The concept of utilizing iTwin Capture Modeler in the design of railway infrastructure

Koncepcja wykorzystania iTwin Capture Modeler w projektowaniu infrastruktury kolejowej

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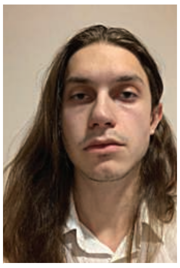

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Abstract: The paper investigates the feasibility of utilizing iTwin Capture Modeler software, which is designed for generating 3D models from photogrammetric data, in the design of railway infrastructure. Basing on general requirements of photogrammetric data acquisition and previous micro scale analysis, the methodology was developed. The study presents the results of an analysis of an existing double slip on straight tracks located in Koscierzyna Railway Museum. The generated 3D model allowed to determine the geometric layout of the analysed crossing.

Keywords: *Project; Railway track; Photogrammetry; Digital twins*

Streszczenie: W artykule przedstawiono możliwość wykorzystania oprogramowania iTwinCapture Modeler, przeznaczonego do generowania modeli 3D z danych fotogrametrycznych, w projektowaniu infrastruktury kolejowej. Bazując na generalnych wytycznych pozyskiwania danych fotogrametrycznych oraz poprzednich analizach w skali mikro, opracowano metodykę. Artykuł przedstawia wyniki analizy badań fotogrametrycznych wykonanych na istniejącym rozjeździe krzyżowym podwójnym z iglicami wewnątrz czworoboku rozjazdu, znajdującym się w Muzeum Kolejnictwa w Kościerzynie. Wygenerowany model 3D pozwolił na odtworzenie parametrów geometrycznych istniejącego rozjazdu.

Słowa kluczowe: *Projekt; tor kolejowy; fotogrametria; cyfrowe bliźniaki*

Introduction

Photogrammetry technology is applied in many areas related both to civil engineering and surveying. The development of railway transportation systems necessitates the implementation of new technologies and tools for railway infrastructure design, such as the use of modern software capable of simultaneously incorporating multiple design aspects, including the track layout of existing and planned lines, layout plans, railway profiles and terrain models. Owing to their accuracy and the solutions used for generating 3D models, photogrammetric techniques may improve the entire design process. Additionally, the tools in question may also be even essential, when dealing with specific conditions of the existing state of a particular structure undergoing upgrading. In this article, the authors present the results of their research on the utilization of photogrammetric techniques in railway infrastructure design, employing Bentley Systems' iTwin Capture Modeler software for creating digital twins. The study included the development of the methodology for creating photographic documentation, the processing of the acquired data into digital twins in the form of a 3D model, the integration of the obtained railway infrastructure data into a unified information set. Basing on this dataset, the existing layout of a selected railway infrastructure element was reconstructed in Bentley Systems' OpenRail Designer software.

Literature overview

In order to collect the data referring to the considered topic, a literature analysis was performed. The analysis was based mainly on publications in the form of scientific articles, describing topics such as: 3D models, methods of data acquisition for later usage in 3D modelling and the usage of digital twins data of infrastructure objects in practice. The potential benefits of using 3D models to archive the existing condition, especially in the case of historic buildings, were described in the article [7]. Namely, the Authors used Bentley iTwin Capture Modeler software and presented their thoughts on the data acquisition process. In the article [10] potential ways of using digital twins were shown. In particular, investment areas related to infrastructure facilities were discussed. The Authors of the article [14] made an analysis of current and past investments in the railway infrastructure branch in Germany. Described methods were realized in the form of public procurements and performed using BIM. Based on the analyzed examples, the authors drawn out current practices and proposals of recommendations of BIM usage in investments. The article [8] focused on the requirements that digital twins should fulfil in the case of the railway industry. In the authors' opinion an important question is the possibility of strengthening of dependencies and relations between collected data. Additionally, conclusions and recommendations from the research were transferred to organizations, that use digital twins in their daily operation.

The Author of article [9] focused on literature describing aspects of digital twins in the railway sector. It is worth mentioning that the publication discusses the development of digital twins over the years, the approaches to data integration and the possibility of capturing data using various tools. Consequently, the development of digital twin models in the railway industry was considered. Potential usage in railway infrastructure was also shown. In article [5], the most important challenges in the aspect of digital recreation of railway infrastructure were presented. Digital twins, with the help of the connection between digital models and data, allow the simulation of the object's behavior in its lifetime. An important aspect is that more accurate data is collected during the whole lifespan of the infrastructure object. This allows for more precise system operation, that helps to predict possible problems, which positively impact safety and effectiveness of object exploitation. The Author of articles [2] and [3] focused on the usage of virtual bridge constructions recreation. In both cases, benefits of the recreation of bridge construction were confirmed. Benefits are visible during the object's entire lifespan beginning from construction, the possibility of construction creation control and the early detection of places of potential collisions between branches. Application is also possible during object maintenance, which allows to adjust methods of conservation to the current state of construction.

Aspects of railway infrastructure maintenance were the subject of many articles. In article [1], the authors describe the usage of digital twins to predict rail wear. To model the process, the data about: train, used materials in railway and real results of measurements was used. This way makes it possible to precisely assess the infrastructure behavior in the foreseeable future, which makes it easier to plan maintenance works. In article [13], the authors team created a concept of a system and virtual model, which recreates the railroad fragment with cubature objects. They used tools such as: BIM with 3D visualization, IoT networks, edge computing and deep learning. In the article, the authors focused on data transmission and overflow of specific components of the informatic network. Authors discovered potential benefits of the usage of this specific solution in the aspect of: current planning and maintenance of objects, and construction design. The usage of advanced methods of data processing was also considered by the research team [15]. In the described solution, visualization of infrastructure elements was previously digitalized. Basing on data from laser scanning i.e. point cloud 3D and with the help of dedicated programs, data extraction and interpretation was achieved. Subsequently, the data was enriched with photographic documentation, which enabled realistic visualisation in a 3D model. Methods of creating 3D models that can be implemented in digital twins and ongoing monitoring of the condition of railway infrastructure and space design were also demonstrated.

The usage of advanced methods of data acquisition is also used in railway engineering object inspections. Article [11] describes the use of UAVs (drones) for photogrammetry in the case of infrastructure objects. The use of this method makes it easier to reach hard-to-access places, which can have a positive impact on employee safety and minimise disruptions to rail traffic. However, potential problems with the use of drones and examples of UAVs in use were also highlighted.

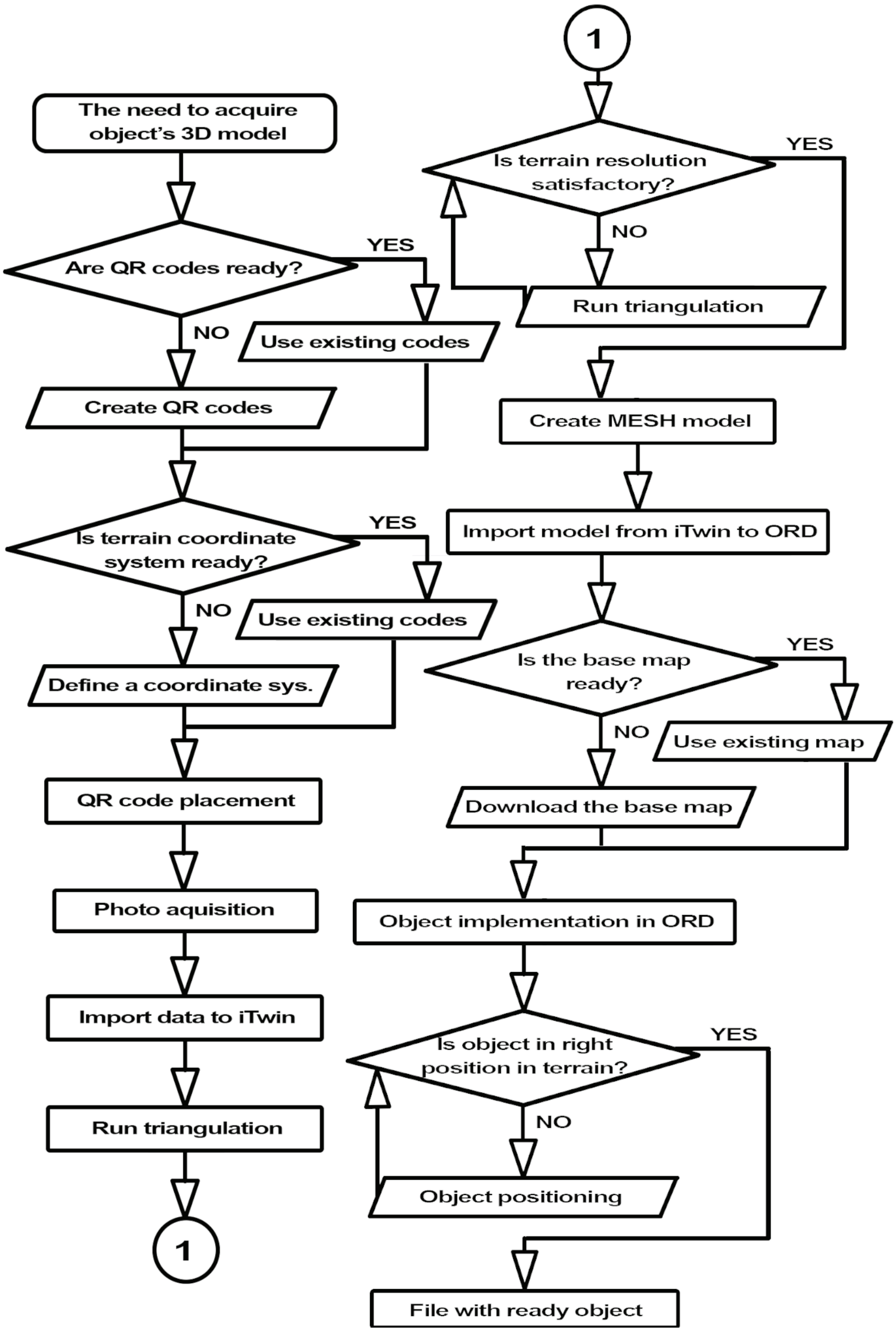
Research apparatus

Digital cameras and devices with a photo function were used to collect data, which was then processed using special software. The parameters of these devices are presented

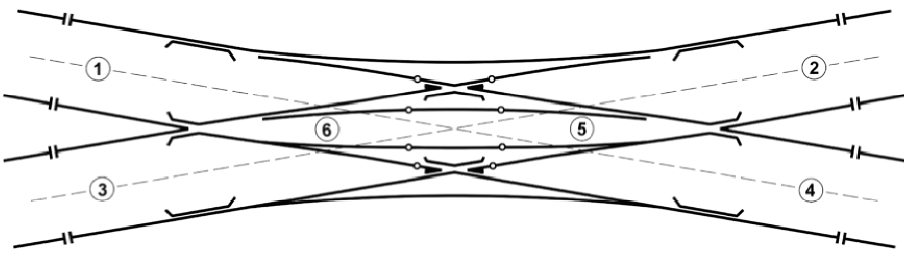
1. Location and image of turnout measured in the article [6]

2. Generated 3D model of a railway miniature model

later in this chapter. To edit the data and create 3D models, the research team used Bentley iTwin Capture Modeler 2024 (version 24.1.6.2220) software, installed on PCs with various components capabilities. Photographic documentation was created using a DSLR camera with a zoom lens and mobile devices (smartphones) equipped with digital cameras. Digital files were saved in .jpeg format. DSLR camera that was used was Canon EOS 80d, used lens was CANON EF-S 18-55 mm f/3.5-5.6 IS STM [4]. The camera was equipped with a small-scale matrix APS-C (22.3x14.9 mm) with 25.8 Mpix resolution. The photos were taken at the shortest focal length of the lens, which was 18 mm. Second DSLR was Nikon D5000, used lens was Nikon 35 mm f/1.8 G AF-S DX . The camera was equipped with a small-scale matrix APS-C (23.6x15.8 mm) with 12 Mpix resolution. Digital files were saved in .jpeg format. In addition, the authors used Samsung Galaxy Note 8 (f/1.8 lens, 1/2.55-inch sensor, 12 Mpix) and Apple iPhone XS (f/1.8 lens, 12137 Mpix) devices to take photos of the test object. During photography session, native screen zoom was used (without digital zoom). Photos made, used for work with 3D model, were not edited in photo editing software. Natural geometrical distortions from optical systems of used devices were left intact.



3. Macro-scale object 3D preparing methodology



4. Location of photographic survey points

Tab. 1. *Aerotriangulation data for point No. 6*

TrailNo.	Photogroup number	Number of photos	Total resolution	Number of automatic tie points	Terrain resolution min.	Terrain resolution max.
1	7	130	1.7 Gpix	6764	0.00210	0.0100
2				6336	0.00054	0.0025
3				6397	0.00054	0.0025
4				6402	0.00054	0.0025
5				6422	0.00054	0.0025
6				6396	0.00054	0.0025
7				6436	0.00054	0.0025

Analysis results

The research group carried out photographic documentation on the premises of the Railway Museum in Kościerzyna, which contains its own track infrastructure. For analysis, a double slip on straight tracks was selected (Fig. **1**). The slip is not in regular use, which made it possible to safely obtain the required documentation. However, the slip also showed signs of significant wear, likely due to the lack of maintenance.

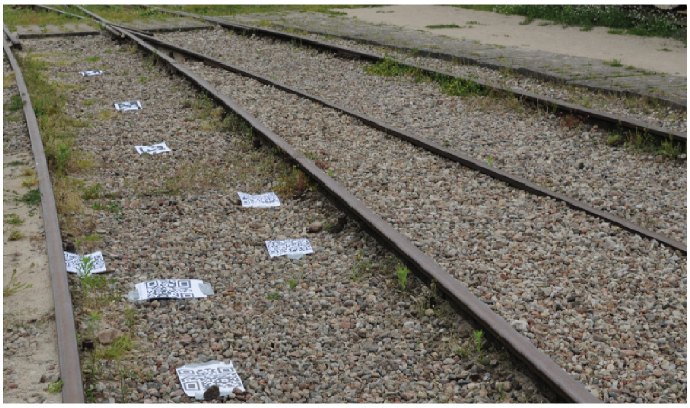
Development of the methodology required for acquiring photographic documentation involved creating photographs and a digital twin at a micro scale in order to determine the requirements for the macro scale. For the micro scale example, two previously printed QR codes were placed 1 meter apart, measured between their centers, to establish the scale for the generated model. Each member of the research team then took a set of photographs of a railway miniature model placed in the Department of Transport Engineering in Gdańsk University of Technology. The photos were taken with varying quantities, angles and distances from the model, with each image differing in these parameters. The acquired photographs were imported into iTwin Capture Modeler to create a 3D model (Fig. **2**).

The created model exhibited low accuracy for small scale objects, such as the buffer stop. However, at the general scale, the outcome was satisfactory. The micro scale tests made it possible to define more precise and improved methods for use in the later stages of the research (Fig. **3**).

The required photographic documentation was prepared by a four-person research team. The slip was divided into six areas (Fig. **4**) in order to organise the process of taking photographs and further design work. The weather conditions during data collecting process were as follows: air temperature 18°C, relative humidity 60%, cloud cover 80%, no precipitation [12]. The existing weather conditions allowed for good visibility and proper photographic documentation. Accounting for weather conditions is crucial, as atmospheric precipitation can result in water droplets settling on the rail surface or water accumulating in some areas of a slip, especially in the crossing. Such factors may cause the reconstructed 3D model to contain errors.
Work in each point began with placing previously printed QR codes in two configurations:

- two points positioned 1 meter apart, measured between their centers in a straight line;
- three points positioned 1 meter apart, measured between their centers, but arranged perpendicular to the central point.

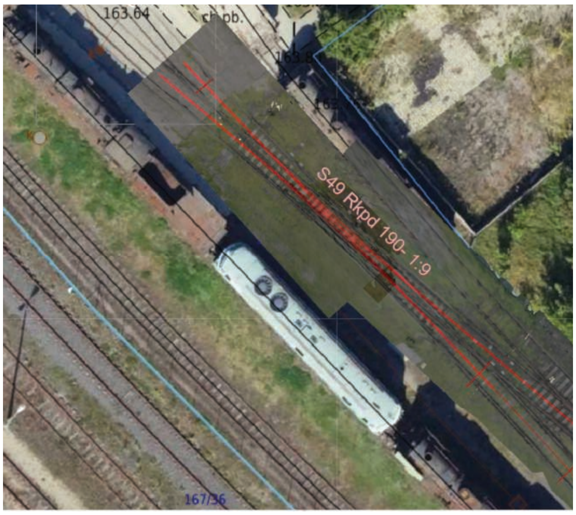
Additionally, AprilTags were placed at a distance from the reference points defined by the QR codes (Fig. **5**). The QR codes were arranged to determine the distance between individual elements and to establish an X-Y coordinate system for further work



5. Example of QR codes and april tags location based on photo from point No. 1

6. 3D model (from one measuring point) made in iTwin Capture Modeler

7. Section of the slip 3D model made in iTwin Capture Modeler



8. Double slip on straight tracks in situation plan

in the 3D model. The AprilTags were used to define fixed points in space. After placing the QR codes and AprilTags, photographs were taken by walking twice around the QR-code layout – first at a closer distance of approximately 2 meters, then at a further distance of approximately 5 meters. Additionally, in several locations, photographs were taken using a smartphone camera, pointing it towards the left rail, the right rail and the sleepers between the rails. The device was oriented along the track centerline at a height of approximately 1 meter above ground level. The photos were taken from two different shooting positions, by one of the authors. Meanwhile, the remaining members of the research team performed photographic documentation from two additional positions and arranged the necessary QR codes and AprilTags in the previously described configurations. The markers were placed on the ground and secured with stones in order to provide protection against movement. On the Nikon device and the smartphone camera, the option to record the devices' GPS position in the photo metadata was enabled. However, due to the unknown accuracy parameters of the devices' GPS modules and the significant variation – exceeding several meters – in the recorded positions, the use of this positioning data was abandoned in the subsequent data-processing process.

The main software used to process the collected data was iTwin Capture Modeler. A standard data-acquisition process was performed: the photos were sorted in the correct sequence, their completeness was verified and information about the photographic equipment parameters was inserted into the program. Next, the aerotriangulation process was carried out multiple times, enabling the determination of photo positions. The control-point reading function was used to establish the scale of the object and the local coordinate system.

Although, the software was able to recognize and read the points from the QR codes on some photographs, most of them had to be entered manually. With each subsequent aerotriangulation, the terrain resolution improved. The terrain resolution was specified with reference to the block's unit of measurement, which in this case was meters. The block parameters for point No. 6 are presented in the table No. **1**. Finally, the slip surface was exported (Fig. **6**, Fig. **7**) as a .3sm (RealityMesh) file.

The procedure carried out and the result achieved allowed the obtained results to be transferred to a designing software. Thus, for further work on the data the tools available in Bentley OpenRail Designer 2024 were selected. Raster map background and surface-terrain files generated in iTwin were implemented. The surface of the entire slip was saved in six separate blocks. This approach was adopted due to the inability for merging blocks that do not contain external georeferencing data. Each block had its own local coordinate system, which prevented the software from combining the generated

9. 3D model made in iTwin Capture Modeler with zoom on turnout elements surfaces. The map background from the Geoportal online service [6] was used to position the slip surface in its real-world location and to verify that the objects' scale was preserved. This approach has been chosen because no coordinate-system data were available in the terrain-surface files. During data collection, the research team did not have access to GPS positioning devices with the required accuracy. To place the created slip area correctly, its position was adjusted using rotation and scaling tools. Once the generated terrain blocks were inserted in their correct positions and the map background visibility was reduced to near transparent, the slip was positioned with the track centerline used as the reference point.

Despite the lack of information regarding the actual parameters of the analyzed slip, the functions available in the program allowed the slip located at the museum site to be identified as double slip on straight tracks with parameters S49-190-1:9 (Fig. **8**). Additionally, basing on the digital terrain model data obtained from the Geoportal online service [6], the profile of the slip was created. If the slip surface in the iTwin software had contained complete georeferencing data, it would have been possible to rely solely on the information collected in the photographic documentation.

The methodology proposed by the authors enables the identification of both the type and the technical condition of individual railway infrastructure components, such as sleepers, rail fastening systems, fishplate rail joints, rail type as well as the condition of specific slip elements including, among others, switch blades and check rails (Fig. **9**). Basing on the generated 3D models, the sleepers were identified as wooden, exhibiting visible wear in the form of surface cracking. The K-type fastening system was assessed to be in satisfactory condition. The rail joints within the slip were determined to be conventional fishplate joints showing noticeable corrosion and a rail gap several millimeters. The check rails and switch blades were captured with sufficient quality to allow clear identification of their condition. Widespread corrosion was observed on all steel components of the slip, including the rails and check rails. Additionally, significant vegetation overgrowth of the slip was observed on the track, particularly in the areas between the sleepers

The methodology may also support the identification of technologies used for joining rails (jointed rail track or continuous welded railtrack), the assessment and degree of ballast fouling and the identification of track components in ballastless track or in level crossings.

Conclusions

Upon completing the research task, the following conclusions can be drawn. When applied to real-world conditions, several difficulties were identified that may hinder the effective use of the collected data. The most significant of these is the need to establish a link to a geographic reference system. To achieve this, the geographic coordinates of know reference points, tie points or the positions of the devices used to capture the photographs must be measured.

The preferred approach is to use equipment capable of providing high precision, such as an RTK system. Consumer-grade photographic devices or mobile phone cameras do not provide GPS accuracy sufficient for tasks of this type. UAV devices (drones) offer more accurate positioning systems, however their use may be restricted or difficult withing railway areas [11].

Having precise geographic position data makes it possible to merge multiple blocks into a single, larger area. This feature is specific for Bentley iTwin. It also enables the imported data to be used, for example, in GIS systems for further terrain visualization. Due to the nature of the software, which fundamentally operates on the principles of photogrammetry, the most critical elements are the photographic documentation and the placement of reference points in accordance with photogrammetric guidelines.

During data collection, QR codes were used as control points, however, to be successfully decoded, they require to be photographed with high resolution. Many of the points placed in the field were blurry or obstructed by track components or vegetation, making their identification in the model difficult or, in most cases, impossible. To avoid this, it would be advisable to change the surface on which the codes are placed or to use control points in another form, such as posts or survey poles.

When creating multiple blocks of a single object, the transitional zones between these areas are particularly important, as errors in terrain representation may occur there due to insufficient photographic data.

A major advantage of photogrammetry based data collection is the speed of acquisition. A consumer-grade photographic device and proper operating technique are generally sufficient. Another critical factor is the IT infrastructure, which must provide adequate processing power to handle large data sets. However, in some cases, even non-specialized hardware may be sufficient for smaller tasks. The iTwin software allows the computational engine to be installed on a server or operated through a cloud-based service, which can help to offload processing from individual devices.

Based on the presented method, it is possible to reconstruct the geometrical layout of a specific slip. During the research, it was observed that the solution also enables the recreation of a track axis layout. The presented methodology has the potential to be utilized in the concept design process. Current cartographic elaborations available to obtain from public institutions are not yet in the form of the 3D elements that would assist the BIM modeling process. Thus, it is understandable that infrastructure designers are currently seeking more effective solutions for 3D design.

The concept of using photogrammetry based software appears to be a promising direction for terrain measurement and design, particularly in the context of railway infrastructure. Although more accurate and reliable geodetic measurement methods are currently available, there are specific applications, such as inventory surveys, where the capabilities offered by Bentley iTwin may be sufficient for performing such tasks. Currently, it is not a universal or error-free solution, but over the time there is a possibility that the methodology will gain wider popularity across various fields.

Summary

The aim of the presented research was to assess the possibilities and scope of using iTwin Capture Modeler software in railway infrastructure design. The research carried out by the team of authors included the development of a methodology for acquiring, processing and using photogrammetric data. It was found that the software could be used to support an alternative method of determining the geometry of a railway object and as an alternative to traditional map bases. In order to improve the method, it would be necessary to determine the exact geographical positions of photographs and control points, and to use the possibilities of taking photographs with advanced photographic equipment and other techniques, including drone flights or laser scanning. ◀

Source materials

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