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Three-dimensional laser scanning for structure documentation and construction management: A case study of renovation and rebuilt of metro tunnels

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ABSTRACT

The dynamic development of modern technologies allows the construction of devices that change the current approach to the design and inventory of buildings. The Terrestrial Laser Scanning (TLS) of large-scale objects improves the existing state's documentation and the building reconstruction design phase, especially in the interdisciplinary Architecture, Engineering, and Construction sector(AEC) approach. Understanding these applications' wide range of technical requirements and considerations is crucial in projects. This research aims to investigate the validity and quality of using TLS for the structural expertise of a metro tunnel. The analysis exploits and focuses on laser scanning technology applications for testing the analysis accuracy of monolithic concrete walls in a building of extended length. The study results indicate that the technological advancement in Building Information Modelling (BIM) presents extraordinary opportunities for AEC professionals to use laser scanning in a holistic, collaborative workflow based on 3D model-based design and data quality.

1. Introduction

The Architecture, Engineering and Construction (AEC) industry can be characterised by high labour intensity, which follows high safety risk and low productivity [1,2] compared to other business sectors. Modern methods of managing building infrastructure facilities are forcing researchers and contractors to use increasingly accurate practices for designing and facilities management. The existing facilities management is of utmost importance in the AEC sector, especially in sustainable business [1,2]. This is related to the possibility of using both Building Information Modelling (BIM) applications and sensors to check the quality of the work and its defects. The examination of the latter is particularly important for retrofits and extensions of existing structures, especially in adverse conditions or linear objects that are difficult to measure traditionally, such as old bridges [3], motorways and railway infrastructure or underground tunnels [4,5]. The ability to shape detailed three-dimensional (3D) models, especially in a BIM environment, allows access to a centralised database, enabling design, coordination and exchange of information in the whole course of a building's lifecycle without loss of data quality on each element of the building [6–10]. Accurate and relatively quick examining the structural health of engineering structures, especially in assessing the risk of static work changes, is critical in determining the structure's safety.

Moreover, using this data in the design documentation enables interdisciplinary collaboration between the architect and the structural designer and with other specialists. These 3D data typically have a parametric character. They are applied in rapid design generation, assembling and assessing information in planning, decision-making, estimating the costs, and tracking the material distribution [11–13].

In the construction industry, the Quality Assessment (QA) of existing buildings is implemented to prevent potential problems by identifying the structural condition of the as-built construction. Implementing QA might minimise the safety-related construction risk and guarantee the project's service life and economic value [14,15]. More buildings were produced in the 21st century than in all previous centuries. The requirement for maintenance and the reconstruction of existing structures to meet new demands has become one of the main areas of research in building management [16,17]. The development of technologies

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allowing contactless sensing techniques to monitor civil structures has become one of the research areas in recent years [18]. The 3-dimensional point cloud has become more precise and ready to use in the AEC sector, mainly in 3D reconstructions, geometry quality inspection, construction progress tracking, performance analysis and safety management [19,20].

The paper aims to analyse the potential of Terrestrial Laser Scanning (TLS) possible usage in the AEC sector. The case study outlines where these tools can be applied to improve the development of project documentation. The structure is designed as follows: the first section provides an overview of the problem and the research question. The next is an overview of the state of the art and research on TLS for structure documentation and construction management. The following section examines the methodologic approach to structural deformation assessment in buildings designed for rebuilding. Next, the results are presented and discussed further. The conclusions summarise the usage of TLS in the AEC sector, especially in reconstruction designs, with the study limitations and further necessary research indicated. The methodology of this paper employs the literature review research and a case study on the condition survey of the existing structure of the metro tunnel.

2. Research question

Using professional AEC sector appliances such as TLS and their application in Building Information Modelling (BIM) presents extraordinary opportunities to enhance the designing and management process. The main research questions of using TLS in architectural and structural designing and construction management are: (1)what phases can be improved by TLS, (2) to what extent does TLS improve the quality measurements of already existing objects, such as metro tunnels, (3) how BIM can be enhanced with the usage of structural analysis based on 3d cloud point?

Providing the answers how to obtain the answers to above questions, the TLS was used in the project of rebuilding and renovating the oldest metro station in Warsaw. Under the design of extending its capacity to train turnaround, the station presented an excellent example of an old building that needs to be thoroughly identified to prepare the rebuilding documentation. The research aims to answer to what extent the TLS technology can enhance and improve the designing process of such an interdisciplinary object, which connects architectural, structural and installation designs.

3. Background/Literature review

3.1. Laser scanning technology

Three-dimensional laser scanning technologies can acquire the surrounding area's data by adjusting it to 3D point clouds, where each point receives X, Y, and Z coordinates. When comparing the available Terrestrial Laser Scanning to traditional methods, a significant improvement in the precision and resolution of the results is apparent [21]. Research work related to the shaping of 3D models from a point cloud of existing objects concerns, algorithms for removing erroneous drawings and combining the point cloud into a 3D image, structural analyses of load-bearing elements, and the possibility of generating BIM models.

TLS allows for a simplified inventory procedure for complex architectural details and the structural analysis of existing buildings [22], even in difficult-to-access engineered structures [23]. Data collection from scanners mounted on a fixed tripod allows precise information about the geometry of the points of the building under study. An additional advantage of 3D scanning is the information about the intensity of the laser light beam's reflection, i.e. the surface brightness, which makes it possible to obtain a 3D view of the surveyed object, also in colour [24]. The number and accuracy of measurements depend on the density of the point cloud and the number of scanners performing the measurements. Reduced measuring time is a significant advantage of TLS. The survey takes only a few minutes, depending on the point cloud's density. The digital representation of a point cloud is created from the superposition of all points made by independent scanners after mutual orientation in space. Software used to assemble and prepare the object model are Autodesk's ReCap and Faro's Scene. Fig. 1 compares a view of the inside of a metro tunnel taken with a traditional photo (Fig. 1a, 1c) and with the Scene program (Fig. 1b, 1d). An advantage of using Faro software is the ability to check all the dimensions of the objects since all points from the cloud have their coordinate parameters preserved in 3D.

3.2. Current research and development

The use of technologies that support the design and the monitoring of the multiple functions of facilities in the AEC sector is being researched, particularly in the application of BIM. These technologies vary from basic monitoring and managing construction to preparing detailed documentation [25]. With the ability to create a point cloud within minutes and with mm level and below accuracy, this technology allows for usage in Architectural Engineering Construction and Facilities Management(AEC/FM) [26], enabling detailed documentation, construction monitoring, precise detailing of architectural details, cultural heritage records and urban scale facilities.

In construction, the technology is mainly based on developing model-based solutions, with which it is possible to create 2D drawings based on point cloud scanning. The joint use of TLS and BIM in structural design and rebuilding improves the as-built documentation and construction quality control. The TLS and BIM application presents the 'Scan-to-BIM' and 'Scan-vs-BIM' approaches. The former involves generating BIM 3D models from the actual point cloud. The latter compares the actual point cloud and the BIM model. An essential feature of the use of TLS technology is the possibility to carry out measurements in difficult-to-access and also complex engineering structures such as metro tunnels [27,28], where surveying becomes much more complicated, and the cost of the equipment often exceeds the use of scanning, without achieving results as accurate as with a point cloud. The table below shows the main research themes related to using TLS in science (Table 1). The most relevant research based on TLS technology, linked with the case study research, concerns the usage of point clouds to conduct a structural analysis of existing constructions. The structural analysis based on TLS is conducted on heritage buildings, such as The Ariza Bridge in Spain [29], large-scale facades [30], BIM-enabled measurements of steel frames [31] and cracks detection in building walls [32,33] support the need for exploring this technology mainly in a complex structure.

3.3. Case study object history

Warsaw Metro is Poland's first underground train system [58]. There are currently 36 stations plus one technical station (TS) on the north–south line (M1) and the one connecting the left- and right-bank parts of the capital (M2). Further stations on the upper west-east (M2) and lower east–west (M3) lines are in the planning and construction phase.

The history of the Warsaw Metro dates back to the interwar period (1918–1939), when the first resolution was made in 1925. Unfortunately, the state of the economy and the subsequent World War II interrupted the planning of this investment. The project was resumed in the'80 s thanks to signed cooperation with the USSR. The first 11 km section between Kabaty and Politechnika stations was opened in 1995, and in 2008, the construction of the remaining M1 line was completed, now comprising 21 stations and 23.1 km in length. The expansion and rebuilding of the metro have become crucial factors due to increasing traffic volumes and growing problems with access to the city centre. The current infrastructure does not allow for increased train volumes [59]. Therefore, rebuilding and renovating the existing infrastructure

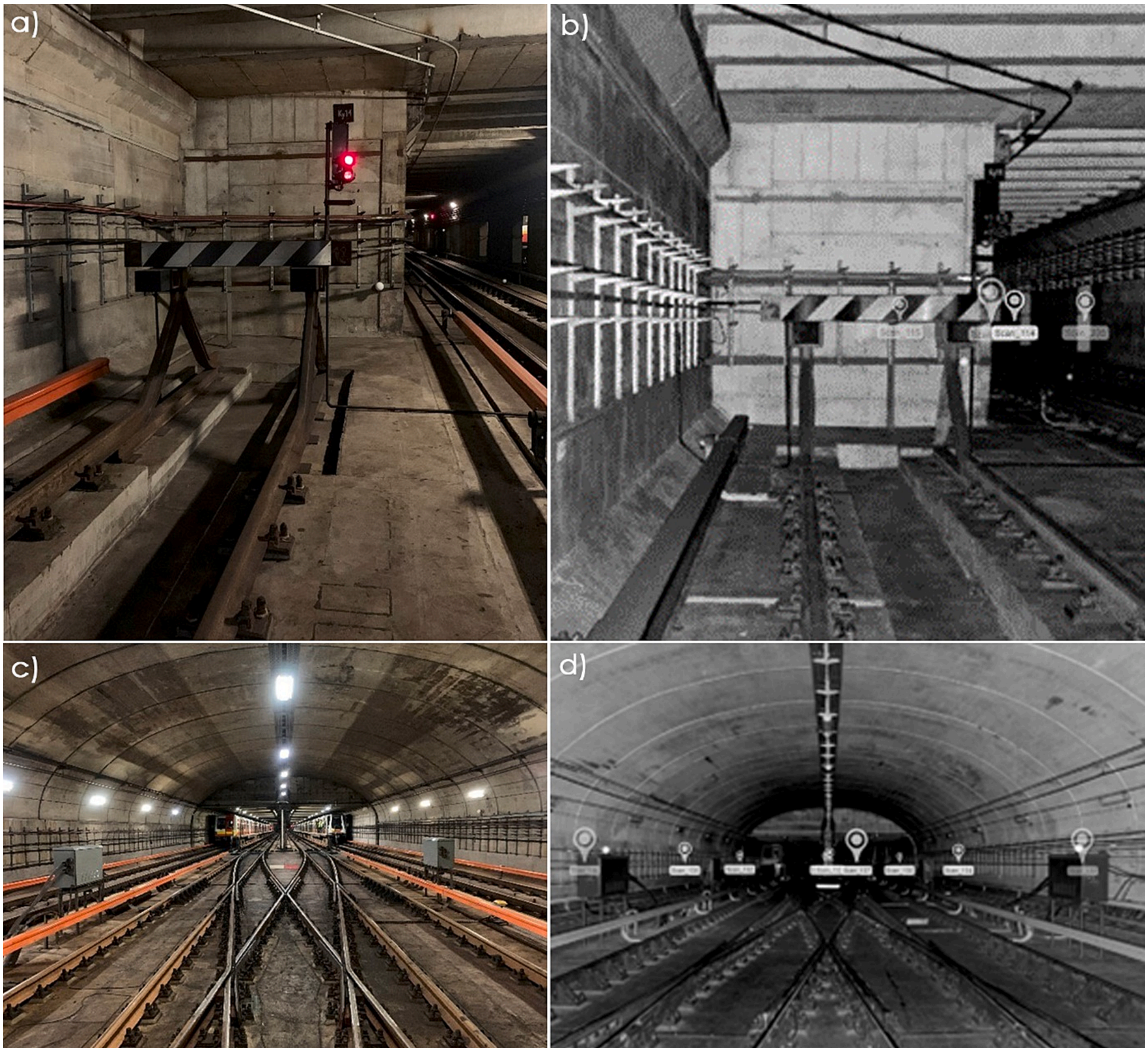

Fig. 1. Comparison of view quality differences of metro tunnel: (a), (c)) with 2D images and (b), (d)) terrestrial laser scanning results using Faro from a 3D view from the point cloud - possibility to count distances between points in real-time (authors' photos).

Table 1
Studies focused on the application of terrestrial laser scanning technology in structural quality assessment (QA).

Reference	TLS Research Subjects
[34–38]	Acquiring the data from terrestrial laser scanning (TLS)
[37–42]	monitoring historic and heritage buildings
[43–52]	Measuring Construction activities/Structural Damage Assessment
[35,53–57]	Acquiring terrestrial laser scanning data to BIM models (Scan-to-BIM)
[52,56,57]	Scan-vs-BIM

between A1 Kabaty station and the tunnel leading to Technical Station (TS) is necessary to enable more efficient stock.

The TLS survey is a part of the planned investment that consists of expanding and reconstructing the track system within the A1 Kabaty subway station and the tunnel behind this station, with tracks leading to the Kabaty Technical Station (KTS)located further away. The Kabaty station is at Aleja Komisji Edukacji Narodowej in the Ursynów District of Warsaw.

The project aims to reduce the turnaround time of subway trains that end their run at A1 Kabaty station and set off again towards A23 Młociny station. By reducing the turnaround time, it will be possible to increase the frequency of trains on Metro Line I and thus increase the number of passengers transported daily. Achieving the assumed objectives of the investment will contribute to reducing car traffic in the city, which is a significant source of noise and emissions of pollutants and greenhouse gases (GHG) into the air. Implementing the project in question aligns entirely with the City of Warsaw's pro-environmental policy. Improving the quality of transportation in the capital is becoming an urgent problem contributing to the growing amount of smog in the city centre [60].

The analysed investment will contribute to the improvement of zero-emission transportation within the capital city of Warsaw. It will increase the frequency of metro trains, thus increasing their capacity. Increasing the share of travel utilising electrical motor vehicles (which includes the subway) results in a decrease in noise and GHG emissions, i.e. has a positive impact on acoustic conditions in the urban environment, the climate and the state of air quality. The implementation of the project is in line with the policy of reducing the environmental impact and adapting to climate change. It should be treated as a pro-environmental investment, which will positively impact the environment during the operation phase.

4. Materials and methods

4.1. Case study purpose

The subject of the TLS case study was the metro tunnel of the A1 Kabaty station and KTS, located in the southern part of Warsaw, Poland (Fig. 2). The measurements were carried out following design studies for the rebuilding and reconstruction of the technological part of the tunnel. The under-analysis structure started service in April 1995 as the starting station of line M1. Due to the required increase in train traffic, an extension of the stand-off track line and two connections between the rails were designed to speed up the trains returning and increase the metro traffic capacity. The use of TLS technology to take accurate measurements was essential due to the ability to take fast and precise measures. The Warsaw metro operates continuously, with the only technological break between 1 and 4 a.m. TLS technology was the superior technology that offered the possibility to take accurate measurements at night without stopping the metro operation for passengers. The test site is constantly used as a space for returning trains, so taking measures could not take up the entire time of the metro's technological break.

As the technical documentation was produced in the'80 s, it was necessary to thoroughly analyse the structure's existing condition. Preparing documentation that meets current requirements and checking the structure's technical condition in terms of deformation and the possibility of using the current structure in extensions and conversions was essential.

As of today, the A1 station's operating technology is as follows. After arriving from the A23 Mlociny station, trains stop on track 2 near the passenger platform (western platform edge). After the passengers have left the train set, they descend into the layover tracks. If they are directed to the KTS, they continue to move on track 2. They can also move on track 3 or 4. If directed toward the A23 Mlociny station, they go down to track 3 or 4, depending on their availability. Then, after changing cabs, they are substituted on track 1 near the passenger platform (eastern platform edge) and continue heading to the destination station.

It should be noted that from a traffic organisation point of view, there is a collision situation during the exit from track 2 to track 3 and from track 4 to track 1. The respective runs are conflicting, and it is impossible to implement the exit run simultaneously. This situation has a significant impact on the length of the train succession time. Tests carried out thanks to TLS technology are expected to check the quality condition of the walls of the part that will be subject to expansion, contributing to a reduction in the turnaround of trains to 90 s (currently, this time is, on average, 130 s longer). Studies of the impact of the expansion of the A1 Kabaty station of Metro Line I were conducted by employees of the Warsaw University of Technology [61]. The ongoing design work is expected to streamline how the metro works and allow it to carry more passengers, especially during rush hours, by relieving the burden on vehicular transport on Warsaw's streets.

4.2. Metro tunnel details

Station A1 is located on the Avenue of the National Education Commission, under the intersection with Wąwozowa Street. The

Fig. 2. Warsaw metro plan of all stations, running and design [access: 18.08.2022, Source: https://commons.wikimedia.org/wiki/File:Plan_systemu_metra_w_Warszawie.svg].

beginning of the station (hm − 4 + 01.76) is located about 250 m south of Narrows Street, and the end of the station (hm + 1 + 92.0) is located about 290 m north of Narrows Street(Fig. 3).

The rebuilding and development of part A1 and KTS are under redesign to ensure the smooth return of trains on the long tracks (Fig. 4). There are three rails which connect station A1 with KTS and one technical rail which ends in the connection between those two technological parts. Extending this one rail by 36,0 m and creating two additional cross-connections between the rails and the technical platforms improves the capability of trains' returnability. The hall with the passenger platform will be left unchanged. The stand-off rails consist of two technical platforms and four tracks separated by a row of reinforced concrete pillars; the station is approximately 17.2 m wide.

At the end of station A1, after extending the station body by 36.0 m, a cross-connection between tracks 1 and 3 was designed. Track B1, located behind station A1, has a straight section about 100 m long, which rises slightly upwards. The tunnel continues with three tracks separated by a reinforced concrete wall with technical openings (visible in Fig. 7). The width of the tunnel at this point is 13.42 m.

The examined length of the tunnel is 107.96 m.

The structure of the trail tunnel at this location is the longitudinal wall. It consists of two aisles of different spans, an eastern one that is 4.60 m wide (subject to survey) and a western one that is 8.50 m wide, which partially widens to 8.80 m at the length of 9.0 m.

The outer and inner walls of the tunnel were made of reinforced concrete and had a thickness of:

– east wall 0.4 m
– central wall 0,35 m
– west wall 0.5 m.

The ceiling is made of precast reinforced concrete 'T' type slabs. The height of these structural elements in the east aisle is 0.6 m, and in the west corridor, it is 1.1 m. The slabs are supported on short cantilevers that form part of the tunnel wall structure. The floor slab structure has been braced by flooding the slabs with a top concrete layer with a maximum thickness of 19 cm. This concrete also forms a sloping waterproof layer. 72 precast 'T' type floor slabs were laid in the east aisle under analysis, designated PS-3.5–450/150/60.

The reinforced concrete walls were monolithically connected to a 0.6 m thick reinforced concrete foundation slab.

The tunnel in the section described is straight in the plan. The difference in the ground level between the surveyed ends of route B1 is 1.35 m. The structure is divided by two dilatations. Each section is 36 m long. Only the first section located at the junction with station A1 is three centimetres shorter.

4.3. Case study

Investigations of the technical condition of the structure concerning the support structure of a metro tunnel were carried out based on three phenomena that reduce the durability of the concrete system: active water leakage of the tunnel, scratching and deformation of the tunnel envelope. The subject of the present article is the latter phenomenon, which was investigated through a 3D scan. The structure study was divided into four main phases, according to the workflow in Fig. 5.

The structure in the technological part of the tunnel is bare of finishes so that the technical condition of all reinforced concrete and steel structural elements is well visible. In this part, the tunnel construction consists of monolithic reinforced concrete elements such as eastern and centre walls. The ceiling slabs are made as precast 'T' type slabs. The foundation is a monolithic reinforced concrete slab of fixed thickness.

Straight lines describe the walls in plan in the individual dilatation segments with one or no bends. In each cross-section, all walls are mutually parallel (eastern and middle walls).

The structural height of the tunnels is constant along the entire length and is 4.85 m clear height from the floor and bottom slab.

The study of tunnel deformation was carried out using terrestrial laser scanning. A FARO Focus scanner was used for the measurements. Fourteen omnidirectional scans were performed, and a single scan varied from 1.5 min to 2.5 min. The survey was carried out over a length of 107.96 m. Deformations of the external east and the central walls were investigated. The 3D point cloud model was prepared, and designers had access to 3d views based on Autodesk ReCap Pro software. The preparation of such a 3D model was crucial to preparing a technical survey of the 2D plans and section and preparing the structural analysis of the reinforced concrete load-bearing elements before the planned renovation. The 3D model based on the point cloud is presented in Fig. 6.

The walls and precast ceiling beams were tested in terms of deformation from erection to current state. The analysis covered vertical deviations, the deflections of the beams, and their horizontal alignment on the short cantilevers.

A virtual reference model was created for the deformation analysis of the tunnel in the IFC format to evaluate the point cloud (Fig. 7). It was created by creating a virtual curve of the cross-section; the curve was standardised for the entire tunnel length. The curve was fitted into the point cloud, the tunnel's vertical slope, and its horizontal courses. Further, a comparison was made between the results from the point cloud and the reference model in the software CloudCompare. Deviations of the actual shape of the tunnel (represented by the cloud) with the reference model were presented in the form of a colourful spatial deviation map in the result section (Figs. 8, 9, 10). CloudCompare enables precise verification of the deviation at a specific point of the tunnel. The original structural design did not describe the maximum acceptable wall and slab deflection. However, in the "*technical specification for the execution and acceptance of construction works,*" there are some maximum deflections given:

(a) spacing of ribs ± 0.5 %, but not by more than 2 cm,
(b) deviation of formwork from straightness or the plane by 0.1 %,
(c) differences in the thickness of the boards ± 0.2 cm,
(d) deviation of walls from the vertical by ± 0.2 %, but not more than 0.5 cm,
(e) bulging of the surface by ± 0.2 cm over a distance of 3 m,

Fig. 3. Location of the under-analysis region (red rectangle) in the KEN street and the Metro entrances (black triangles).

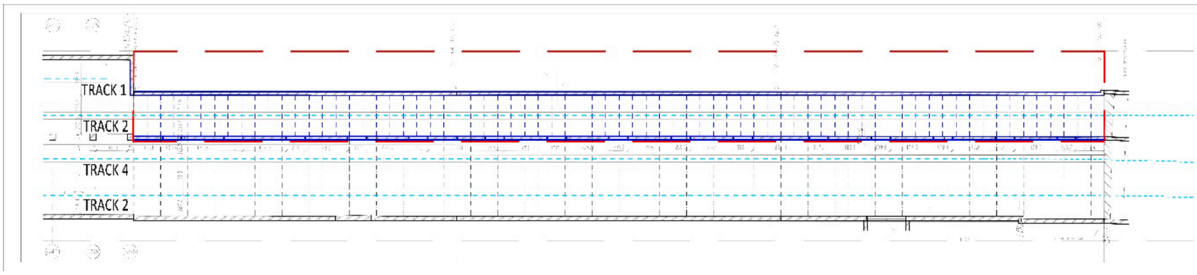

Fig. 4. Plan of the surveyed section of the underground tunnel, the dashed line shows the extent of reconstruction, and the blue colour indicates the elements of the structure subject to analysis.

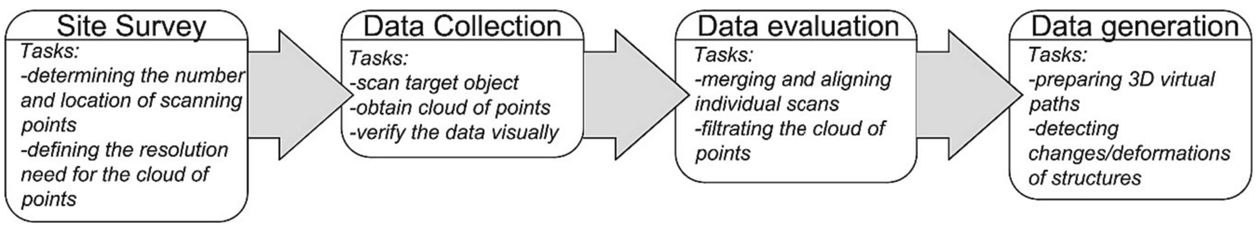

Fig. 5. Workflow for terrestrial laser scanning project.

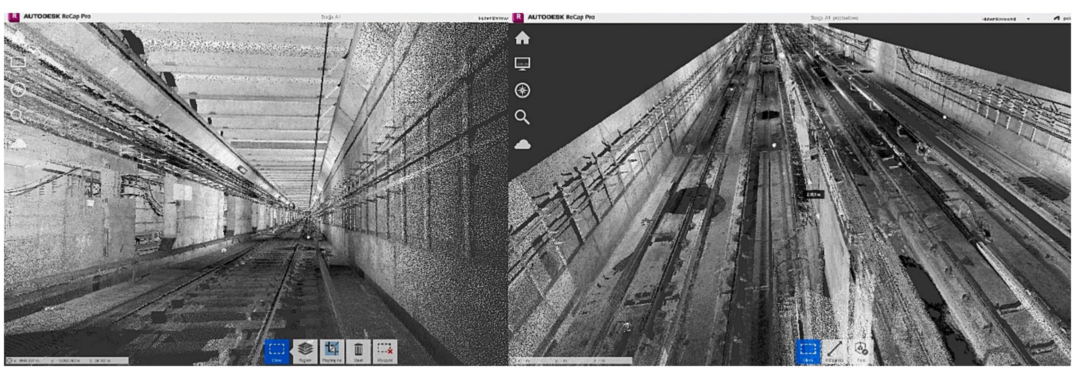

Fig. 6. Point cloud viewer in ReCap Pro soft.

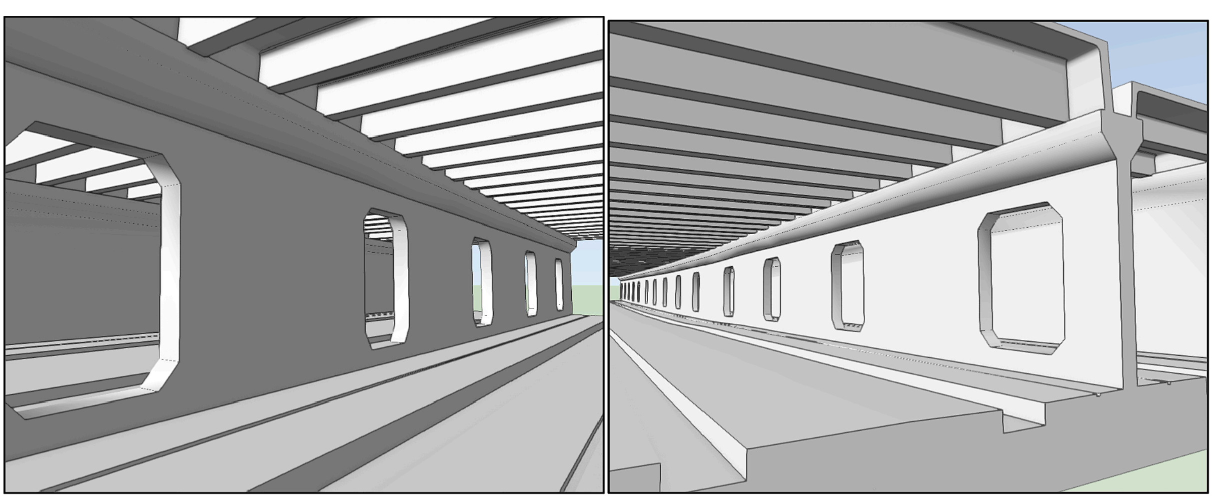

Fig. 7. Refferal IFC file built on point cloud (software: Vectorworks, authors compilation).

(f) deviation of internal dimensions of formwork (concrete sections):
 – 0.2 % in height, but not more than −0.5 cm,
 – +0.5 % in height, but not more than + 2 cm,
 – 0.2 % of a thickness (width), but not more than + 0.5 cm.

5. Results

Visual examination showed that the concrete is smooth, without cracks, cavities or dampness. There is no reinforcement or effect of

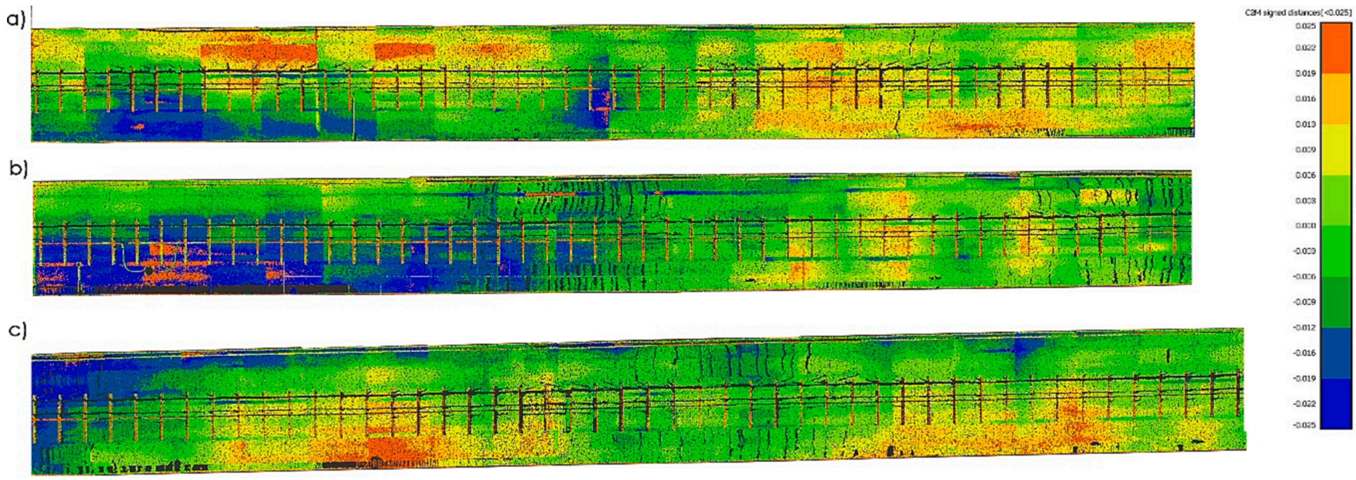

Fig. 8. Deformation analysis of the eastern external wall, a) section from the A1 station side, b)middle section, c)section from the KTS side, on the side deformation legend.

concrete carbonation visibility. The reinforcement cover is preserved, and no other damage is visible. Small cracks caused by dynamic forces from moving trains are visible. These cracks do not propagate into the foundation slab and do not affect the structure. The visible elements of the steel brands used for prestressing the prefabricated floor slabs show progressive corrosion. They do not require replacement, only maintenance, which is typical of this construction element.

The results of the deformation test of the tunnel partitions performed with the TSL did not show excessive deflections. All given deflections do not exceed the maximum deflections given in chapter 3.3. However, unevenness due to the inaccurate positioning of the beams on the walls is evident. Some of the beams' bottom sides do follow the horizontal course level. Structural analysis based on Eurocodes detected that for the given structure the maximum deviation of the deflection could not exceed 3.025 cm. The variation occurring in the walls does not exceed the given max deflection, receiving a maximum value of 0,025 cm (Figs. 8, 9, 10). The eastern (Fig. 8) and central (Fig. 9) walls are straight and vertical, and no long-term deformations resulting from the creep of concrete subjected to constant soil pressure loading were detected. Unevenness is evident, resulting from the imperfect formwork technology used to construct the walls. Significant faults in the wall surface occur at the dilatation joints. A technological break in the concreting of the walls at the height of one metre is also visible. The faults between the individual wall sections vary within a range of 5 cm. These deviations do not affect the static operation of the walls. The technical condition of all elements comprising the structural system of this part of the tunnel is good.

Using the 3D models created by the point cloud as information on the structure's visual condition allows the architect to develop as-built documentation. Moreover, it allowed the development of documentation on the quality condition of the system: the deformation maps shown in Figs. 8-10 show not only the exact values but also the deflection trends and the areas potentially at risk of damage.

6. Findings

The findings of this study show that the use of TLS contributes to accurate measurements of complex and challenging engineering structures, which until now could only be diagnosed using expensive and time-consuming geodetic methods. TLS measurements allow for the precise analysis of existing engineering infrastructure and quick construction of existing facilities. This is particularly important when measuring engineering structures of considerable length and varying depth, as in the case of a metro tunnel. Thanks to point cloud analysis, the analysis of the load-bearing structure allows a general indication of the quality of the system and global deformations but also the investigation of whether local anomalies and overstressing of load-bearing elements occur. Accessibility and time management are vital components of designing and measuring construction activities. The surveys did not interfere with normal metro operations due to taking measurements at short notice. They could be carried out within a four-hour window of metro downtime (preparation and dismantling of equipment, location of scanners, data collection). Comparing the research found in the literature review with a metro tunnel, it is clear that in each case, using TLS technology helps in fast and accurately collecting data about the structural performance of the buildings, which are very

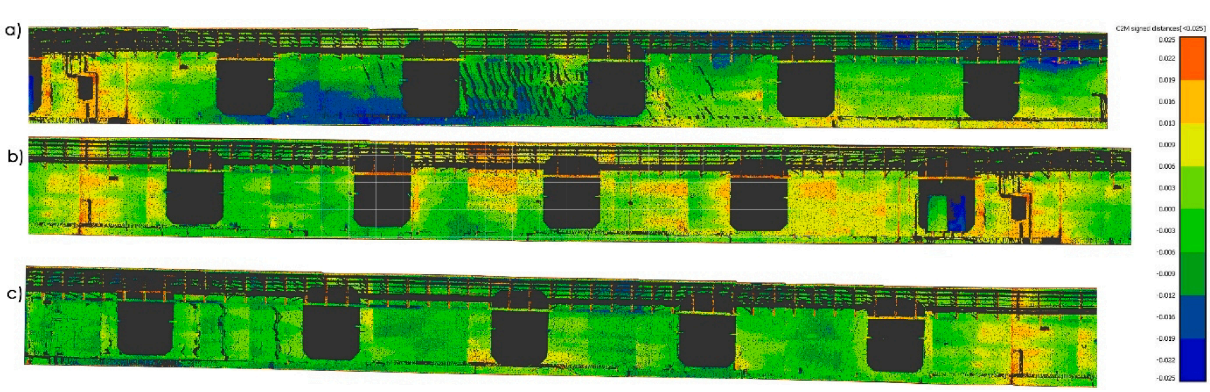

Fig. 9. Deformation analysis of the inner wall, a) section from the A1 station side, b)middle section, c)section from the KTS side, on the side deformation legend.

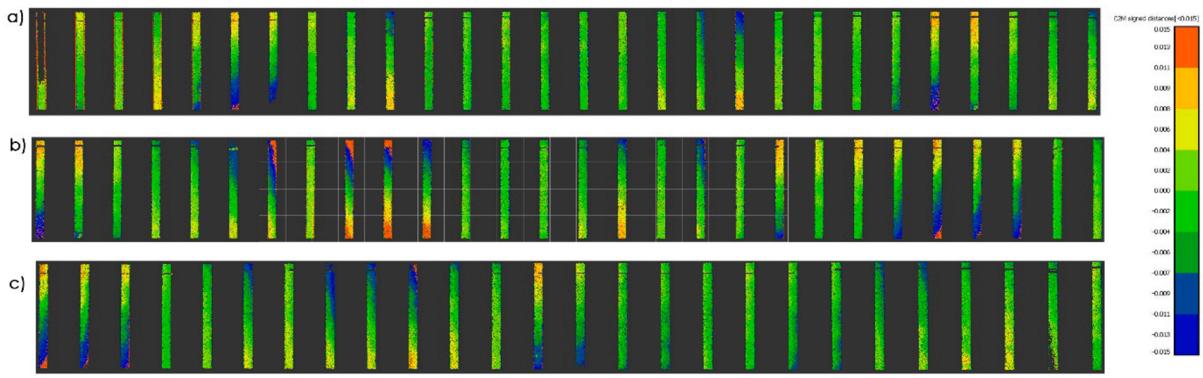

Fig. 10. Deformation analysis of floor beams, a) section from A1 station side, b)middle section, c)section from KTS side, right deformation legend.

complex or challenging to reach. Linear structures, such as metro tunnel technological stations, are challenging to measure, especially because of the analysis of linear deformations of load-bearing elements and height differences of railway installations. In addition, the development and increasing accuracy of TLS tools will increase their popularity in the AEC sector and geology. Nevertheless, the significant amount of data resulting from point cloud execution still poses problems of time-consuming hours of data analysis and processing, even for simple objects.

In the case of manual measurements, the preparation of accurate inventory documentation is much more complicated. It can contain many inaccuracies that can lead to costly changes during construction with planned rebuilding and revitalisation. Determining the actual behaviour of the underground tunnel's structure is extremely important, especially with additional vibration loads from moving trains.

Furthermore, another reason contributing to the rising importance of TLS in the AEC sector is the possibility of introducing more detailed information about buildings through BIM applications in design [62]. 3D models created from point clouds that can be edited in a CAD environment improve communication between stakeholders, architects, and structural designers. In terms of architectural and structural design, establishing as-built documentation improves the quality verification of the building's quality in subsequent redevelopments. The structure shown in the case study, using TLS analysis, can be easily redesigned to meet more complex needs. For architects, the 3D models created from the point clouds allow them to plan the refurbishment, and for the structural designer, they help to offer an efficient regeneration and redevelopment process.

The use of TLS capabilities in technical projects in the AEC sector significantly accelerates the possibilities of design work, especially in the reconstruction or expansion of existing technical infrastructure of linear facilities. The study of the subway tunnel presented in the article allowed accurate documentation not only of the existing condition of the facility but also of the quality condition of the structural elements, significantly improving the process of expertise and guidance for the following stages of the design of the extension of this part of the tunnel. Interprofessional cooperation, based on accurate elevation data of rebuilt linear elements (catenaries and power grids) and deformation of structural elements, allows for avoiding errors caused by traditional design using archival simplified documentation. Implementing the point cloud in IFC files later in design allows interdisciplinary coordination and catching errors at the design and subsequent execution and management stage of the rebuilt tunnel facility.

7. Conclusion

Modern technology speeds up and facilitates the design of complex structural forms in contemporary architectural design. Modern technology and apparatus's dynamic development unprecedentedly allows structures' design and inventory (architectural documentation and the deformation analysis discussed in this article). The limitations of such actions are still visible in insufficient knowledge among architects and structural designers, insufficient cooperation with the specialists using the TLS technologies, and inadequate facilities for high-speed computers capable of bearing the weight of accurate point clouds.

As shown, implementing 3d scanning in the AEC industry and preparing technical documentation of existing buildings for further reconstruction improves the quality of designers' work. Frequent errors in analysing existing structures, especially linear systems, are minimised, leading to cost savings and time savings in preparing additional studies and documentation at later stages of construction work. However, there is still a lack of standard processes to thoroughly analyse the data results, not just the simplified algorithms available in current software. The still high cost of scanning equipment and the need for computers with significant computing power limits the development of 3D scanning equipment for architectural objects. The possibility of cooperation with BIM software when performing analyses of existing buildings shows that implementing TSL in design work is essential in the era of minimising material consumption and production time and adapting designs to technological requirements. The working time optimisation with TLS can also be seen in the interdisciplinary use of this technology. Thanks to the development of 3D point clouds and the possibility of working with BIM, it is possible to prepare not only construction documentation but also architectural or installation documentation, depending on the project's complexity. The development of scanning technology for the operation of load-bearing structures is continually being expanded to include static deformation analysis and the real-time operation of facilities, including the examination of draughts through RFID (radio frequency identification).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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