometry, costs, timetable, and construction circumstances. This made it possible to precisely estimate costs, minimize risks, and optimize technological processes.

The potential of employing BIM in the design of high-speed railway lines was examined by A. Alqatawna, S. Sanchez-Cambronero, I. Gallego, and A. Rivas [1], who concentrated on the advantages of incorporating BIM throughout the infrastructure life cycle. A BIM technique used in an actual HSRL project is presented in the article. Three main phases of the process were mentioned: design, building and maintenance. The idea of I-BIM (Infrastructure BIM) was introduced, highlighting the specificity of infrastructure projects in the design context, which differs greatly from general construction projects. Notwithstanding the advantages (like lower maintenance costs for infrastructure) problems with program interoperability were identified, which restrict BIM's full potential.

BIM with relation to 3D reconstruction of contemporary railway stations is the main topic of the paper [5] by L. Carnevali, F. Lanfranchi, and M. Russo. Modena Piccola and Santo Stefano are two Italian train stations that were the subject of the study. BIM models were designed using close-range photogrammetry and 3D laser scanning. According to the paper, the quality of models is impacted by the challenges of capturing intricate architectural forms in BIM and the restrictions on access to interior building data. The efficiency of international cooperation in construction projects may be impacted by the existing disparities in country approaches to levels of detail (LOD), which were highlighted.

The potential of BIM to transform the administration of big infrastructure projects made possible by collaboration, visualization, and optimization was highlighted by M. Bensalah, H. Mharzi, and A. Elouadi [3]. They contend that BIM is a novel method of project

management that goes beyond software or 3D modelling. However, they point out that both contractors and investors must adopt a new perspective in order to apply BIM in the railway industry.

M. Pasettoa, A. Giordanoa, P. Borina, and G. Giacomelloa [8] talk on the value of I-BIM in the design of Italian railway infrastructure. The following uses of BIM in railway infrastructure design were stated: traffic simulations, collision detection, life cycle information management, visualization, and cost calculation. An analysis was conducted on the situation of a new railway connection in the port of Venice. Three different railway layouts were shown and the best one was chosen using a multi-criteria analysis. It was demonstrated how to use BIM to model specific components of railway infrastructure, including sleepers, tracks and railway traffic control elements. It was underlined how important interoperability and standardization are in the design process.

The process of converting as-built construction documentation (of a railway line) to BIM and GIS standards in the Czech Republic was studied by D. Bartonek, J. Bures, O. Vystavel, and R. Havlicek [2]. Evaluating the effectiveness of updating current CAD documentation to a shared BIM data environment was the goal. This could facilitate future railway investment design collaboration and the public procurement procedure. It was discovered that while data export is simpler in a GIS system, the diversity of objects makes BIM transformation more difficult. The significance of following national standards and using a geodetic reference system was highlighted.

The BIM applications for railway infrastructure design in Germany, Morocco, Norway, Portugal, Sweden, Slovenia and the United Kingdom were examined in the paper by S. A. Biancardo, M. Intignano, N. Viscione, S. Guerra De Oliveira, and A. Tibaut [4]. Again, the necessity of improved interoperability and the establishment of object libraries devoted to infrastructure projects were emphasized. The essay also examines modelling methods in software like Rhinoceros, OpenSCAD and Civil 3D, emphasizing their uses and capabilities.

Methodology

The upgrading of railway infrastructure requires a careful and systematic approach to design and implementation, particularly when considering complex geometries and intricate spatial dependence. This section outlines the methodology used to assess and implement BIM in the railway line upgrading.

BIM Capabilities for Complex Track Geometries

The first step concerned examining and analysing the potential of BIM for designing complex railway track layouts. This analysis was carried out using OpenRail Designer 2023, a specialized software for railway infrastructure projects.

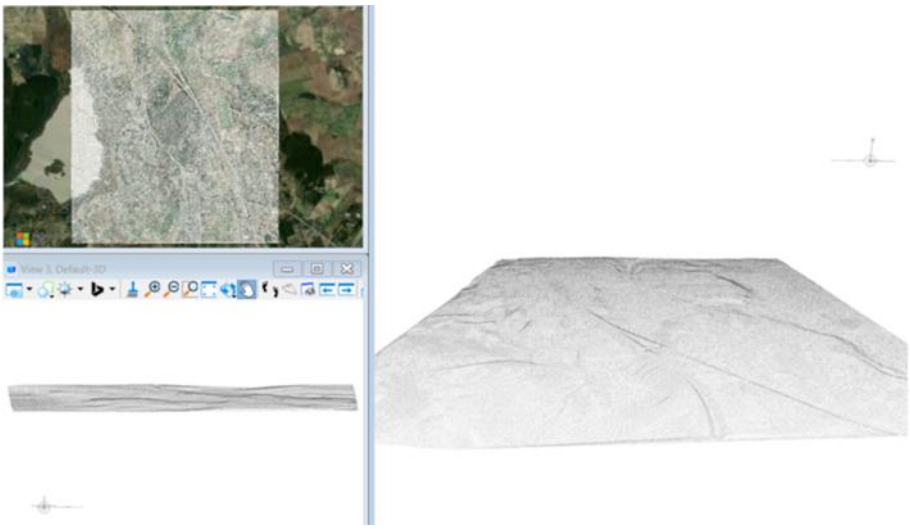
Selection of the Railway Line for Upgrading

For the purposes of this project, a section of railway line no. 218 Prabuty-Kwidzyn (Poland) was selected (excluding stations). The selection criteria included minimal forest coverage, which facilitates the acquisition of elevation data. Additionally, it was observed that this line represents a crucial shortcut, that would significantly shorten the travel time and cost from Kwidzyn to main railway line no. 9, if upgraded.

Collection of Terrain and Orthophoto Data Positioning

Terrain elevation data and orthophotos were collected from geoportal.gov.pl, which is publicly accessible government spatial data site. Figure **1** shows a section of the area where the currently analysed railway line is located. These resources were used to recreate the

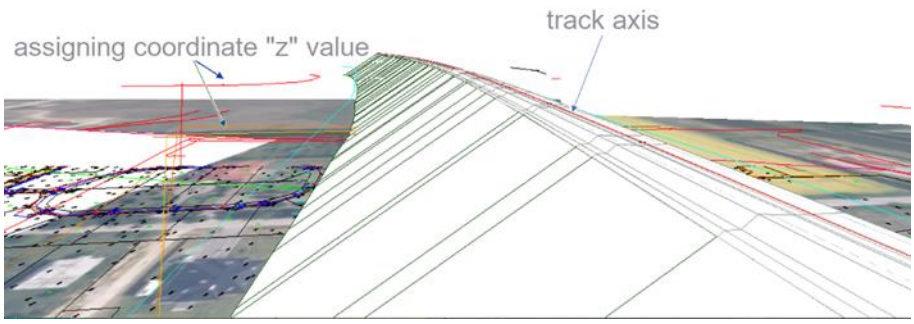
terrain's topography and design the track profile. Map overlays were also exported to improve visualization in the software environment.



1. Area in the analysed railway line – one of the sections

Assignment of Elevation Coordinates to Terrain Elements

To present the modernized railway corridor in 3D using BIM, a request was made to the Kwidzyn District Office for editable cadastral maps. These maps enabled the assignment of elevation ("z") values to terrain elements such as gas pipelines, telecommunication lines, and other infrastructure. Figure **2** shows a side view of land utilities after assigning elevation values.



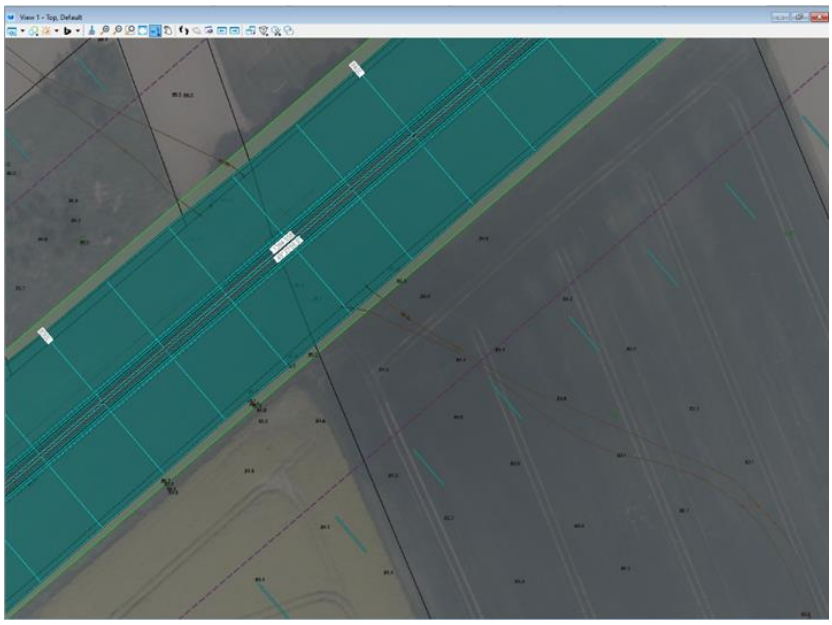
2. Side view of land utilities after assigning elevation values

Analysis and Reconstruction of the Existing Line

The selected section of railway line no. 218 is entirely located in the Pomeranian Voivodeship. It is a standard-gauge, non-electrified secondary railway line between the stations of Kwidzyn and Prabuty (20.974 km). Currently, only single-track operations are conducted, as the second track is non-operational. At the moment, the line is used exclusively for freight traffic. Along the route, three inactive passenger stops are located: Gonty (km 36.834), Licze (km 42.938) and Rakowiec Pomorski (km 46.274). The line's current state allows maximum speeds of 70 km/h, with some segments restricted to 40 or 60 km/h. To accommodate passenger services, these parameters require significant improvement.

The reconstruction of the existing line involved drafting all tangents, creating preliminary track geometry, and adjusting curve radii and transition curves to ensure alignment with the mapped track. A velocity profile analysis was conducted to define the

parameters required for upgrading. Figure **3** shows reconstructed layout nearby Prabuty railway station.



3. View of the layout of the reconstructed section

Preparation of BIM-Based Project Documentation

The final stage involved the modernization of the railway line and the preparation of project documentation utilizing BIM techniques. Curve radii and transition curves were modified to achieve a target maximum speed of 120 kph. Attributes such as rail type and sleeper type were assigned to relevant elements. Additionally, a new track profile with appropriate slopes was designed, resulting in a new speed profile that significantly improves the technical and operational performance of the railway line.

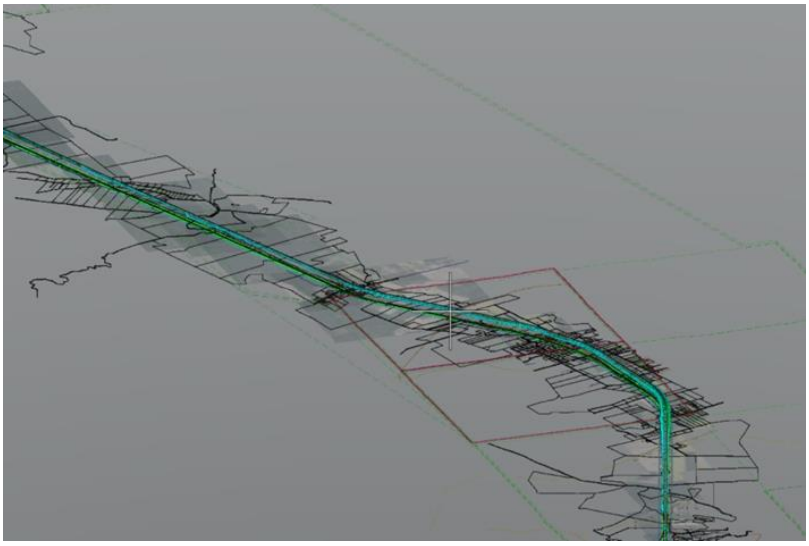
Results

The main objective while calculating the geometry was to achieve P0 level for designing (PLK standards). Although most sections of the upgraded route meet requirements for speed of 120 kph, some exceptions could not be avoided. Unfortunately, due to existing terrain, it would be noneconomic to change track location at very beginning and at the end of the line. As a result speed limits must have been introduced over there (110 and 130 kph respectively). It should not deteriorate traffic performance though, as trains limit their speed right before adjacent stations anyway. Arc parameters with maximum operating speed are shown in Table **1**.

Tab. 1. Designed geometry parameters – arcs

Arc number	Arc radius [m]	Cant [mm]	Lenght [m]	Speed limit [kph]
1	600	130	844.146	110
2	1500	95	647.818	120
3	1500	95	345.359	
4	1500	95	200.287	
5	1500	95	401.239	
6	970	110	1040.804	130

The 3D model of designed line was generated (Figure **4**). Its target profile is possibly noncomplex. Most of the new track was laid on the old embankment. Consequently, the extent of the groundworks was limited. The inclinations are low, from -0.618% to 0.779% (Table **2**.)



4. 3D model of the new line

Tab. 2. Designed geometry parameters – inclinations

Element	Inclination	Linear section lenght [m]	Circular section radius [m]
Linear	-0.321%	1194.079	
Circular			20 000
Linear	0.769%	3107.894	
Circular			20 000
Linear	0.024%	8531.907	
Circular			20 000
Linear	0.779%	3265.121	
Circular			20 000
Linear	-0.618%	1978.554	

Discussion

To facilitate more advanced work, it is necessary to improve and expand certain functionalities in the OpenRail Designer software to overcome existing challenges. During the project, minor inconveniences were encountered due to the specific nature of using OpenRail Designer. Apart from the user interface, which may be unintuitive, especially for new users, assigning elevations to elements such as underground utilities, required manual parameter input. This significantly extended the project realisation time. An essential factor in the effectiveness of project implementation of this type is also the quality of data received from external entities, such as documentation containing underground utility elements.

Small inaccuracies in this type of data, combined with the imperfections of the software, led to circumstances where, for example, after generating a 3D model of the railway corridor, underground utilities appeared above it, which was an obvious error. This required time-consuming manual corrections. Moreover, OpenRail Designer offers a limited set of templates of BIM elements for railway infrastructure, forcing users to create their own libraries or import them from external sources.

Another challenge during the realisation of the was the lack of functionality allowing multiple authors to work simultaneously on a single file, increasing the risk of errors during the synchronization of changes made by various users. Additionally, it was observed that

OpenRail Designer is less stable and more hardware-intensive compared to software like for example PowerRail Track.

Based on the conducted research, the costs and benefits of modernization using BIM can be evaluated in comparison to traditional design methods. Future work on the railway lines upgrading with BIM implementation is recommended to include elements related to train operations and traffic simulations.

Conclusions

This research proved BIM's potential for modernizing railway infrastructure. The project entailed acquiring topography data, geometrically reconstructing existing railways and creating sophisticated project documentation using OpenRail Designer. The renovation included single track and revised settings, allowing for a top speed of 120 kph while greatly improving operating economy and technical performance.

Despite making significant progress, the study identified some problems. They mainly concerned limited BIM component libraries for railway infrastructure, non-intuitive software interfaces, and issues assigning elevation data to terrain parts. These findings highlight the importance of further software development and standardization in order to fully exploit BIM's promise in large infrastructure projects.

Future research should focus on combining train movement simulations and investigating the cost-benefit analysis of upgrading.

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