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Fachbereich Landschaftwissenschaften und Geomatik
Studiengang Geodäsie und Geoinformatik

Development of the workflow for as-built measurements in infrastructure construction using the BIM technology.

Master thesis

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for obtaining the academic degree

“Master of Engineering” **(M.Eng.)**

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Submitted on: 25.08.2021

URN: nbn:de:gbv:519-thesis 2021-0140-4

Declaration for the Master's Thesis

I confirm that this Master's thesis is my own work and I have documented all sources and material used. This thesis was not previously presented to another examination board and not been published.

Neubrandenburg, 25.08.2021

Place and date

Abstract

The spread development of the digital technologies in the scope of the engineering caused the invention of several methodologies for digitalization procedures. Usage of Building Information Model (BIM) already extends to the application for infrastructure objects. Therefore, a demand in the practical implementation of a BIM for every type of the specific objects is sufficient.

In the current investigation, the main goal is to design an optimal technique of an application of the BIM for built bridges. Based on the project documentation and the field measurements of the object it is needed to recreate a digital model using the Revit software.

In order to research the previous achievements, some scientific articles and proposed technologies were analyzed and described in the Chapters 1, 2. How is BIM for the infrastructure management already developed in many countries? What is a more detailed methodology, named Bridge Information Model (BrIM)? Another important question is, how are old objects going to be digitized in a simple and quick way?

In a chapter 3, a procedure of a preparation of the laser scanner Z+F IMAGER 5016 is described. The calibration on the test field and the monitoring of the axis linearity procedures were completed. The result is shown in the mean error values and graphs. Examined the quality of the three modes of the resolution quality: High, Super High, Ultra High.

Procedures of the data capturing, georeferencing, and modeling are described in the chapter 4, 5, 6. All sequent steps from an area surveying to the visualization and data transfer are presented in the investigation. The TLS and aerial imagery were united and transferred in one point cloud, which was a source for the modeling procedure. Using a Revit software, families and components of a bridge were created. Attribute data were taken from the project documentation, and the newly built bridge model on the B96 road was performed to a BIM with LOD 300. Concerning a bridge on a new B96 national road, was realized recreation of the bridge body inclination and rotation along the middle axis using an add-on for Revit named SOFiSTiK.

Content

List of the abbreviations

BIM – Building Information Modeling;

BrIM – Bridge Information Modeling;

CAD – Computer Aided Design;

CRS – Coordinate reference system;

GNSS – Global Navigation Satellite System;

UAV – Unmanned aerial vehicle;

IFC – Industry Foundation Clases;

LiDAR – Light detection and ranging;

LOD – Level of development;

PS – Phase shift;

RTK – Real Time Kinematic;

TOF – Time of flight;

TLS – Terrestrial laser scanning;

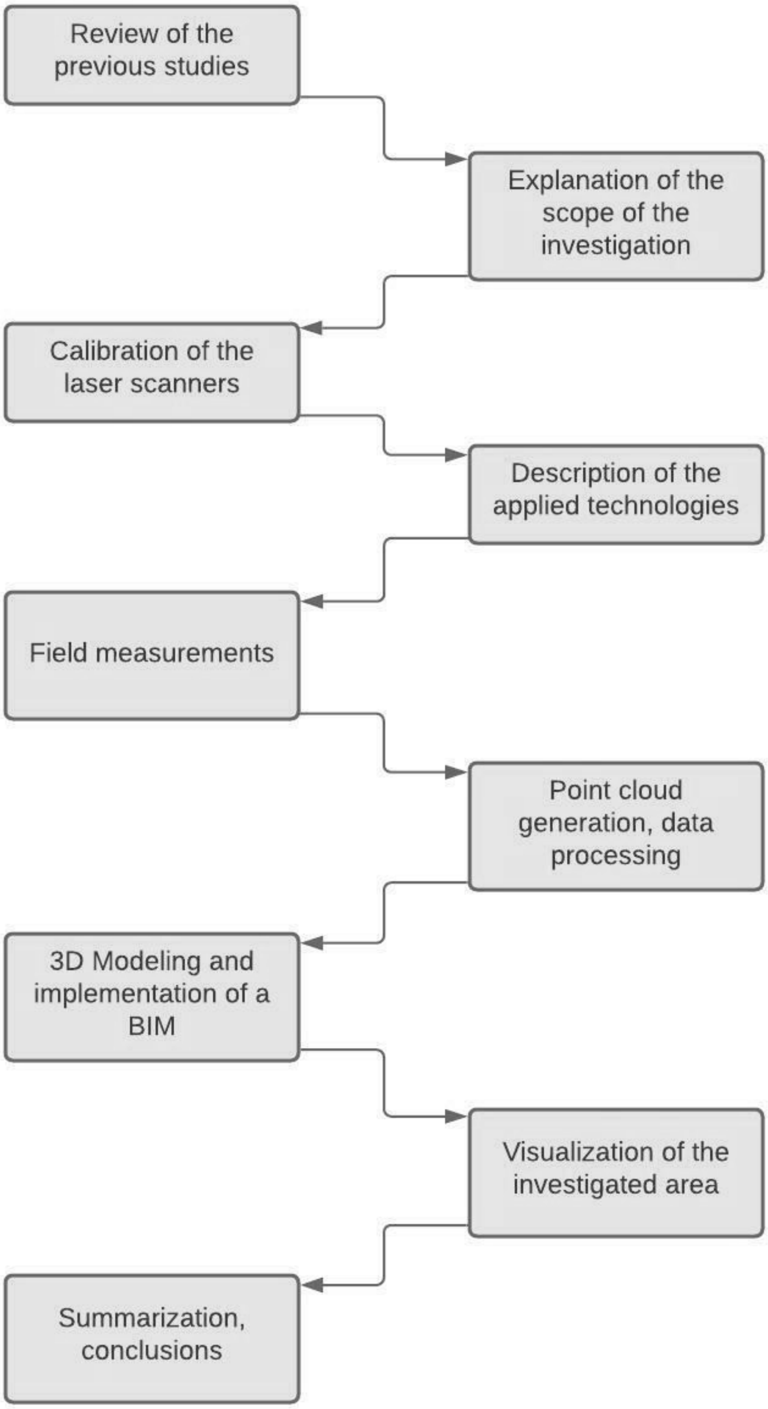
Introduction

Goals and the schema of the thesis

According to the many factors such as the spread of development BIM for different types of the objects, digitalization of planning processes, constant demand in the monitoring, researches in a field of BIM are highly relevant. Design methodology of the BIM for the infrastructure as-built objects on the example of two constructed bridges. The process is divided into subtasks:

- terrestrial investigation of an area of interest. Data capture applying a TLS and an aerial imaging, the georeferencing of surround area to recreate collected data in the selected coordinate system;
- processing of the laser scanning and an aerial imagery data. Evaluation of a terrestrial surveying with respect to the coordinate reference system. Quality control of the point clouds registration, georeferencing concerning the scale of the projecting points onto the earth surface;
- process of a modeling, based on an integration the point clouds captured with using a laser scanner and an UAV. Implementation of the optimal technique to recreate a 3D model of the bridges, further development of the model till reaching requirements of a BIM.
- visualization of a designed BIM model, ensuring a model transfer and integration to the other formats. Investigation of a quality data transfer to Industry Foundation Classes (IFC) format, meaning unification all presented data in BIM.

Schema of the workflow within the thesis



1.1. The laser scanning and 3D modeling

A terrestrial laser scanning (TLS) often named LiDAR (laser imaging, detection, and ranging) is a method of a measuring the distances to the numerous points in a space that belongs to the different objects in a range of view a laser scanner device. The laser scanner emits a beam to the target, which reflects backward. In that way, the laser scanners immediately calculate XYZ coordinates *(Vosselman and Maas, 2010)*. The aim of TLS is a representation of different objects and areas in a three-dimensional system (3D). The methodology of a LiDAR effectively applies in the various fields of engineering and research activities such as a geodesy, surveying, geomatics, and geophysics. As a result of a TLS, high-accuracy 3D models can be designed. That caused rapidly increasing an efficiency of the laser scanners for solving engineering tasks, instead of the classical measuring devices *(Travis & Taylor, 2019)*.

3D modeling is the process of creating a representation of any objects in the three dimensions according to the selected coordinate system *(„3D modeling“, 2021)*. The most associated areas with a 3D modeling are creative industries, but nowadays with growing up the technologies, the 3D is a usual thing in surveying. In the field of engineering, a 3D modeling of a spatial data require a high-precision geometry (size and shape) of the objects, therefore a LiDAR only the one way to reach this condition. Based on a sufficient amount of the scans from various angles and sides, which are merged together, using a special software, a 3D model can be recreated.

Thanks to a LiDAR technology, a laser scanning found a high utility in the construction industry. A high density of the laser beams gets enough data to recreate a detailed 3D model of an object, during the construction period. An obtained model may apply for deformation monitoring, but it is not all benefits of a laser scanning data. With the addition of a required attribute data belonging to every part of an object, a 3D model may be transformed into 4D (scheduling construction) and 5D (quantity and cost calculation). As an outcome over mentioned, Building Information Model (BIM) will be presented *(Gleason, 2013)*.

According to several opportunities of a laser scanning in different industries of application, this measurement technology has found a big efficiency, especially TLS in Architecture, Engineering, and Construction (AEC).

1.2. Types of the laser scanners

Regarding the type of sensor, optical 3D measurement devices distinguish by the passive and the active sensor *(Peresunko, 2019)*. A laser scanning technology works by using an active type of sensor. An electromagnetic waves transmitted from the sensor to the point on a surface, reflect backward and the energy of a returned signal provides the value for further determination of a 3D data (*Chiabrando et al, 2013*).

According to the principle of distance measuring, there are two main laser scanner types: Time-of-Light (TOF) and Phase-Shift (PS). In the TOF laser scanners a beam detector measure the time of the laser pulse way emitted to the target, and reflected backward. The measurement range of this type of scanner is up to 6 kilometers (RIEGL VZ-6000, Fig. 1 a)), but the speed of sending a beam is lower. PS laser scanners measure up to 2 million points per second (Faro FOCUS S 350 PLUS, Fig. 1 b)). In the PS method, the distance measure by the phase difference of the waveforms on the exit and entrance of a beam to the detector *(Spar 3D, 2004)*.

a) *(Riegl, 2021)*

b) *(Faro, 2021)*

Figure 1.1 TOF and PS laser scanners

The scanners with the Phase-Shift method are more sensitive to the detection of a color, brightness, and roughness changes on the surface, which are important for the purposes of a building refurbishment and the creation of a detailed 3D model of an object.

The application of the TOF laser scanners is more varied. Many years before, the performance of the laser scanners depends on a range of measurements. TOF laser scanners provided most valuable devices. TLS with the TOF laser scanners are suitable for the tasks, where the opportunity of a long-range laser beam is required. Topography, mapping, terrain research, and monitoring belong to the industries of application the TOF laser scanners. According to these conditions may conclude, the TOF laser scanners find the best application in Airborne Laser Scanning systems.

In *Suchocki, 2020* a radiometric information of the point clouds provided by the Time-Of-Flight and the Phase Shift types of the laser scanners for diagnostics measurements of buildings was compared. Such parameters as a variation of intensity, roughness, and noise of geometric data were analyzed. The results show the best suitability of the PS laser scanner for such fields of the exploitation.

For an example of comparison the following laser scanners: Trimble GS200 and Leica P20 for civil engineering in the urban areas were analyzed. Procedure of a scanning, technical characteristic, data processing, quality of results, and cost-effect of a rental were compared. As a result, both scanners have not substantial differences in a usage and scanning quality. The rent of Trimble GS200 is lower, while the Leica P20 laser scanner provides higher speed *(Truong-Hong et al, 2014).*

Taking into account the work properties of a laser scanners, selection of the devices directly depend from the purposes of investigation. Therefore, division of the PS and TOF laser scanners is important during preparation and planning of future projects.

1.3. Examples of the usage of the laser scanning technology

Highly precise and long-range measurements allow the application of devices emitting the laser beams for many tasks. There are a lot of types of the laser scanners depending on the field of usage and technical characteristic. Based on the position of devices during the data capture, Airborne Laser Scanning (ALS), Mobile Laser

Scanning (MLS), and Terrestrial Laser Scanning (TLS) can be classified. Moreover, there are a TLS corresponding to air in planes or in the UAVs, to mobile equipment in vehicles or boats such as Simultaneous Localization and Mapping (SLAM). The ability to work at high speed with an accuracy of data capture up to sub-millimeter concerning the low cost of the job gets more benefits than traditional measurement methods *(Rashidi et al, 2020)*. Therefore, one can conclude in the geomatic and surveying: a laser scanner is the most effective measurement device in a relation to the quality of the results, time of work, and cost-effectiveness. Of course, the field of their usage is wide, but not for every engineering task the laser scanners are suitable.

Monitoring of the building's deformation requires high precision measurements, with quality up to tens of millimeters. Today this is one of the tasks which civil engineers solve with an application of the TLS. In *Yang et al, 2017* technology of the TLS for the deformation monitoring of the arch structures was implemented using a laser scanner Z + F IMAGER 5006. Thirteen epochs of measuring the research object were recorded in order to optimize the point cloud. Owing to the post-processing, standard deviation of the surface was reduced by 23%. Approximated surfaces were calculated using a polynomial transformation. As a result, the authors reached a value of 2 mm in a standard deviation of the polynomial surface.

Puente et al, (2012) analyzed the deformation of the motorway underpasses using the mobile LiDAR Optech Lynx system. The geo-referenced point cloud was textured in the QT Modeler software using the parameter of intensity. Geometrical deformation of the underpass was evaluated in Matlab software. According to the created transversal and longitudinal profiles of the 50-th meters length underpass, a deformation is approximately 5 mm.

In *Zeidan et al, (2018)* large structural elements from the two materials as reinforced concrete and steel under the load was monitored by using of the Terrestrial Laser Scanning and applying for the “ANSYS” Program. In the research, Faro Focus 3D laser scanner was used to measure steel and RC elements under the load with 5, 10, 15, 20 and 23 tons. Deformation of the RC reached 26 mm along the mid-span under the pressure of 23 tons, and the steel structure deformation under 35-ton load was 8 mm.

Terrestrial Laser Scanning of the bridges is very relevant at the moment through the quick changes in the construction technologies and technical data of laser scanners. Therefore, a lot of techniques based on the TLS of the bridges, and a monitoring were conducted. High-temperature deformation of a bridge over the Daning river, China with a long-span steel truss arch was performed in the following research: *Chu et al, (2018).* The length of the main span is 432 m, therefore the authors concentrated on a data acquisition using the RIEGL VZ-1000 laser scanner. A point cloud data were analyzed before and after the temperature rise on the area closed to the bridge. As a result, a layout scheme of points for data capture for such types of bridges is proposed. A surface under the deformation was represented by applying NURBS method based on the displacement function of an original surface.

Accuracy of a georeferencing and computation of the deformation while TLS of a dam in Cancano Lake, Italy was performed from the acquired point clouds of two laser scanners long-range Riegl LMS-Z420i and a medium-range Leica HDS 3000. The authors proposed two methods of the deformation computation: the shortest distance between points of a point cloud; the nodes of a regular grid *(Alba et al, 2006)*.

Geometry calibration of the aerial and terrestrial laser scanning technology was performed in *Pfeifer & Briese, (2007).* Deep analysis of technical data such as wavelength, sensors, the principle of the distance measurement, dynamic range, etc. for selected types of laser scanners was completed. In a result of conducted experiments the authors purposed a georeferencing with GNSS Antenna above the scanner in order to reach a high precision. The outcome of the data acquisition was generated Digital Terrain Model (DTM), based on the segmentation and clustering of the scanned point cloud.

Aerial Laser Scanning (ALS) application can provide the opportunities not only in a 3D modeling but also in a research of the earth terrain. A powerful technique in water body exploring is the Airborne Laser Bathymetry (ALB). Due to the combination of the laser scanners and multi-spectral cameras, active and passive remote sensing data are acquired simultaneously. This type of data provides the various benefits for the research in the field of hydrology, ecology, and water management. The modern sensors for ALB belong to the following laser scanners: Leica/AHAB HawkEye III, Riegl VQ-880-G, Teledyne Optech CZMIL Nova, etc. *(Sörgel, 2017)*.

In *Belgiu, (2014)* data from the ALS were used for the Object-Based Image Classification technology widely known from GIS. The goal of the research is the detection of the building types from the ALS data. This technique required a coherent raster input layer, in this case, generated from the ALS point cloud. The ontology of the distinguishing different types building applying an object-based classification was checked. Classification of the buildings based on the following features: extent, shape, height, and slope of the roof. C++ programming algorithm was developed by author to set up the requirements of classification. The task was completed with accuracy directly depending on the size of the building: for smaller objects the higher accurate, for bigger the lower accurate.

According to *Wang, (2019)* Mobile Laser Scanning (MLS) is the most suitable technology to recreate the huge areas in 3D format. The article reviewed and compared some MLS devices from the market. Detailed analysis of the previous research regarding TLS, ALS, and MLS completed, relying on it advantages of MLS were presented. A higher point cloud density and structure capable to move to the place of a MLS over the ALS and TLS. Typical fields of a MLS application are the Transportation Infrastructure Mapping, Building Information Modeling, Utility Surveying, and Mapping, Vegetation Mapping and Inventory, and Autonomous Vehicle Driving.

The usage of a MLS happens during a movement. It requires the high precision of positioning the data from the inertial navigation system (IMU) and global navigation satellite system (GNSS) to be computed immediately. *Liu et al, (2019)* presented an experimental case study of the improving a positioning accuracy in MLS. To reduce inaccuracies in the signal sent from GNSS to MLS was purposed two novel techniques named “robust weight total least squares” (RWTLS) and “full information maximum likelihood optimal estimation” (FIMLOE). As a result, purposed techniques successfully improved the accuracy in the terms of RMS, Mean, and Stdev in the 3D orientations of MLS.

1.4. Origin of the thesis

Application of Terrestrial Laser Scanning for the creation of BIM of the bridge is the main goal of the thesis. Based on previously mentioned examples of the research, were decided to select a constructed bridge over the river as a study object to investigate a workflow of a BIM for infrastructure objects.

As now the world is fully in a process of the digitalization completing in every industry, there is a demand in an application for the new cloud-based technologies. This process is directly concerned with an infrastructure construction. In order to increase implementation of a BIM in Germany, the Federal Ministry of Transport and Digital Infrastructure (BMVI) presented a phased plan for the introduction of a BIM on December 15, 2015. The plan (Fig. 1.2) purposes three stages of the preparation to apply a BIM regularly in the BMVI's area of a responsibility.

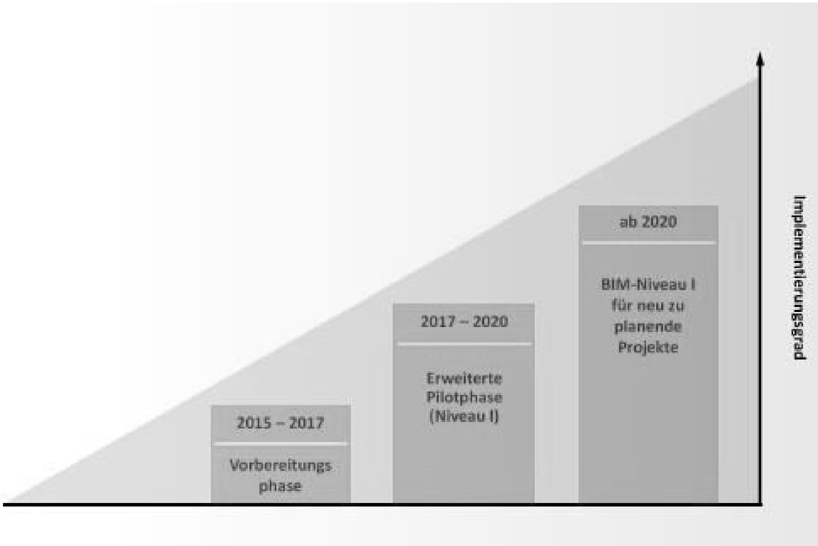


Figure 1.2 Schematic representation of phased plan *(BMVI, 2021)*

Therefore, the selected goal and methodology of the research in the frame of this thesis are highly relevant. According to government statements, mentioned above, we may conclude, that in the future for the planning new objects and for the recreation models of the already constructed objects BIM is going to be mandatory.

Description the scope of the investigation

2.1. Building Information Modeling (BIM)

A definition of a Building Information Modeling (BIM) describes a working method for the planning, construction and management of buildings and other structures with the aid of the software. All relevant building data is digitally modeled, combined and recorded. The projected structure is also geometrically visualized as a virtual model *("Building Information Modeling", 2021)*. According to ISO 19650:2019 a BIM defines as the "use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions"*(British Standards Institution, 2019).*

The spread of the BIM development in Architecture, Engineering and Construction began in the last decades, thanks to the increasing of the computation opportunities, while processing in the three-dimensional space required a huge capacity of the internal memory and RAM, powerful processor, and graphic card. With the additional information about the elements of the projected or constructed object, such as a colour, material, relations, etc. a 3D model transform into a BIM. Moreover, respective to the time and the cost information, 4D or 5D BIM may be reached *(Gleason, 2013)*.

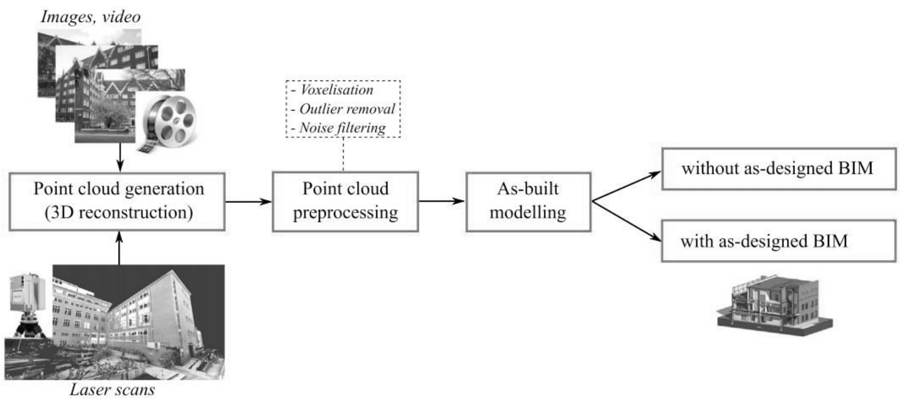


Figure 2.1 As-built modeling processing (*Patraucean et al, 2015)*

Firstly, the use of this technology was concerned with the buildings, as understandable from the name of a BIM. *Patraucean et al, (2015)* proposed a methodology for the creation of an as-built BIM (AB BIM). The article focused on the technology AB BIM generation, applying a laser scanning data (Fig.2.1).

Because of the non-visibility some building elements, are possible to recreate only a reduced version of the complete BIM. Described the following approaches of the generation AB BIM for the recognition of the built building elements and relationships: geometric primitive detection, point cloud clustering, shape fitting, classification. Demand in the AB BIM may exist when is required to check all as-built conditions corresponding to the designed, and in a case of the updating a BIM to recreate the current conditions of the object.

3D laser scanning as a reality capture data technique is integrated into the process of a BIM was reviewed in *Almukhtar et al, (2021)*. Three-step methodology to capture the building was developed: a systematic review of the previous research in the industry, field survey of an investigated object (Headington Hill Building, Oxford), a BIM integration framework, with a data carried out from the 3D laser scanning. The process of a point cloud data registration and improvement is completely described. Afterward, through the manipulation with the data formats, a point cloud has been prepared to the integration into a BIM, with an aid of the Trimble Realworks and Autodesk Revit software.

In order to maintain a clear audit of the trail by the constant monitoring and updating the as-built model, Construction a BIM Project Management system (ConBIM-PM) was purposed by *Lin et al, (2016)*. This web-based system allows the communication with all engineers involved in the workflow. A database of the system contains all technical data about modification, updates of all as-built models. Using a web environment the required reports and feedback may be utilized. The main advantages of the ConBIM-PM can be used during the construction process, while the operative information exchange is required. And of course, all previous versions are stored during the construction process in order to avoid the mistakes in updating.

Taking into account the previous experience of the implementation of a BIM for the as-built modeling, the following methodology going to be tested in the frame of the current investigation. Since these examples belongs only to the buildings, and the scope of the research concerned to the infrastructure objects, principal difference in the application of a BIM technology may occur. More detailed the following questions are explained in chapters 2.2, 2.3.

2.2. Area of the investigation

According to the task which appears in AEC industries more often, a BIM for as-built infrastructure objects is the relevant direction for further investigation. Several examples of the previous researches listed above, as well as a plan of implementing BIM into the all infrastructure projects in Germany under the responsibility of the Federal Ministry of Transport and Digital Infrastructure *(BMVI, 2021)*, indicate the actuality of the development of this technology. Therefore, the area of the newly constructed bridge over a creek Sehrowbach (Fig.2.2), located on the state road B96 (555 – km 1,8) near Stönkvitz in the county Vorpommern-Rügen (Mecklenburg-Vorpommern) is selected as an investigated object.

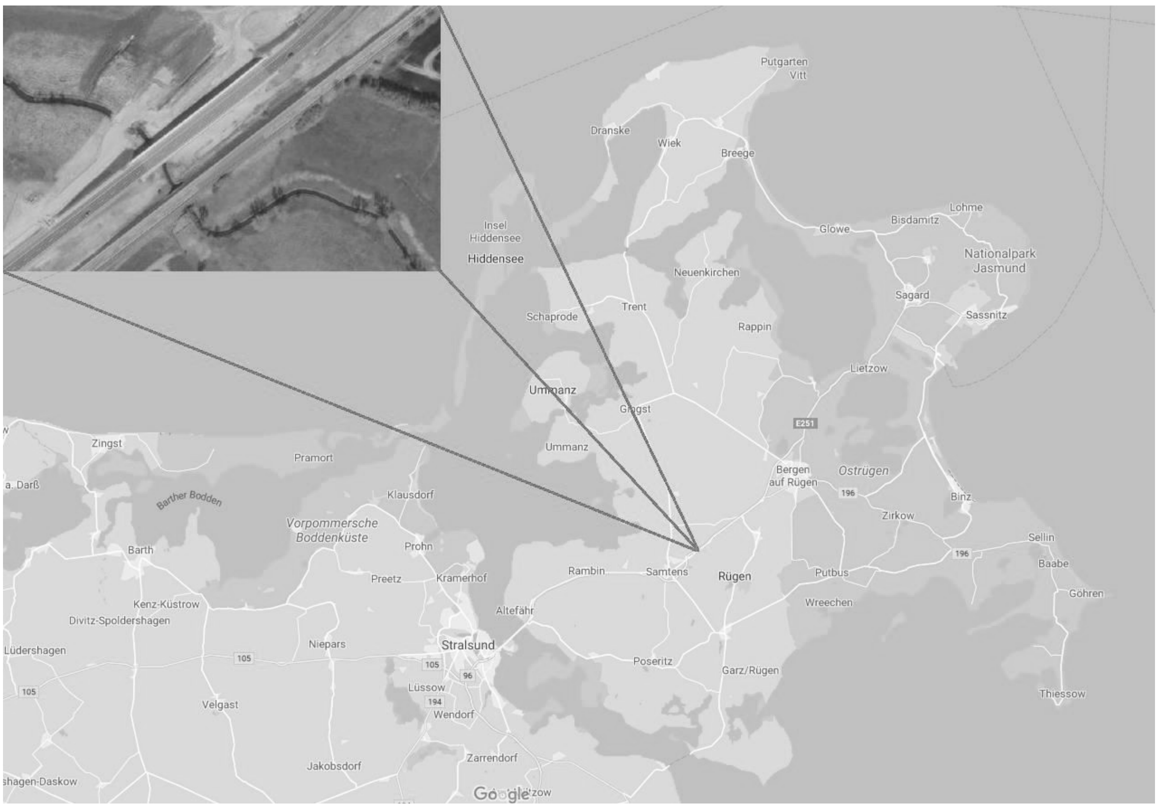


Figure 2.2 Location of investigated object (Google, 2021)

BIM of the infrastructure objects has different characteristics, as well as a shape, length of elements. And most important is another condition of the modeling process. Therefore, *Pszczolka, (2019)* proposed to use Norwegian standards as a guidance to BIM, aimed to standardize the flow of the information and reduce the cost of modifications during the construction phase. Mentioned standards were developed to improve a BIM of the roads, which was partly accessed with the bridge modeling. As a scope of the research is concerned to a BIM in infrastructure, is required to continue a review of the sources, where the following example apply.

2.3. Explanation of a Bridge Information Modeling (BrIM)

The main goals of a BIM are improvement of the level of the design in a case of a projection and preparation stage, the introduction of the information about an object relations and properties in a case of the finished construction stage. Data standardization directly belongs to the BIM, because of the high efficiency of an operation with parametric data to lead the project during the whole life-cycle. Taking into account completely different dimensions of the bridge and buildings or other constructions was established a practice of BIM in bridge-building named Bridge Information Modeling (BrIM) *(Cho, 2009)*. According to *Trimble Solutions Corporation, (2021)* there are the following milestones in a BrIM: 3D visualization, planning, and scaffolding, formwork and concrete pour, virtual assembly, automated machine control, smart inventory.

Implementation of the BIM technologies for the infrastructure is highly relevant. Only a few countries completely switch approaches in the projecting period. Instead of classical 2D CAD drawings Australia, Norway, Finland and Sweden already apply BIM for the infrastructure objects, as well for the bridges. As mentioned in the previous chapters, Germany approved a plan, according to which all projects developed by BMVI need to contain BIM. In the frame of the proposed plan for application a BIM in the infrastructure, were completed pilot projects. In *Borrmann et al, (2016)* was described a procedure of the completing a BIM for Auenbachtal, Petersdorfer See, Filstal bridges in Germany. The article purposed a distribution of the whole process onto the subtasks that need to be completed such as the goals of a BIM, suitability of application, technical specifications on naming software and formats, organizational specifications on responsibilities, and deadlines. On the examples of every bridge presented in the project, conditions, and prerequisites set between the client and contractor were reviewed in detail. 17 maturity metrics is being developed in such a way, that it can be used for other BIM projects in the future, to record and document the gradually increasing a maturity of the BIM implementation.

Preparation of laser scanner to the research

3.1. Errors during the laser scanning. Procedure of the self-calibration.

As the laser scanners are high precision measurement devices, a precision of distance measurements and quality of output results required constant monitoring. To avoid increasing the errors and ambiguities, the laser scanner needs periodically calibration. According to *Soudarissanane et al, 2011* the following errors can impact on the laser scanning process: instrumental imperfections, atmospheric effects, properties of the object, measurement configuration and scanning geometry.

Instrumental errors can be identified as a systematic and random, which can arise suddenly under the influence of the external factors. Random mistakes affect the precision of the distance measurements and an angle of rotation during the scanning procedure. *Cosarca et al, 2009* in detail described each category of errors. To the instrumental belongs the range and angular accuracy, boundaries effect and axis errors. Surface and multipath reflection errors depend on the physical properties of a scanned object. The atmospheric effects classified the temperature, humidity and atmospheric pressure. Distortions from motion and interfering radiation as well a methodology of scanning can be an additional source for technique mistakes. Furthermore, very important for the interpretation laser scanning data is the width of a laser beam. *Weichel (1990)* defined a calculation of the width of the laser beam:

$$r(\rho_r) = r_0 \sqrt{1 + \left(\frac{\lambda \rho_r}{\pi r_0^2} \right)^2} \quad (1)$$

where:

- $\boldsymbol{\rho_r}$ is range relative to the beam waist location;

- **r** is the radius of the laser beam;

- $\mathbf{r_0}$ is the minimum radius of the laser beam called the beam waist

In a practice, different widths of the beam can affect the quality of the corners and boundaries detection. The greater distance and angle of the beam the width of it is linear greater.

After the laser scanner has been delivered to the user, a functional calibration model with all parameters can be estimated by self-calibration based on recreated calibration point field. As the laser scanners have not standardized specifications competently with other surveying devices, highly relevant is a development of the test procedures for the laser scanners, based on the scientific and practical properties. *Holst et al, 2016* purposed the configuration of an optimal calibration field accordingly to the scanner specifications. During the research, were defined parameters of the outcome data, to control applying of a calibration in a test field. Conformity of the real resolution and noise, as well a range of measurements and depending on scanning conditions required by a manufacturer can be detected as a result of calibration in the test field. Finally, the authors concluded, that the development of the test field is still not finished, because of not estimated calibration parameters correlated to the potential laser scanner imperfections.

3.1 Calibration of terrestrial laser scanner Z+F IMAGER® 5016

Thanks to the availability of a test field for calibration geodetic measurement instruments in the University of Applied Sciences (Hochschule Neubrandenburg), was performed a calibration of the laser scanners Z+F IMAGER® 5016 (Fig. 3.1) provided by Hochschule Neubrandenburg and a private enterprise Ingenieurteam Nord GbR.

Figure 3.1 Front view of a Z+F IMAGER® 5016 *(Zoller+Fröhlich, 2021)*

Test field located in the spacious hall of a university building, and consist from 14 strongly fixed and removable Z+F Profi Targets. The points were placed on a different height level and equal distance from each other around whole test field. The schematic illustration of the test field is shown on *Figure 3.2,* where targets are depicted with red quad and approximated standing point of the measurement device depicted with the point under a sign A::0.

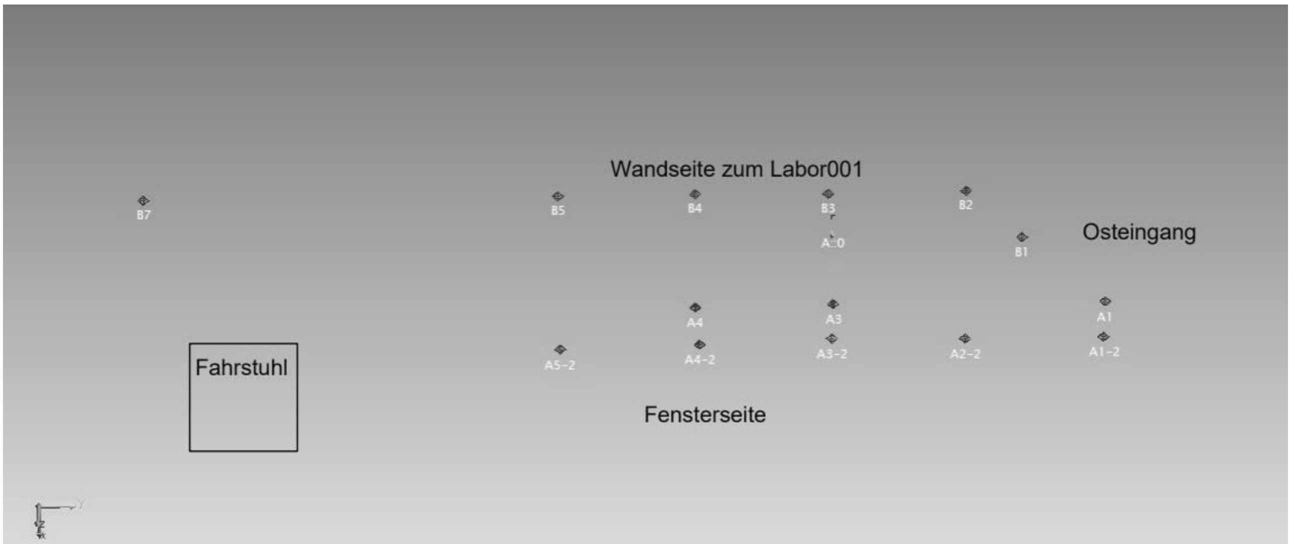


Figure 3.2 Schema of the test field

The test field was constructed in 2018. The coordinates of the targets were defined with high precision measurement device Leica Absolute Tracker AT960-LR *(Fig. 3.3(a))* measuring on a Leica round prism located in a nest of the target bracing *(Fig. 3.3(b))*.

a) b)

Figure 3.3 Laser Tracker and prism-target

Taking into account very high precision of the measurements provided by the laser tracker *(Table 3.1)*, the results were set up as a standard coordinates.

Table 3.1 Technical specifications of a Leica Absolute Tracker AT960-LR (Hexagon metrology, 2015)

Quality of measurements	
$U_{x,y,z}$	+/-15 µm + 6 µm/m
Distance quality	+/-0,5 µm
Dynamic targeting	+/-10 µm/m
Orientation	+/-15 µm + 8 µm/m

Measurement on a prism was conducted because of the bracing of the targets (Fig. 3.4 (a)) constructed in a way to allow simple changing between targets, prism, etc.

a) b)

Figure 3.4 Bracing and a target on it

The calibration aim of the laser scanners are following:

- detection of the deviations of the measured coordinates in the three qualities of resolution: High, Super High and Ultra High;
- definition of a suitability of the resolution qualities according to the distances of the target.
- comparison of the obtained results with a manufacturer declaration.

Additionally, the standard coordinates defined in 2018 were controlled by conducting the new measurements with a laser tracker. That gave one more scientific opportunity - to control the stability of the test field, through the calculation of a difference between the measurements in 2018 and 2021.

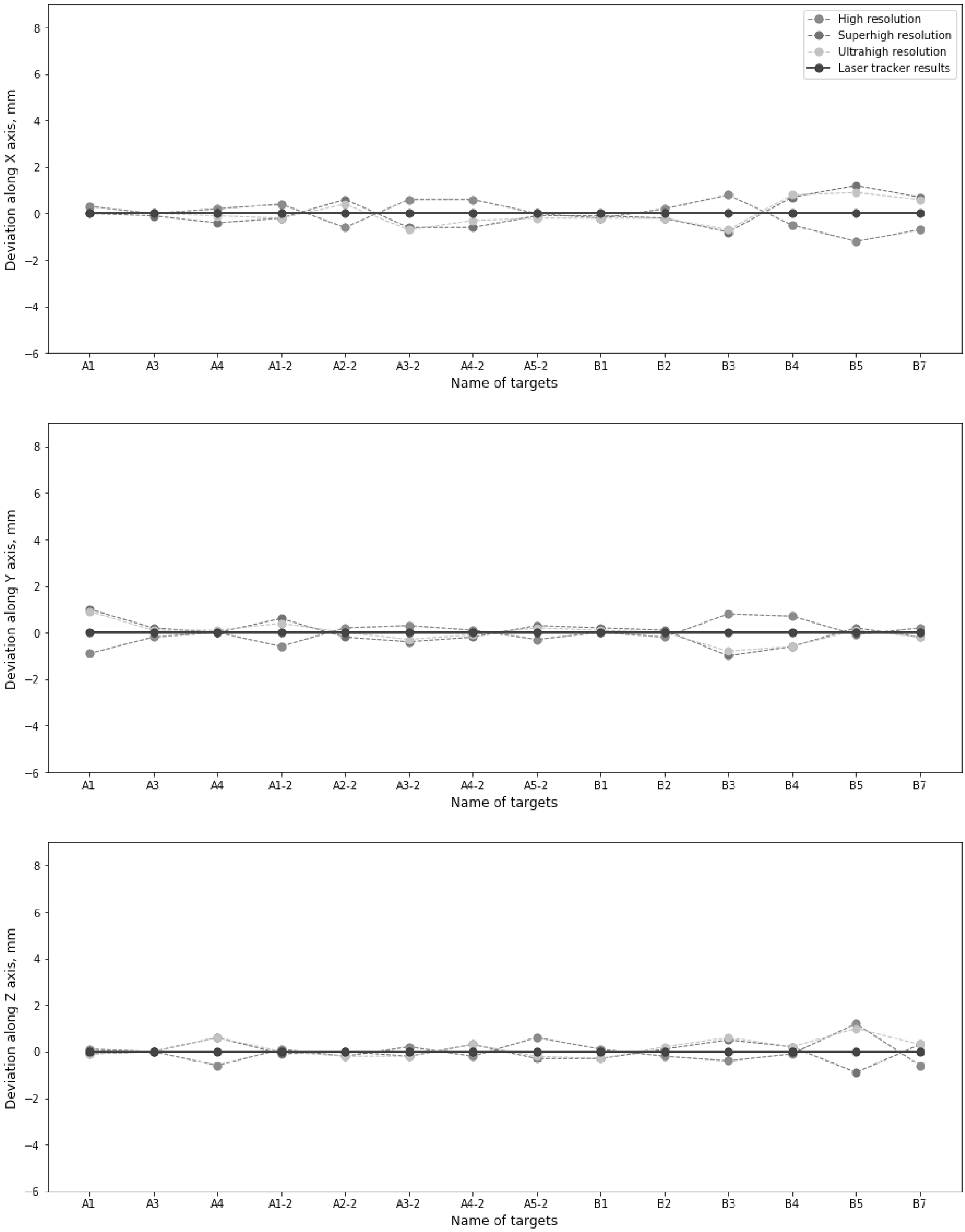


Figure 3.5 Deviation along the X, Y, Z axis (device from Hochschule Neubrandenburg)

Analyzing *Fig.3.5*, one may conclude, that the mean values of the deviation along three axes are rather small (till 1.2 mm). The biggest deviation occurred on the points *B3, B4, B5, B7* along the all axis, moderate deviation located at the points *A2, A2-2, A3-2, A4-2* along the X-axis; *A1, A1-2* along the Y-axis; *A4, A5-2* along the Z-axis. Taking into account properties of the scanning resolution and quality, a deviation of the points *B5, B7, A1-2, A5-2* explain long-distance from the scanner position (20 – 40 m). Another factor that could directly impact on a deviation is the angle of the plane of a target (Fig.3.6), as an example targets on the points *B4, A3-2, A4-2* directed not to the scanner position, rotated and scaled target may cause an inaccurate detection by a software algorithm.

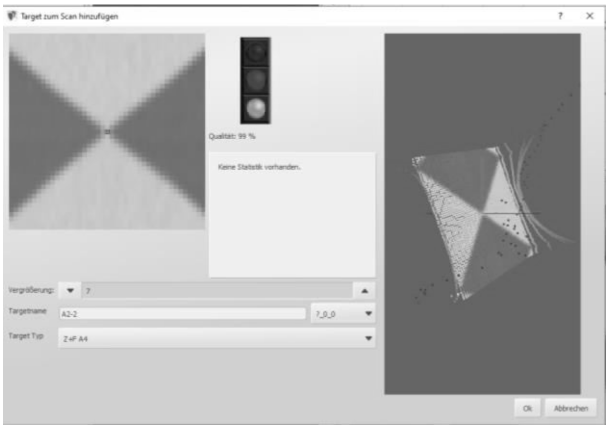


Figure 3.6 Target A2-2 during process of detection

The quality of the targets detection directly depends on the resolution of scans and distance. Therefore, three scanning cycles are performed in three resolutions: High, Super High and Ultra High on both laser scanners. Analysing Fig. 3.5, 3.7, may distinguish a difference in the deviations between the High, Super High and Ultra High resolution. The technical characteristic of the listed resolution defined by the manufacturer is shown in Table 3.2.

Table 3.2 Technical specifications (Zoller + Fröhlich GMBH, 2017)

Resolution	Pixeldistance	Pointdensity	Pixel/360°	Ideal distance to the targets
High	H, V = 0,033°	6,3 mm * 10 m	10000	> 5 m
Super High	H, V = 0,016°	3,1 mm * 10 m	20000	> 20 m
Ultra High	H, V = 0,008°	1,6 mm * 10 m	40000	> 40 m

Coming out from the optimal distance to the point in a space, may explain moderately deviation along the X, Y, Z axis in High resolution, where the values reached up to 9 mm at most remote point *B7*.

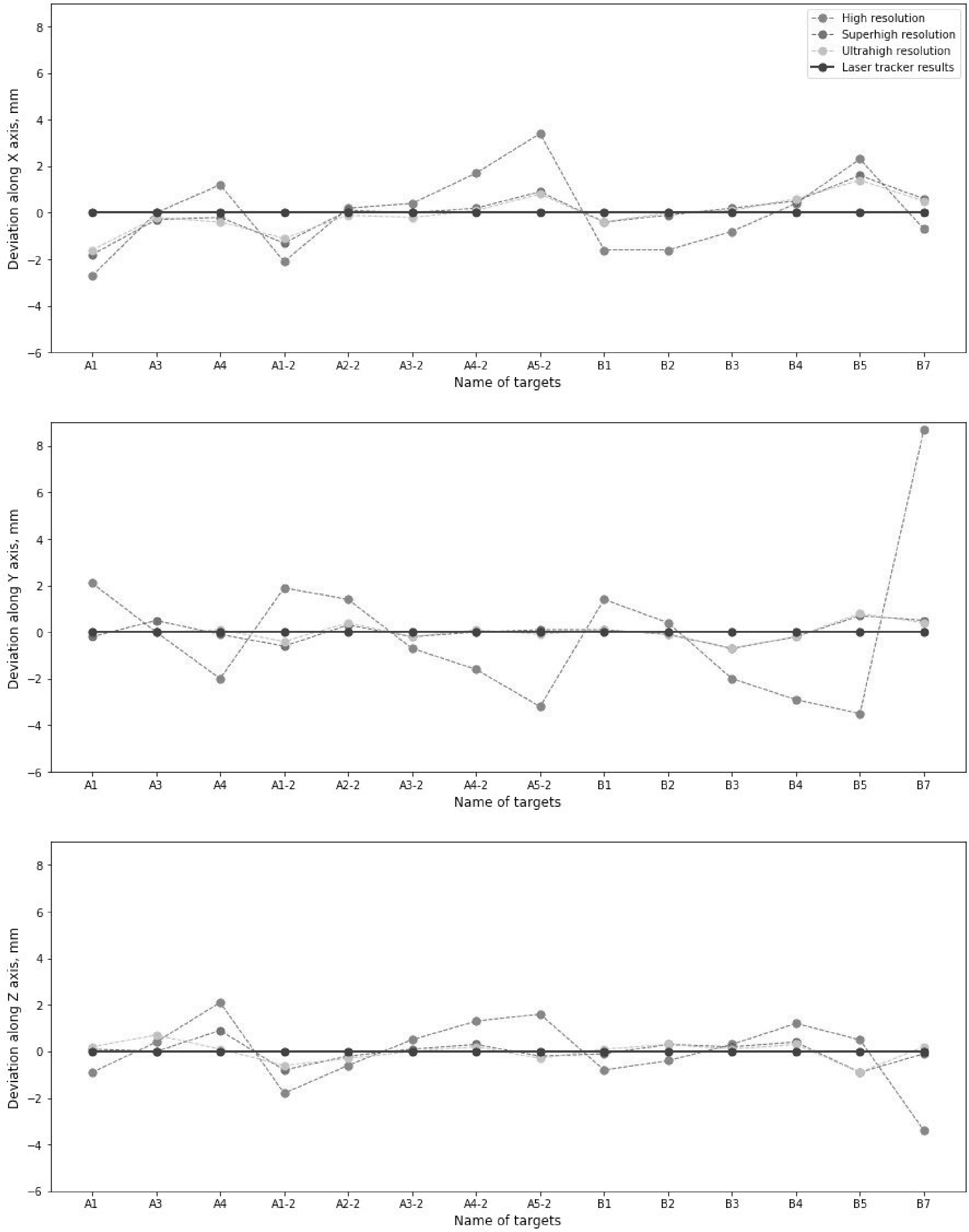
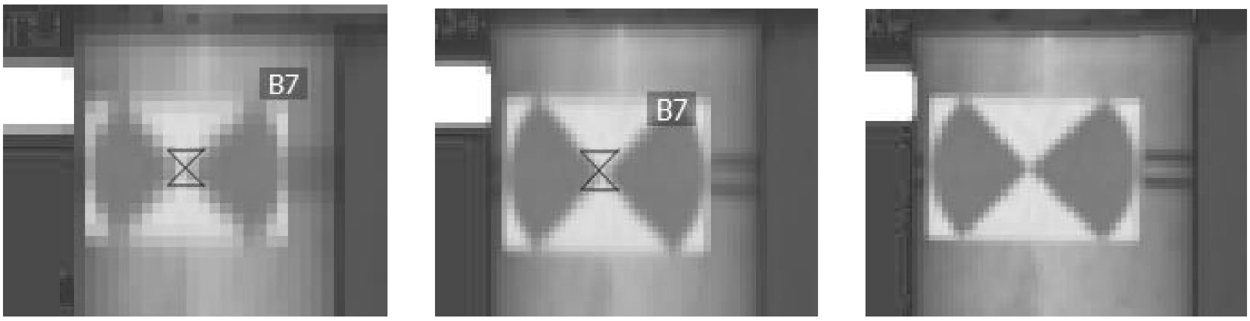


Figure 3.7 Deviation along X, Y, Z axis (device from Ingenieurteam Nord GbR)

Practically, the resolution impacts the quality of a scan. The greater distance to the object, the inferior quality of the scan will be got, the same concern the pixel dimensions (Fig. 3.8).
The images presented the most remote target from the scanner position *B7* (~ 33 m).



a) High b) Super High c) Ultra High

Figure 3.8 Cut parts of the scans of three resolution quality.

To organize a summary of a calibration the calculated standard error of the mean, based on three resolutions and deviations along the X, Y, Z-axis. The results from both laser scanners are listed in the Table 3.3, 3.4.

Table 3.3 Standard error of the mean (device from Hochschule Neubrandenburg)

	High	Super High	Ultra High
X	0,31 mm	0,21 mm	0,23 mm
Y	0,19 mm	0,23 mm	0,16 mm
Z	0,21 mm	0,14 mm	0,16 mm
XYZ mean	0,42 mm	0,34 mm	0,32 mm

Table 3.4 Standard error of the mean (device from Ingenieurteam Nord GbR)

	High	Super High	Ultra High
X	2,82 mm	0,66 mm	0,53 mm
Y	9,27 mm	0,15 mm	0,12 mm
Z	1,97 mm	0,20 mm	0,16 mm
XYZ mean	9,89 mm	0,71 mm	0,57 mm

Summarizing, the values of a deviation confirm the compliance in the quality of the scanning results accordingly to specifications provided by the manufacturer. Both laser scanners supply the high precision outcome, in a High resolution the mean deviation is more noticeable than in the Super and Ultra High, especially from the laser scanner of the Ingenieurteam Nord GbR. But all values in a comparison with the conditions of a calibration and properties of the test field are in the range of allowance. The absolute difference in the measurement cycles with a laser tracker in 2018 and 2021 is presented in the *Fig. 3.9.* Values of deviation along the X, Y, Z-axis are depicted in the color bars.

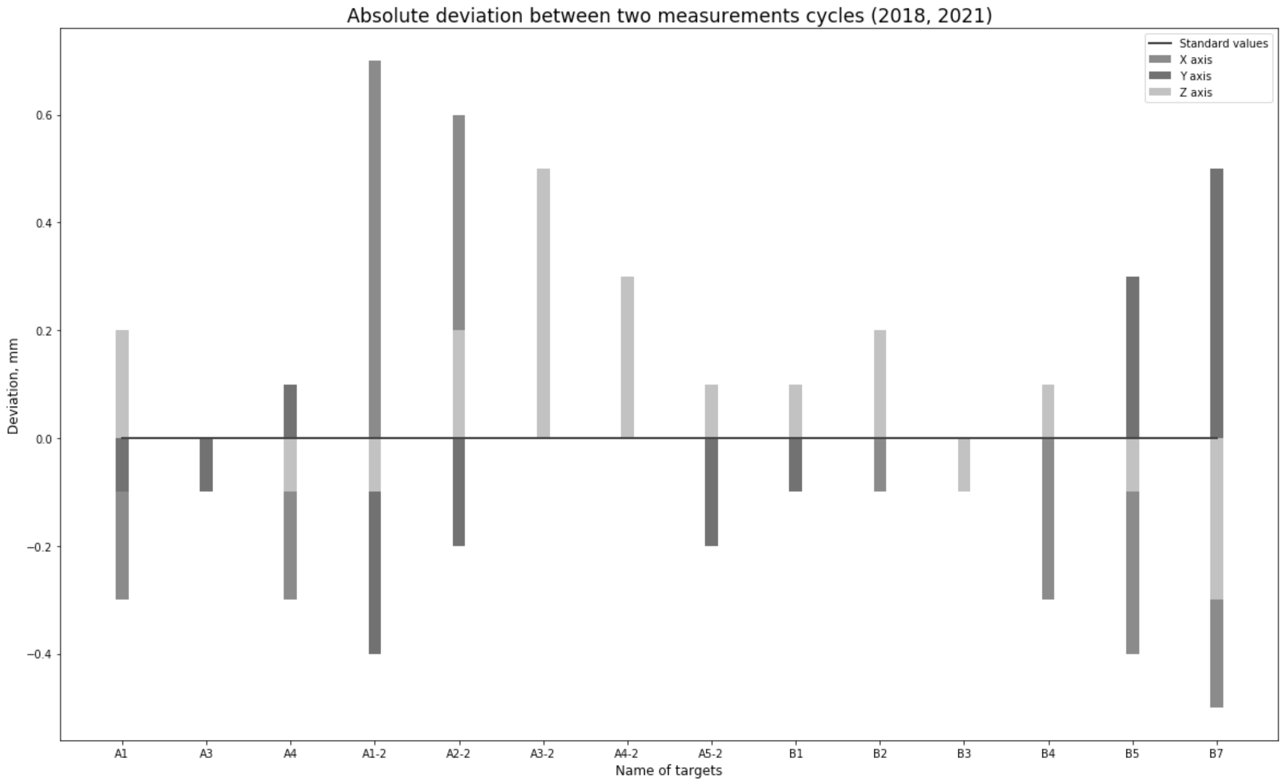


Figure 3.9 Deviation of test field (2018 – 2021)

Summarizing completed calibration is possible to conclude:

- the laser scanner measurements confirm quality guaranteed by the manufacturer, even more, the results are better;
- difference between the Super High and Ultra High is not significant, which allows to assume equal scanning quality for the predefined ranges of usage;
- taking into account two cycles of the measurements with a laser tracker, test field deformation is missing, because of deviation on every target less than 1 mm.

3.2 Linear deviation monitoring of axis Z+F IMAGER® 5016

Excepting the calibration of the laser scanner in a case of the target detection and calculating a difference from the standard values, there are other controls of the possible systematic errors, emerging by the process of laser scanning. As a laser scanners principle of the work is very similar to the total stations, many error tests may be implemented as well to the both types of devices.

Sawicki & Kowalczyk, 2016 purposed research into the collimation and horizontal axis errors influence on the Z+F laser scanner accuracy of verticality measurement. On the example, a TLS Z+F 5006h, was performed an investigation of the possible linear deviations to the verticality of the measurements. Based on the measured angle and distance to a prism, using some formulas, coordinates of the targets in local CRS were defined. According to selected by the authors methodology, the error of the horizontal axis can be calculated with the following expressions:

$$i = \frac{Hz_{FR} - Hz_{FL} \pm 200^g}{2} \tan(Z) - \frac{c}{\cos(Z)} \qquad (2)$$

where *I* – error value, *c* – collimation error, HzFR and HzFL – right and left face of the horizontal axis angle, Z – zenith angle.

Heinz et al, (2018) performed an accuracy assessment of the laser scans on the real measurement objects. The authors completed the TLS measurements with four different devices in the same area with the same defined conditions. The positions of the laser scanners were chosen in such a way that the wall section was scanned at the measuring distances of 5m, 10m and 20m with an angle of the incidence of 0°, 30° and 60° respectively *(Fig. 3.10)*.

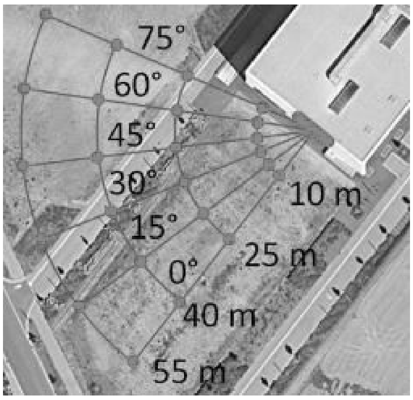


Figure 3.10 Positions of the laser scanners

The aim of the investigation was to compare the calibration results with guaranteed specifications by the manufacturer. Also, was conducted a comparison of the test object measurement in two faces with a Leica ScanStation P20. The deviation between the scans in the some areas reached not more than 1,5 mm, which confirmed compliance to the factory settings. Another tested laser scanner a Leica BLK360 was classified as not compliant to the manufacturer settings, because of sufficient deviation in scans from a different position, which reached up to 4,5 mm. Taking into account analyzed researches was decided to complete monitoring of non-perpendicularity of a horizontal and vertical axis of laser scanner Z+F IMAGER 5016. As in the case of a calibration, as well for this task were provided the both laser scanners. The way of the investigation was purposed by Prof. Wilhelm Heger and -M.-Ing. Martin Kiskemper. For the planned implementation of the research an aluminium plate with a high-precisely flattened surface was produced. The measurements of a non-perpendicularity were completed with an inclinometer manufactured by Carl Zeiss Jena (Fig. 3.11).

Figure 3.11 Inclinometer Zeiss placed on a steel stand.

The precision of an inclination is 30'' what allows to reach twice better quality in a post-processing. Non-perpendicularity of the both laser scanners were defined through the measurements of an inclination on the top of the device in two positions (Fig. 3.12): parallel to the display (Fig. 3.12), perpendicular to the display.

a) position parallel to the display b) position perpendicular to the display

Figure 3.12 Inclination of the laser scanner measurements

In the practice, the inclinations were measured at the different angles of the devices orientation from 0° to 360° with the step 45° in two faces. This technique gets an opportunity to control the results and avoid the mistakes during measurements. Absolute measurement units of the inclinometer are degrees°, minutes`, seconds``. As the place of the test investigation is precisely flat, the values need to be close to a zero. Of course, after the measurements in all positions the both laser scanners have been reached values from 0` to 4` what confirms the favorable conditions for detection of the non-perpendicularity of the axis. Afterward, to standardize the received results, the values were converted into the decimal degrees (Tab. 3.5, 3.6).

Table 3.5 Inclinations value at the different orientation angle of the laser scanner

Hochschule Neubrandenburg

a) parallel to the display

	Offset (F1+F2)/2	Value (F1-F2)/2
0°	0.013°	-0.021°
45°	0.013°	-0.021°
90°	0.013°	-0.013°
135°	0.013°	-0.013°
180°	0.013°	-0.013°
225°	0.008°	-0.008°
270°	0.013°	-0.013°
315°	0.013°	-0.021°
360°	0.013°	-0.021°

b) perpendicular to the display

	Offset (F1+F2)/2	Value (F1-F2)/2
0°	0.013°	0.046°
45°	0.013°	0.046°
90°	0.013°	0.054°
135°	0.017°	0.050°
180°	0.017°	0.050°
225°	0.013°	0.046°
270°	0.013°	0.046°
315°	0.008°	0.042°
360°	0.013°	0.046°

Table 3.5 Inclinations value at the different orientation angle of the laser scanner

Ingenieurteam Nord GbR

a) parallel to the display

	Offset (F1+F2)/2	Value (F1-F2)/2
0°	0.013°	0.004°
45°	0.008°	0.008°
90°	0.008°	0.008°
135°	0.013°	0.013°
180°	0.008°	0.008°
225°	0.008°	0.008°
270°	0.008°	0.008°
315°	0.013°	0.004°
360°	0.013°	0.004°

b) perpendicular to the display

	Offset (F1+F2)/2	Value (F1-F2)/2
0°	0.013°	-0.021°
45°	0.013°	-0.021°
90°	0.013°	-0.021°
135°	0.008°	-0.025°
180°	0.013°	-0.029°
225°	0.013°	-0.029°
270°	0.017°	-0.025°
315°	0.013°	-0.021°
360°	0.013°	-0.021°

Where F1, F2 are position of level device in Face 1 and Face 2.

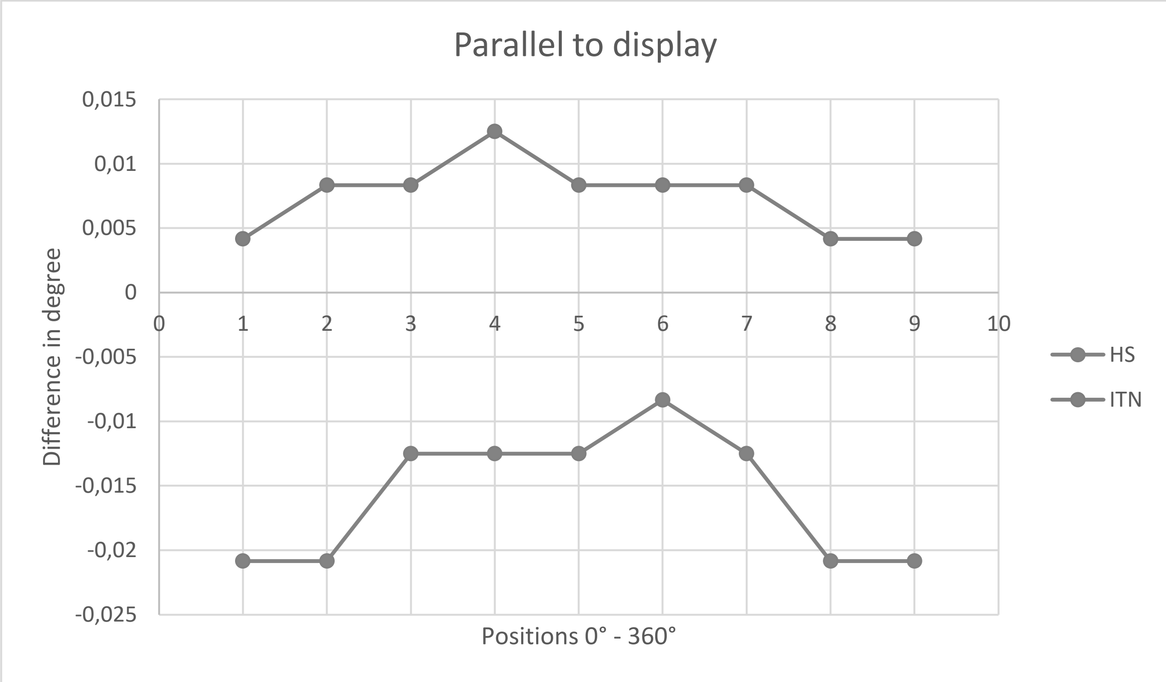


Figure 3.13 Differences in position parallel to the display

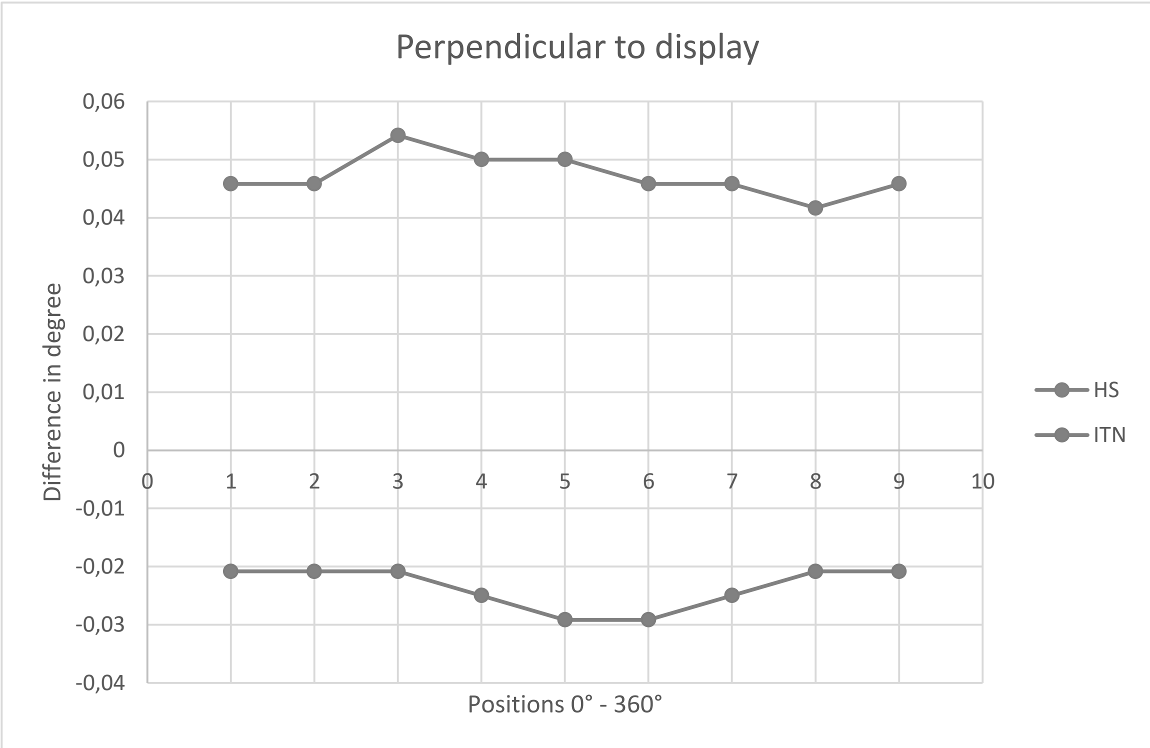


Figure 3.14 Differences in position perpendicular to the display

Corresponding to the results, the biggest deviations from the zero were in measurements of the laser scanner Hochschule Neubrandenburg in a position perpendicular to the display and reached up to 0.06° (Fig. 3.13, 3.14). The values close to the zero have occurred in the measurements parallel to the display of the both laser scanners. To summarizing, the deviations of the both laser scanners are not sufficient.

Technology of a workflow: purpose and alternative

Analyzing the research achievements concerning the scope of the investigation and widely used technologies, was decided to complete the workflow in a unsophisticated way. Application of s TLS, surveying methods, aerial imagery for data capturing and leading software for modeling process in a BIM provides a high suitability and acquires a quality outcome. As the research completed with the support of a private enterprise, was possible to use the most developed and high-cost technologies for realization of the goal.

The field measurements were completed with the following devices:

- Laser scanner Z+F IMAGER 5016;
- Drone DJI Phantom 4 RTK;
- Total station and GNSS receiver Leica Nova TS60, Leica GS15;

and the following software:

- Autodesk Revit;
- Agisoft Metashape;
- Autodesk ReCap;
- SOFiSTiK Bridge Modeller;
- Leica Geosystems 3Dr Reshaper
- Lumion

Application of such devices and software combination cost a lot, because the market price of data capturing using laser scanner and RTK, as well as data processing in listed over paid software drone is moderately high. For the not commercial projects must be planned another workflow and selected another instruments. Though for completing the research was used high-cost workflow, an alternative variant need to be presented.

A lot of new models of total stations have the built-in laser and measurement system based on the laser beam similar to the laser scanner. That allows performing a laser scanning directly from the total station. In *Oleksiuk & Sankey (2014)* presented comparison of the laser scanning and total station survey methods for building modeling. Authors review the following methods in the scope of time and accuracy. On the example of the exterior scanning one building, laser scanning from both devices was performed. In a result, the laser scanner capture the data faster and is more comfortable for user, but price of the TLS and processing software is 4 times higher as the scanning and processing of the total station. Quality difference for such investigated objects is not sufficient.

Provided for this investigation Leica Nova TS60 have function of a scanning of the selected areas, what allows performing a scanning without an involving the high-cost laser scanners, but disadvantage is in a loss of the time. User must define and understand expectations from these methods.

The similar situation occurs with the application of the aerial imagery. DJI Phantom 4 RTK cost 7-8 times greater than DJI Phantom 4, but allow getting the georeferenced photos without a post-processing. In this case loss of time going to be rather sufficient, because of the demand in a measuring ground control points using GNSS and perform manual referencing of the images in a post-processing. Anyway, an aerial imagery with drones and UAVs without RTK is highly relevant and can be applicable for this investigation.

Application of the open-source software saves a lot of the cost, the question is a quality and functionality in comparison with the paid software. In *Hecht & Jaud (2019)* completed the selection and comparison of the free software for a BIM visualization. Authors made an overview on the available software and evaluated them in the scope of geometry generation and visualization possibilities. Import capabilities to Industry Foundation Clases (IFC) were checked.

Decreasing of the costs for such types of work is partly possible. Laser scanning and aerial technology can be simplified, but with the loss of accuracy and time; some software can be replaced on the open-source analogs (FreeCAD, IFC Query, Cloud Compare, Bundler, Open Drone Mapping). For the research purposes it can be acceptable, but for the constant application on the enterprises, technologies with the low-cost solutions can cause decreasing of the work effectiveness.

Field measurements at the area of investigation

5.1. Devices and their purpose

As was described in the *Chapter 2.1* to the area of investigation contains two bridges located on the state road B96 (555 – km 1,8). The main task of the research is to create a BIM of the bridges applying the available techniques. A source of the data for a BIM of the existing objects is the laser scanning. The outcome of this procedure is a high-density point cloud, captured around the device, which allows recreating of objects in three dimensions precisely. Therefore, was decided to complete a laser scanning of the bridges and connected infrastructure.

Z+F IMAGER 5016

As for the previous tests, a Z+F IMAGER 5016 provided by Ingenieurteam Nord GbR for implementation the research. This is one of the newest devices on the market, purposing valuable functionality for the different tasks (Tab. 5.1).

Table 5.1 The main specifications of a Z+F IMAGER 5016 *(Zoller+Fröhlich, 2021)*

Specifications	
Laser class	1
Beam diameter / divergence	~ 3.5 mm @ 1m / ~ 0.3 mrad (1/e2, half angle)
Measurement Range	0.3 m ... 365 m (ambiguity interval) / 1 ft ... 1,220 ft
Distance resolution	0.1 mm / 0.0038 inch
Data acquisition rate	Max. 1.094 million pixel/sec.
Linearity error	≤ 1 mm + 10ppm/m
Deflection system	completely encapsulated rotating mirror with integrated HDR camera and LED spotlights
Vertical field of view	320°
Horizontal field of view	360°
Operating temperature	-10 °C ... +45 °C
Data storage	internal 128 GB SATA, additional 64 GB SD flash card
Protection class	IP 54
Integrated sensors	Barometer, Acceleration sensor, Gyroscope, Compass, GPS

But not for every case a TLS is enough for the precise objects recreation. When the target of the modeling is the exterior or open area, use of an UAV is required.

DJI Phantom 4 RTK

The point cloud data captured during an UAV flight, aid to cover the invisible areas from the ground parts of the investigation area. Flight plans need to be created according to the main rules of the photogrammetry and to the manufacturer recommendations. For the purposes of a bridge modeling as well the other linear objects, using an aerial imagery as a source of the point clouds is very helpful. To complete the research fully, in addition to the laser scanner Ingenieurteam Nord GbR provided a drone DJI Phantom 4 RTK. The device was released in 2018 and now is one of the most customized drones for high-precision aerial mapping. An integrated RTK GNSS provides increased quality of the image referencing, which is important for further point cloud extraction and connecting with a TLS data. Technical specifications are presented in a Table 5.2.

Table 5.2 The main specifications of a DJI Phantom 4 RTK *(DJI, 2021)*

Specifications	
Max Service Ceiling Above Sea Level	6000 m
Max Speed	31 mph (50 kph)(P-mode) 36 mph (58 kph)(A-mode)
Max Flight Time	Approx. 30 minutes
Operating Temperature Range	32° to 104° F (0° to 40℃)
Vertical Accuracy	1.5 cm + 1 ppm（RMS）
Horizontal Accuracy	1 cm + 1 ppm（RMS）
Stabilization	3-axis (tilt, roll, yaw)
Sensor	1" CMOS; Effective pixels: 20 M
Lens	FOV 84°；8.8 mm / 24 mm(35 mm format equivalent:24 mm)； f/2.8 - f/11, auto focus at 1 m - ∞
Max Image Size	864×3648（4:3) 5472×3648（3:2）
Ground Sample Distance(GSD)	(H/36.5) cm/pixel

Combination of the TLS and aerial imagery extends the field of potential usage a technology of a 3D modeling, but exist some nuances which may impact on the final expected results, especially in a BIM. In the next chapter described problem statement of the correct data integration.

Leica Nova TS60 and **Leica GS15**

To design a 3D model of the investigated area in a coordinate reference system (CRS) it is required to complete the standard surveying operations on the site. As for reaching the goals of the research applying the TLS and aerial imagery technologies, resulting data from the both need to be georeferenced precisely and without ambiguity errors. For this purpose, Ingenieurteam Nord GbR provides the total station Leica Nova TS60 and GNSS receiver Leica GS15. Thanks to the wide specifications of the devices, georeferencing completed with the high precision three types of the targets: "Z+F Fein Targets" placed on a tripod (Fig 5.3), "DJI ground marks" (Fig.5.6), paper wall marks. The availability of the controller Leica CS 20, allows completing the measurements with only one person and remotely manage the total station.

Table 5.3 The main specifications of the Leica Nova TS60 (Leica Geosystems AG, 2015)

Specifications	
Accuracy Hz and V	0.5" (0.15 mgon)
Accuracy / Measurement time	Single (prism) 0.6mm + 1ppm / typically 2.4s Single (any surface) 2mm + 2ppm / typically 2s
Range	Prism (GPR1, GPH1P) 0.9m to 3,500m Non-Prism / Any surface 0.9m to >1,000m
Laser dot size	At 50m 8mm x 20mm
Rotation speed / Time to change face	Maximum 200 gon (180°) per s / typically 2.9s
Target aiming range	Circular prism (GPR1, GPH1P) 1,500m / 1,000m 360° prism (GRZ4, GRZ122) 1,000m / 1,000m
Accuracy / Measurement time	0.5" (0.15 mgon) / typically 3-4s
Operating System / Field Software	Windows EC7 / Leica Captivate with apps
Internal memory / Memory card	2 GB / SD card 1 GB or 8 GB

To get coordinates of the set-up point of the total station, used "free station" technology. Were measured three points with a GNSS receiver in a RTK mode. For this task the receiver Leica GS15 and controller Leica CS 20 were used. The technical specifications of the receiver presented in Table 5.4.

Table 5.4 The main specifications of the Leica GS15 *(Leica Geosystems AG, 2015)*

Specifications	
Max. simultaneous tracked satellites	Up to 60 Satellites simultaneously on two frequencies
Satellite signals tracking	GPS: L1, L2, L2C, L5 GLONASS: L1, L2 Galileo (Test): GIOVE-A, GIOVE-B Galileo: E1, E5a, E5b, Alt-BOC BeiDou: B1, B2 SBAS: WAAS, EGNOS, GAGAN, MSAS, QZSS
GNSS measurements	carrier phase full wave length
Reacquisition time	< 1 sec
Accuracy DGPS / RTCM	Typically 25 cm (rms)
Single Baseline (<30 km)	Horizontal: 8 mm + 1 ppm (rms) Vertical: 15 mm + 1 ppm (rms)
Network RTK	Horizontal: 8 mm + 0.5 ppm (rms) Vertical: 15 mm + 0.5 ppm (rms)
Temperature, operating	–40° C to +65° C, compliance with ISO9022-10-08, ISO9022-11-special, MIL STD 810F – 502.4-II, MIL STD 810F – 501.4-II
Memory medium	Removable SD Card: 1 GB

5.2. Georeferencing of the investigated area.

To get a recreation of the area in a selected coordinate system with a respect to the reference, first of all, the classical surveying operation, with a help of the total station and GNSS is required. Before completing this start phase of research, the area around the site is recognized and checked. To avoid a loss of time, an area is analyzed precisely, to select a place for the total station and the targets. Fig. 5.2 presented the schematic measured network.

Afterward, when the total station is placed, a GNSS measurement of three points in the RTK mode is completed. The properties of the coordinate system BRD33-ETRS-NHN16 are presented in Table 5.5. This CRS applied for the measurements in the eastern part of Germany. As mentioned above, this operation is needed to define the coordinates of the total station. Perfectly visible points in the different angles from the total station are measured. Accordingly, the rules are required to measure at least 60 RTK positions on every reference point twice. In combination with the Leica 360° prism it is possible to measure point and orientate the total station together. Using a technology "Free station", are measuring three points of the orientation with known coordinates. When the coordinates of the total station are known, the scanning process was started.

Table 5.5 Properties of BRD33-ETRS-NHN16

Properties	
Ellipsoid	GRS 1980
Geoid	GCG2016
Projektion	UTM33 (L0=15Grad)
Maßstab ZM	0.9996000
Abstand ZM	122000.000
Höhe ü. Meer	0.000

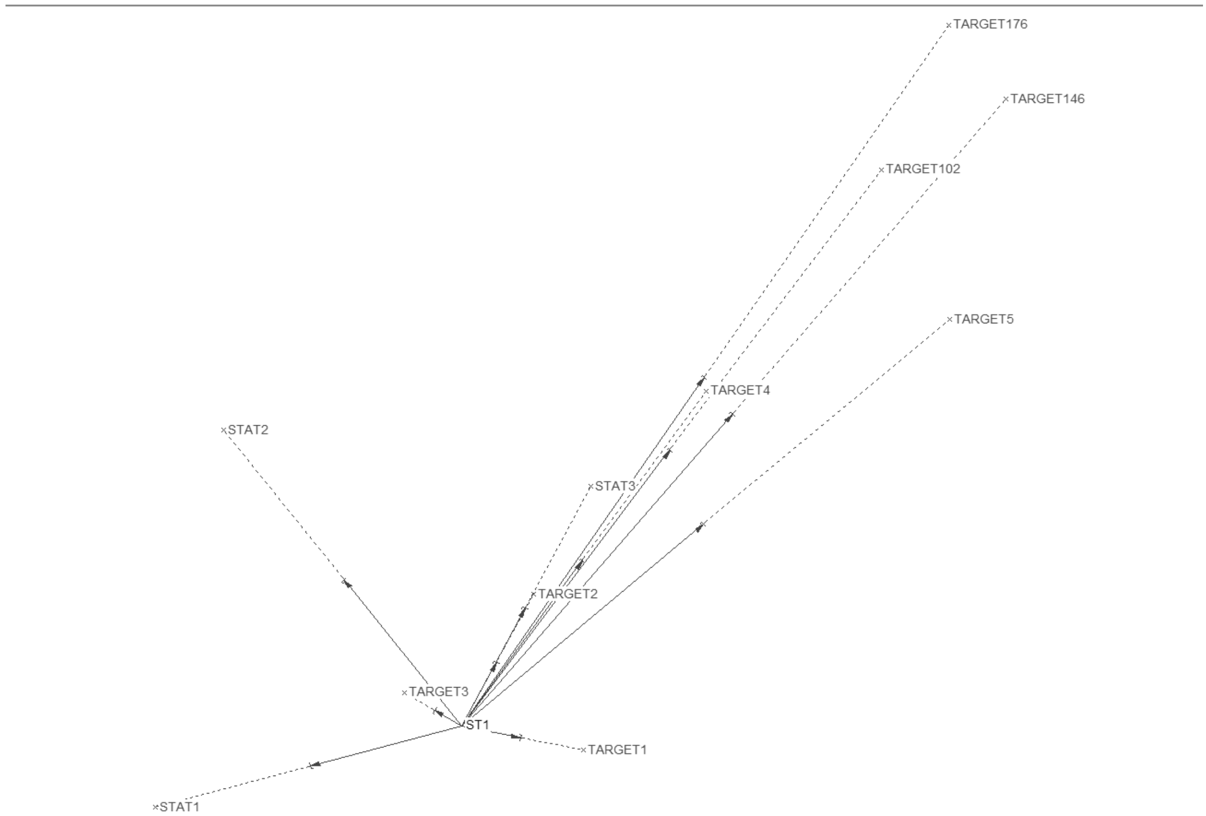


Figure 5.2 Network of the measured targets and reference points

In a result of the procedure "Free Station" reached sufficient quality of coordinate calculation (Tab. 4.6), what allows to provide the further measurements of the targets.

Table 5.6 Result of defined coordinates of total station

	Ost	Nord	Höhe
ST1	33391640.158	6026215.979	6.299
Ergebnis, m.F.	0.006	0.003	0.006

5.3. Terrestrial Laser Scanning

Taking into account a demand of the georeferencing, the area was divided into the parts to set the targets optimal around and with respect to the position of a total station (Fig. 5.3).

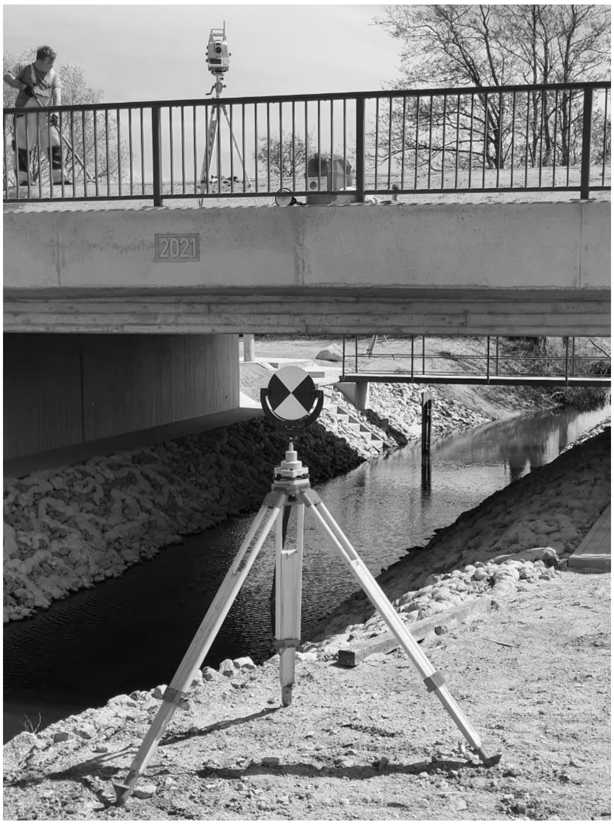


Figure 5.3 Target on a standing

Every target needs to be measured during the laser scanning. In order to get a high-density point cloud, the TLS completing in the High and Super High resolution, depending on the distance to objects. An overlapping area on the scans from different point must enough, especially an availability of the sufficient surfaces scanned from the different positions are very important for the pre-registration. It simplifies the processing of the results afterward. In cases when the target is located at a big distance from a laser scanner, in the menu of a Z+F IMAGER 5016 exist one useful function, which allows scanning only selected area in higher resolution. It spends time and memory but provides improved quality only in interesting areas. All in all, the laser scanning was completed from 26 points (Fig. 5.4).

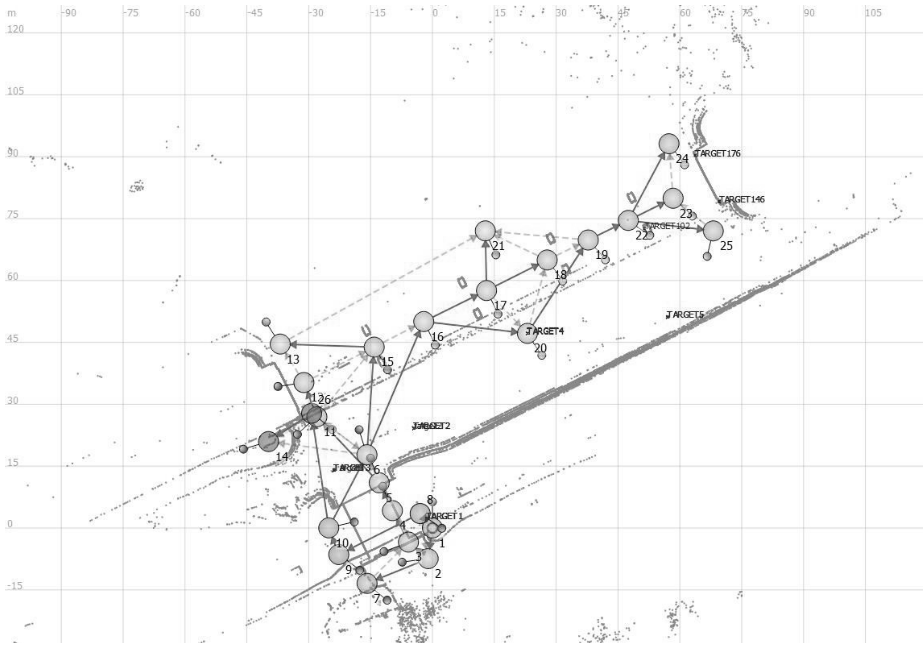


Figure 5.4 Schematic representation positions of the scanner

It is possible to control the process with a using of the tablet computer, where the scans need to be registered. Also, the software provides opportunity to manage the device remotely.

5.4. Aerial surveying

Another way to capture the data is using an UAV. This method is very useful and quick, allows to get an orthophoto, point cloud, DEM, etc. In the frame of the investigation, than was used DJI Phantom 4 RTK provided by Ingenieurteam Nord GbR. In order to capture the data of invisible places from the ground, two flight missions were completed: longitudinal and transverse. More than 800 photos were made. Despite the availability of RTK module in a drone, which allows reaching quality of georeferencing center of cameras up to 1,5 cm, ground reference points are needed. To ensure the correct connection between the TLS and UAV point clouds (Fig. 4.5), the same targets as for the laser scanning need to be recognized from the drone images.

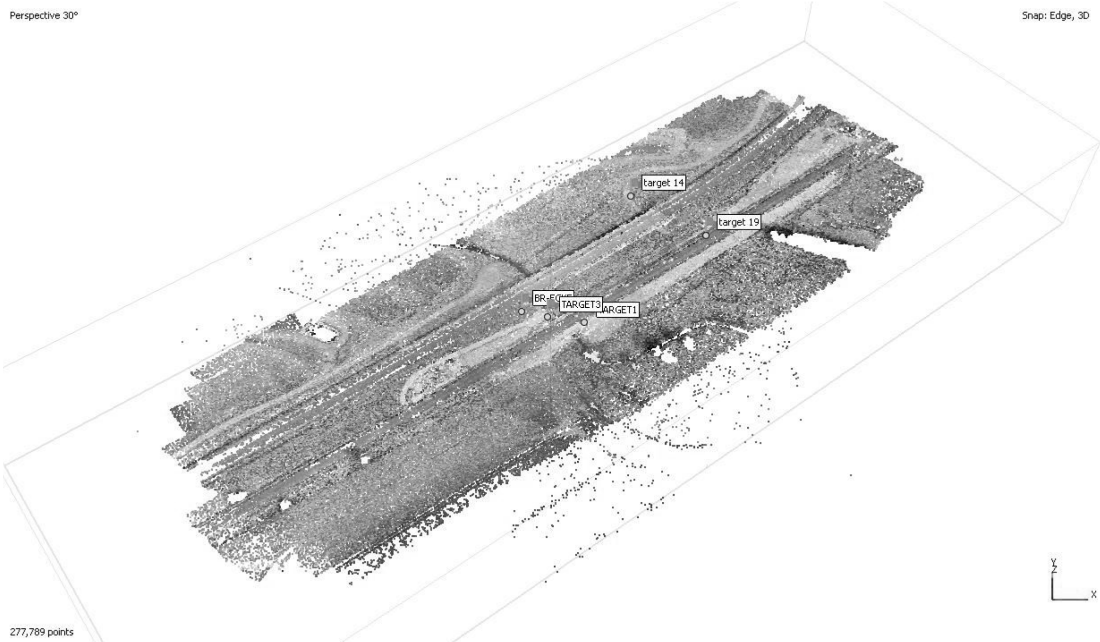


Figure 5.5 Point cloud data captured from the aerial imagery

In a post-processing of the laser scanning data, as well as an aerial imagery requires a referencing. For this purpose in addition to the targets on a tripod, the ground control points are used (Fig. 5.6).

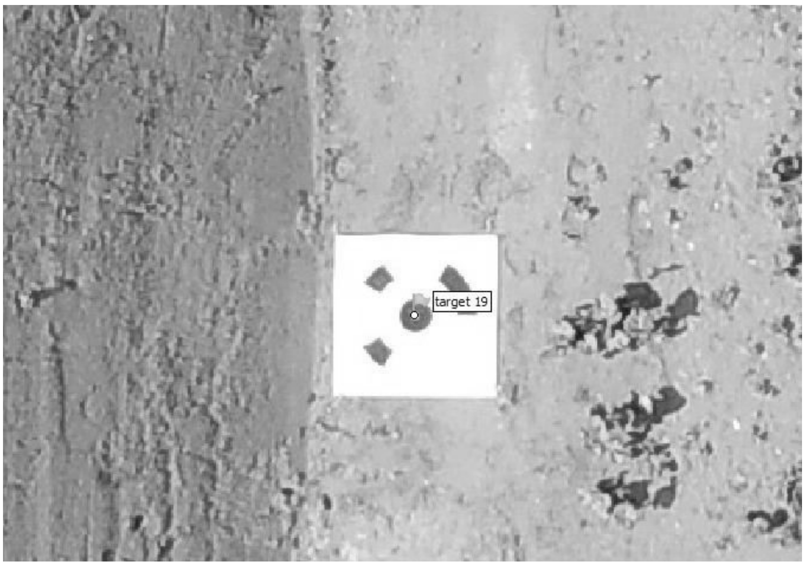


Figure 5.6 Ground control point on a target

Conditions of the conducted flight mission (~80% overlapping between images, 40 m flight height) ensure low ambiguity in a referencing. In the next chapter this procedure as well as a post-processing of the TLS data is described more detailed.

Data processing, preparation and modeling

When the goal is precisely defined and the data captured – beginning the most responsible stage in the workflow. At this stage, every step needs to be completed with a respect to requirements, standards, and ranges of errors.

As the final result of the investigation expecting a BIM of the bridges, the first challenge is the correct data referencing on a scale equal to 1.0. The problem consists of a referencing the resulting model into the CRS for the area of the investigation (in this case to BRD33-ETRS-NHN16) with a scale of 1.0. According to the properties of this coordinate system (Tab 4.5), the scale equals 0.9996. Coming out from this task is required to transform the data from the scale of 0.9996 to 1. DVW (2020) detailed described the ways to get scale 1 in the projected coordinate systems. The instruction presented the transformation techniques to stake out a planning project in CRS with the scale 1. But for the purposes of the current investigation, the scale 1 is possible to reach only in a post-processing. The demand in such manipulations caused by an ambiguity between the planned and constructed object, for every 100.0 m, the difference are 0.04 m. The longer objects, the bigger difference occurs. That is the reason of high importance in a search of a solution of the presented task. Therefore, this challenge was completed in a specific way.

As a GNSS measurement completing in a WGS-84, the resulting coordinates of the measurement points can be transformed into another CRS directly in the controller. It get a choice of the needed reference properties. These points are required to define the coordinates of a total station at the point, from where conducting the following measurements. Applying the program setting "Free Station", this task has been done. The coordinates were calculated in the BRD33-ETRS-NHN16 system. Computation possibilities of the Leica Nova TS 60, allows display a result of the measurement of the targets in the meters or degrees. Moreover, the raw data (distance, horizontal and vertical angle) also available for further calculation. For the usual surveying tasks the availability of the calculated coordinates in chosen CRS is very helpful, it spends a lot of time. But in the case of an investigation, this benefit is not applicable. As the scale of a UTM CRS is 0.9996 and required for a BIM 1.0, the resulted coordinates are not correct for our purposes. It was decided to calculate the coordinates of the targets using the polar method, which means a calculation of the coordinates of the point, applying directly to the north, horizontal angle, and a distance to the target. In the row data, the distance displaying without a CRS scale correction, what allows the assumption of the correctness of the calculated coordinates related to a BIM scale 1.0.

6.1. Processing of the laser scanning data and aerial imagery.

When the data collection is ended, begins the most continuous phase of the investigation. The bulky amount of the data needs to be interpreted, oriented, and connected to one point cloud. Data captured from a TLS, preparing in the Z+F Laser Control software. Firstly, the laser scanning data need to be registered and scan positions need to be connected with a deviation less than 2 mm. As shown in Fig. 5.4 all connections in green are correct. To georeference the model, is required registration with the targets. The list of coordinates uploaded to the software in the .txt format. The targets marking on every scan position when they are visible (Fig. 6.1). Some scans contain cut scenes, where targets are scanned in higher resolution.

Figure 6.1 Marked targets on the scan

When all previous steps are completed, in the additional module named Scantra the error control and final registration were completed. The connection of the scan positions occurs by the finding of the common surfaces between the scans. When automatically not the all positions connected, it is possible to do a manual surface selection (Fig.6.2).

Figure 6.2 Selection common surfaces on scan positions 14 and 26.

When the all scans connected with a green or at least yellow line, registration is completed acceptably. In order to transform the scans into the correct coordinate system, a setting “Global block adjustment” needs to be activated. After the background calculations, appearing the report with adjusted translation parameters of stations, adjusted global point coordinates (Table 6.1), and residuals of the transformation parameters.

Table 6.1 Adjusted global point coordinates

No	Point	x	y	z	sigma_x	sigma_y	sigma_z	sigma_p
1	TARGET1	33391656.594	6026212.699	7.035	0.0013	0.0012	0.0017	0.0024
2	TARGET102	33391696.776	6026290.926	3.701	0.0018	0.0018	0.0025	0.0036
3	TARGET146	33391713.562	6026300.451	4.118	0.0016	0.0015	0.0021	0.0030
4	TARGET176	33391705.933	6026310.483	4.016	0.0016	0.0015	0.0021	0.0031
5	TARGET2	33391649.879	6026233.711	3.036	0.0013	0.0013	0.0017	0.0025
6	TARGET3	33391632.598	6026220.454	3.313	0.0012	0.0012	0.0015	0.0023
7	TARGET4	33391673.117	6026261.079	3.111	0.0014	0.0014	0.0020	0.0028
8	TARGET5	33391705.953	6026270.718	3.546	0.0014	0.0014	0.0020	0.0028

The table columns marked in a red, shown the mean deviations of each target in the relation to standard values. The available values satisfy the error range for the investigation. Therefore, is possible to start the next stage of a TLS data preparation –

scan unification.

To simplify a work with the laser scanning data, several scan positions could unify and index together. For that purposes mostly using an Autodesk ReCap. Manipulating with a point cloud in different formats (.pts, .e57, etc) is possible in this software. The two tasks completing parallel in the ReCap: registration and indexation (Fig. 6.3).

Figure 6.3 Process of indexing in ReCap

This step is quite unsophisticated, but depends on the amount of a data and can complete a few hours. Afterward, were created one separate file contains an all scans within.

On the Figure 5.4 presented workflow of the data processing from the software selection to the point clouds merging.

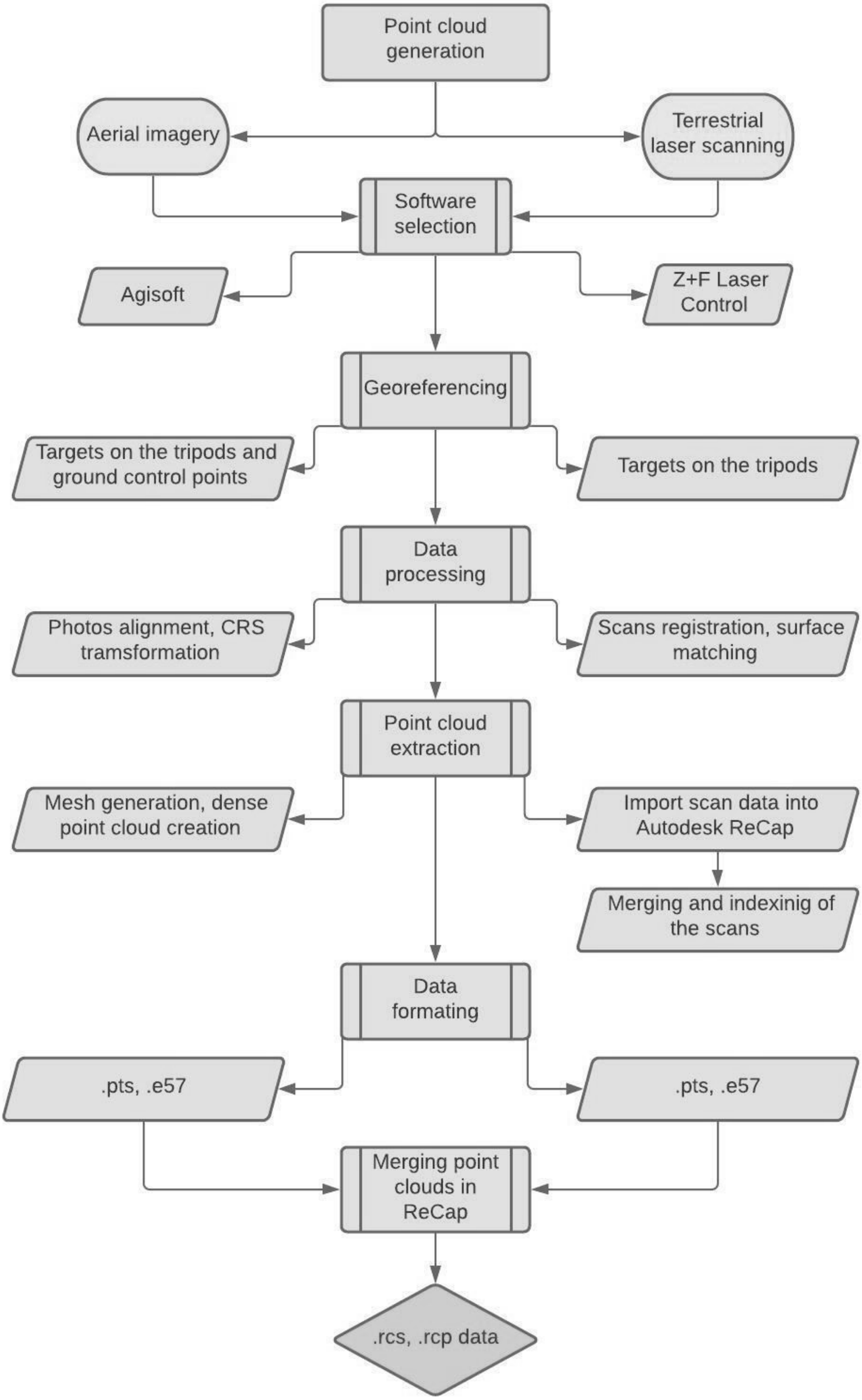
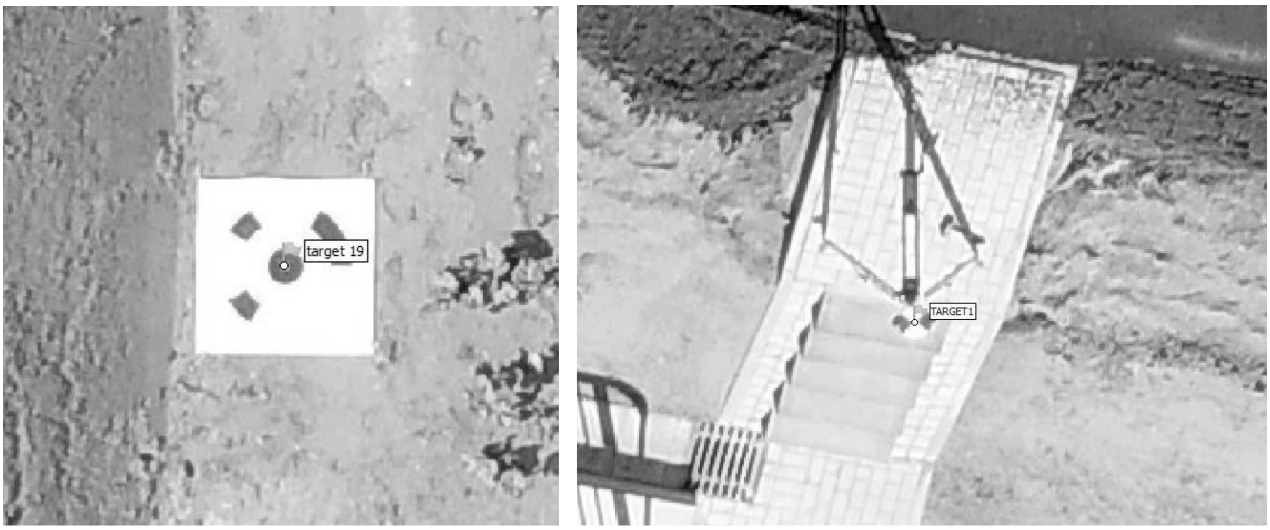


Figure 6.4 Schematic presentation of the point cloud generation

To recreate a full coverage of the study area is a demand in aerial imagery. As described above, two flight missions were completed, around 800 photos were made. Similar to the TLS processing, aerial imagery needs to be georeferenced and orientated. This task completing in a software named Agisoft Metashape. All steps are sequential. Images required an orientation using the coordinates of the image centers. Then the program algorithm will calculate the approximate positioning of each camera.

In order to reach a higher reference precision, on a site were measured control points with a GNSS in RTK mode additionally. The importance of this procedure arises from a demand to improve the precision of the height (Z value). Therefore, a function of the adding ground control points onto the images was applied. It is necessary not only to improve a Z error value, but also to check the correctness of the X and Y values. The list of the coordinates is possible to load as a separate file or to write the values manually. Then, each point on each image, if it is located there, needs to be marked manually (Fig. 6.5). Again, this procedure is quite similar to the marking targets of a TLS.



a) b)

Figure 6.5 Recognized targets in the Agisoft: a) ground control point b) a target on the standing

When each target is placed on the images, the table with coordinates will be showing the columns with error accordingly X, Y, Z axis, and the mean value. After an orientation cameras again, and refreshing of the project data, the values can change a bit. Afterward, the referencing completed, the data is ready for the following processing. Depending on the goals and the level of a detailing, the error range of the referencing can vary. In this case, the following values threshold was reached (Table 6.2).

Table 6.2 Errors in referencing ground control points

Target name	Error X	Error Y	Error Z	Mean error	Projections	Pixel error
TARGET 1	-0,013 m	-0,015 m	-0,038 m	0,043 m	54	0,448
TARGET 2	-0,015 m	-0,011 m	-0,032 m	0,037 m	45	0,445
TARGET 3	-0,007 m	-0,020 m	-0,035 m	0,042 m	60	0,503
TARGET 14	-0,024 m	0,009 m	0,022 m	0,034 m	29	0,375
TARGET 19	-0,027 m	0,0005 m	0,007 m	0,022 m	65	0,496
BR-ECKE	0,004 m	-0,008 m	-0,011	0,015 m	37	0,8

The outcome result of the processing an aerial imagery is a cloud of the point. In the Agisoft is possible to generate a dense cloud from the imagery, contains a space coordinates in the selected CRS and the values of a brightness of the each point in the RGB format. The point cloud required file extension supported by the further software. For the uploading into the ReCap is recommended to save a point cloud in the .pts or .e57 extensions.

As well, as with a TLS data and with point cloud generated from the aerial imagery, in the ReCap software completing indexation and registration of the data. The main reason for using of this software is to connect two point clouds in one scan file. This function organizes the data well and preparing to import into the following software for the modeling. Moreover, in a ReCap, some tools simplify a point cloud and filter the noise. For a TLS data, several scan positions can be unified.

Registered point cloud from an aerial imagery reached ~ 4 GB and TLS point cloud ~ 9 GB. To improve the visualization, the point clouds are represented in different colors (Fig. 6.6).

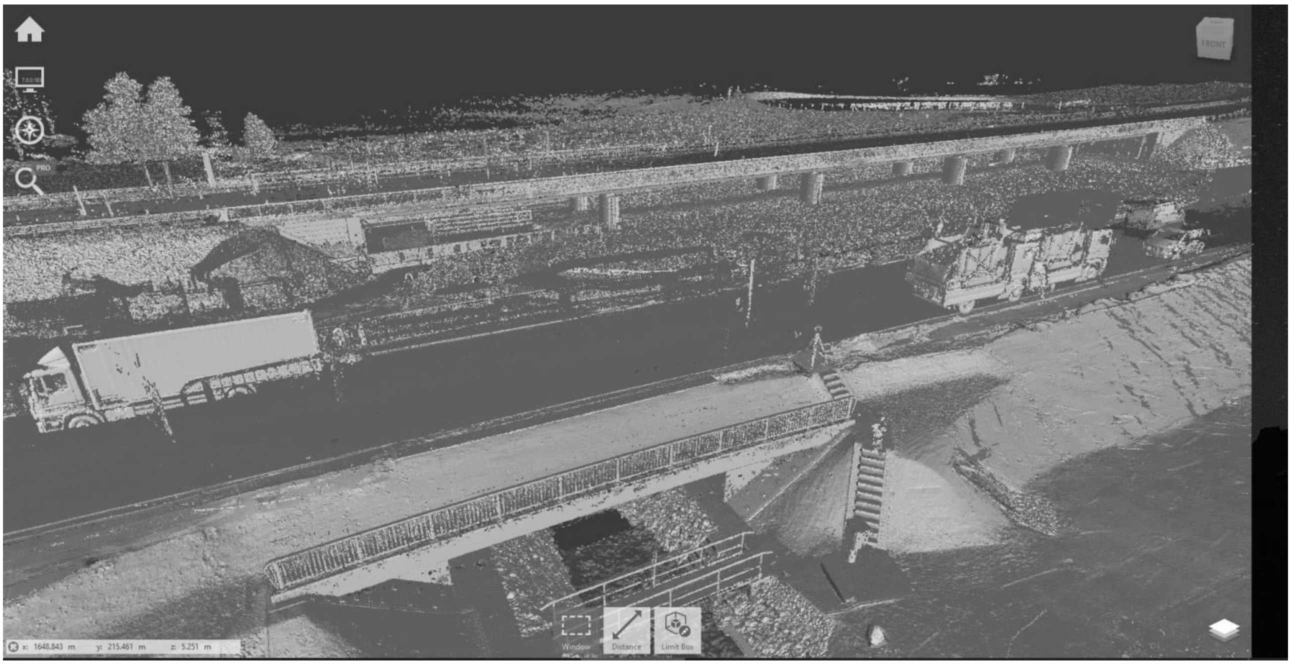


Figure 6.6 Point cloud captured from the laser scanning (green) and from the aerial imagery (pink) in a ReCap software.

When previous steps completed, the data is prepared, and the process of a 3D modeling with a further implementation of a BIM can begin. The point clouds are referenced and unified in the one file and saved in the extension .rcp (project file for Autodesk Revit).

Procedure of recreation 3D model of investigated area

According to the goal of the investigation, the process of a BIM of the infrastructure objects on the example of the two bridges needs to be designed and described. As mentioned in the previous chapters, a BIM is a technology of the extended three-dimension modeling. The finished BIM model contains additional attribute information about the properties, size, cost and type of an object. Depending on the goal, a BIM can be created in the different levels of a detail. In a commercial activity Employer's information requirements (EIR) define a level of a detail. Theoretically, the existing international definition of the two components: Level of the model detail (LOD) relates to the graphical design and Level of the model information (LOI) relates to the attribute data. These definitions are standardized under BS EN ISO 19650, according to which, the five levels of a detailing the BIM classified: LOD 100, LOD 200, LOD 300, LOD 400 and LOD 500. Proportionally to the increasing a detailing, as well increased the value of LOD (BIM Wiki, 2021).

Taking into account analyzed information, decided to complete the modeling in the software Autodesk Revit. The functional possibilities of this software are satisfactory for the BIM as well for the goal of the investigation. First of all, the united file (.rcp) with the point clouds was uploaded into the program. Afterward, need to complete some preparation steps to organize the data, and simplify distinguish of the area. Depending on the user, the checklist before the modeling process can vary.

7.1. Newly built bridge on the road B96 (old)

As a BIM required a lot of the data, which are impossible to get from field measurements, are needed additional planning documents. Thanks to the department of the road development Vorpommern-Rügen county, was provided several documents and drawings of a newly built bridge on the road B96. According to the principle of a BIM, the bridge was divided into the families, which constructing separately in a Revit. All families need to be parametrized and saved. Figures 7.1, 7.2 presented sections of a bridge in the two-dimensional drawings. All provided documents contain the schematic representations of the bridge sections and attribute data about the physical dimension and material properties. According to the available information is possible to recreate a 3D model precisely, with further perspective of the integration to the BIM.

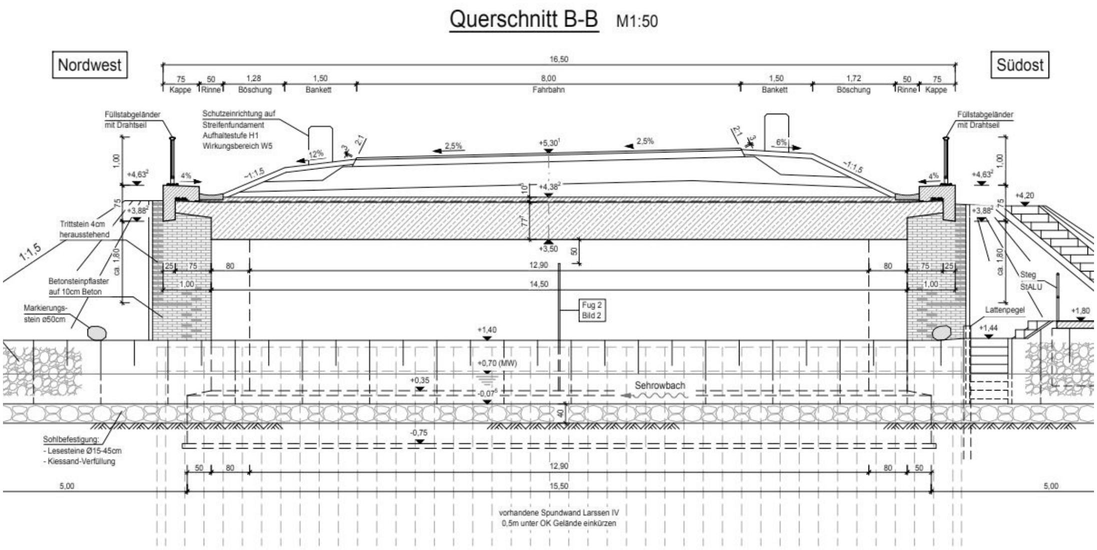


Figure 7.1 Cross-section of a bridge through the center

During a work process, one question is unsolved. When all dimensions and object properties are known, are the field measurement needed? Regardless of this fact, with available laser scanning data, recreated 3D model can be a lot more precise and with taking into account incorrectness in the building process, which caused deviation from project data presented in the documents.

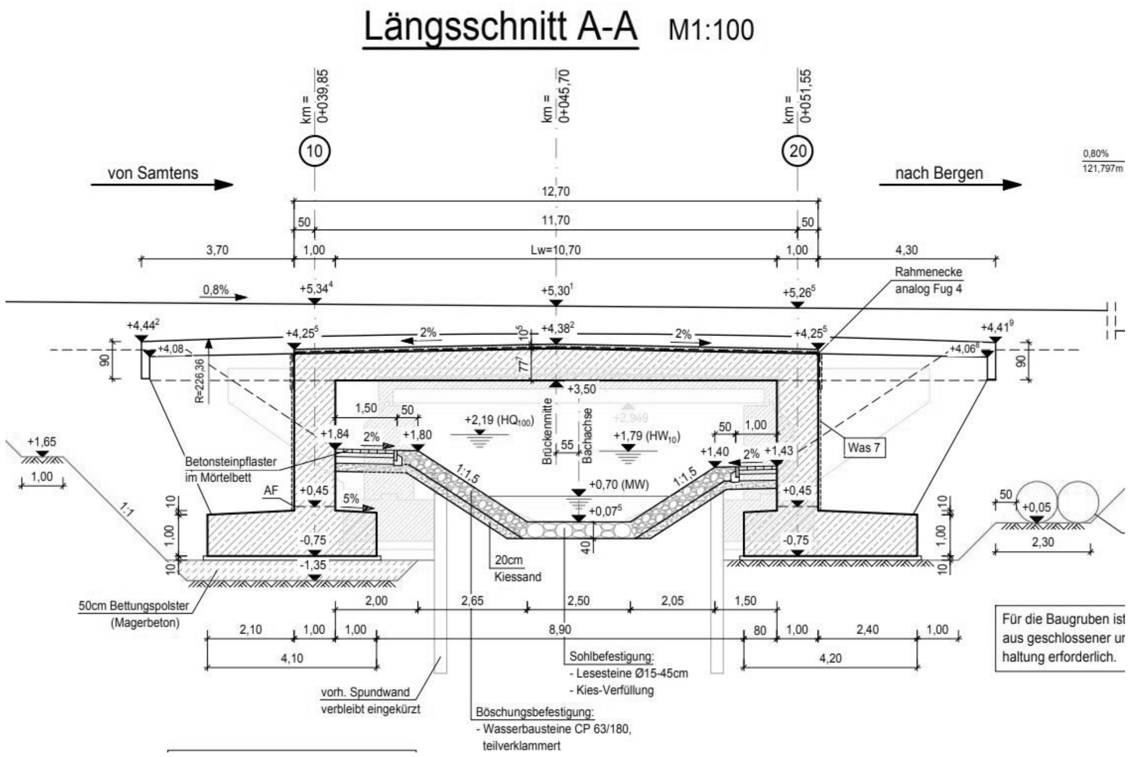


Figure 7.2 Longitudinal section of a bridge through the edge

Therefore was decided to let the project data for the objects located under the ground, or which impossible to scan. And for all visible on a scan data objects, real measured values needs to apply. The final model is presented in the actual dimensions, also getting a possibility of the quality control of the newly built bridge.

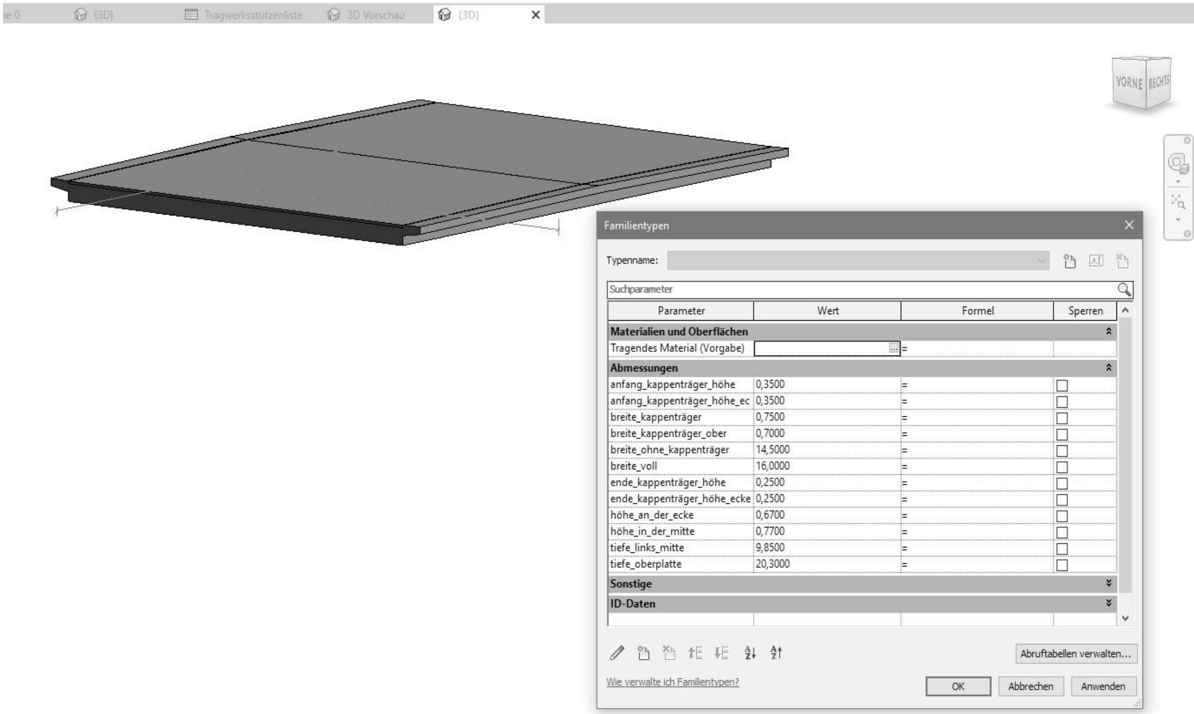


Figure 7.3 Family of higher part of bridge construction

As presented in the Figure 7.3, each family is required to add parameters, in order to provide the attribute information. This is the first step to the implementation of a BIM technology. When the all families are created and saved, the modeling process begins. With using the functionality of a Revit, the components of a bridge were connected in one stable figure according to the project documentation.

In order to expand the model to the BIM, additional attribute information needs to be given. Material of the elements is a very important parameter, which is using as an input parameter for the calculation of the cost, weight, etc. In a Revit software, the model libraries containing a lot of the groups and types of materials, with several properties such a physical density, weight, color, etc. Using this parameter, the properties of the model define more precisely. Another highly important parameter is a volume. Revit algorithms allow calculate a volume automatically for some types of the families, but not for all. Availability at least material properties and volume get a more extended representation of the model, quite close to a BIM. That fact directly indicates the high actuality of the project documentation for the already built infrastructure objects.

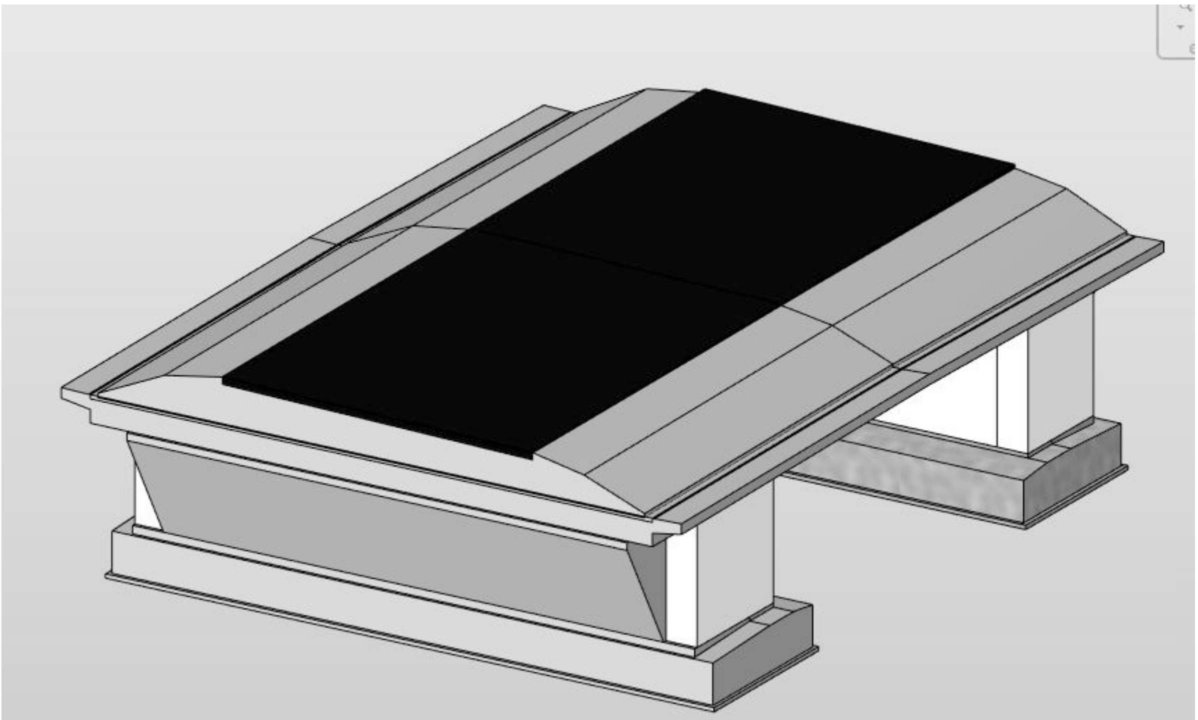


Figure 7.4 Recreated 3D model of a new bridge through the road B96

Figure 7.4 presented the 3D model of a newly constructed bridge. This is a raw model, contains only the components with project dimensions. That means a perspective of extending to a BIM. At the following, stages needs processing of the attribute data. Revit software ensures a full workflow of a BIM technology, beginning from the drawing to the stage of exporting and visualization. To reach a LOD 300 of a BIM is required to add the general information about the components of the model. Having the data about the volume and material, is possible to add a computed parameter of a price. It is realizing through the multiplication of the volume on a price per m^3 of the material. Addition cost to the model properties extends 3D to 4D according to *Gleason, (2013)*. In the frame of this educational investigation is not correct to assume or define the level of a development of the BIM and if the result really reached a BIM level.

Regarding a Revit specifications, were created the tables with an attribute information (Fig. 7.5, 7.6) containing calculated price per component, based on the market price of materials per m^3.

<Tragwerksstützenliste>				
A	B	C	D	E
Familie und Typ	Volumen	Tragendes Material	Kosten pro m^3	Kosten pro Bauteil
STB Stütze - rechteckig: STB 300 x 500	38,59 m³	Ortbeton - bewehrt Verputzt	117	4514,80
STB Stütze - rechteckig: STB 300 x 500	38,59 m³	Ortbeton - bewehrt Verputzt	117	4514,80
STB Stütze - rechteckig: STB 300 x 502	7,72 m³	Ortbeton - bewehrt Verputzt	117	902,67
STB Stütze - rechteckig: STB 300 x 501	6,59 m³	Ortbeton - bewehrt Verputzt	117	771,56
STB Stütze - rechteckig: STB 300 x 502	7,79 m³	Ortbeton - bewehrt Verputzt	117	911,81
STB Stütze - rechteckig: STB 300 x 501	6,61 m³	Ortbeton - bewehrt Verputzt	117	773,80
Ortbeton - bewehrt Verputzt	105,89 m³			12389,44
Stütze Betonplatte 001: Stütze Betonplatte 001	221,19 m³	Beton, C40/50	143,5	31740,29
Stütze Baufundament 100: Stütze Baufundament 100	176,74 m³	Beton, C40/50	143,5	25362,73
Stütze Baufundament 200: Stütze Baufundament 200	200,01 m³	Beton, C40/50	143,5	28700,74
Beton, C40/50	597,94 m³			85803,77
Gesamte Volumen	703,83 m³			98193,20

Figure 7.5 Attribute table for the structure columns components

In Revit is possible to create the table according to their type, therefore were presented two separate tables for the generic models (Allgemeine Modelle) and for supporting columns (Tragwerkstütze).

<Bauteilliste für allgemeines Modell>				
A	B	C	D	E
Familie und Typ	Volumen	Material	Kosten, pro m^3	Kosten pro Bauteil
Befestigungsaufbau 001: Befestigungsaufbau 001	119,72 m³	Umgebung - Rollierung Schüttung	500	59858,71
Befestigungsaufbau 002: Befestigungsaufbau 002	116,67 m³	Umgebung - Rollierung Schüttung	500	58334,67
Umgebung - Rollierung Schüttung				118193,39
Asphalttragschicht 002: Asphalttragschicht 002	11,70 m³	Asphalt, Bitumen	184	2153,54
Asphalttragschicht 001: Asphalttragschicht 001	11,03 m³	Asphalt, Bitumen	184	2029,89
Asphaltdeckschicht 001: Asphaltdeckschicht 001	3,15 m³	Asphalt, Bitumen	184	579,97
Asphaltdeckschicht 002: Asphaltdeckschicht 002	3,34 m³	Asphalt, Bitumen	184	615,30
Asphalt, Bitumen				5378,69
Gesamt				123572,07

Figure 7.6 Attribute table for the structure generic model components

The price of the material is taken from the internet market places. The resulting values in EUR in the column "Kosten pro Bauteil" are approximated, and calculated only for example. According to mentioned above requirements for the BIM, may assume that the created model of a bridge (Fig. 6.4) with the attribute information (Fig. 6.5, 6.6) can be classified as a BIM with a LOD 300.

7.2. Bridge on the road B96 (new)

As mentioned in a chapter *Area of the investigation*, two bridges are located in the interested area. One bridge on the new road B96, and another bridge on the old B96 road, built in 2021. Described above procedure of a BIM for the new bridge is not acceptable for the second bridge. This is possible having enough data: a point cloud and the project documents. As for the bridge on the new B96 road is not provided any project documentation and is available only the TLS data, BIM can't be created. Because the functionality of the modeling is very restricted, recreated model of the bridge can be not more than simple 3D model.

Anyway, it is a useful for research purposes to compare processing in the different conditions and with a different amount of the available data. Moreover, the main goal of the modeling bridge on a new B96 road is recreation of the inclination of the bridge body, and their rotation along the central axis using the Revit tools.

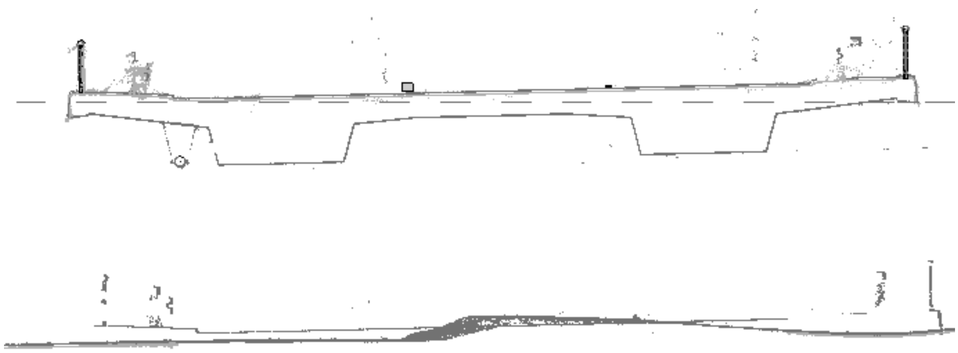


Figure 7.7 Vertical profile of the bridge (start view)

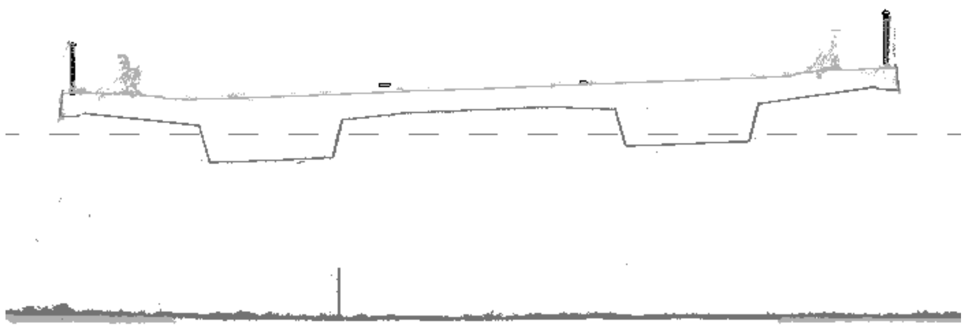


Figure 7.8 Vertical profile of the bridge (end view)

Fig. 7.7, 7.8 presented the view of the bridge body profile at the end and the beginning of an object. In the green color presented a point cloud from the TLS, and in an orange point cloud from the aerial imagery. The task is to recreate with a high precision a body of the bridge. After several attempts to find the suitable instruments within the Revit, was decided to continue research of specific add-ons. In process of analysis, was found an add-on, named SOFiSTiK Bridge Modeler. According to the main functions of the presented add-on, is possible to recreate the longitudinal and latitudinal profile of the bridge on the investigated area. In the menu of the SOFiSTiK Application Manager (SAM) the selected type of add-ons or separate software can be selected.

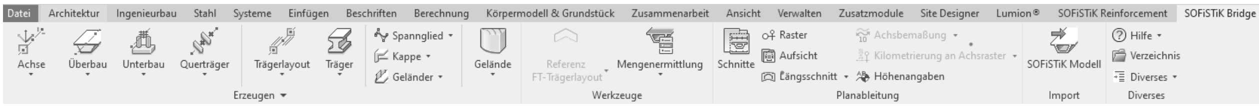


Figure 7.9 Tools of the SOFiSTiK Bridge Modeler

In the case of a current investigation, the central axis of the bridge uploaded into the Revit. Applying the functions of the SOFiSTiK, a body of the bridge, parapet, railing, and coverage were created. Together with the program data of add-on, downloading the families for every type of the component presented on a tool panel. It is very helpful by planning the new bridges, all procedures users need to complete are clear and simple for understanding. As the main goal of the investigation is a recreation of the still existed bridges using the point clouds from the TLS and aerial imagery, the use of the SOFiSTiK is more complicated. Simply explaining, in the case of the current investigation, all instruments of this add-on as well as a BIM technology, need to be applied inversely. It means, that axis and all components need to be fitted to the forms, drawn by point clouds. This procedure increases a time for the recreation a 3D Model but decreases a quality. Anyway, the following methodology was implemented.

The central axis (Fig. 7.10) of a bridge was created firstly. The coordinates of the 7 points were taken from the marking of the road and added to the .txt file, which was uploaded into SOFiSTiK. As for this bridge not provided the project documentation, all dimensions need to be fitted accordingly to the point cloud data. Defining dimensions of every element of the bridge requires a lot of the time. That is the main disadvantage of the inverse BIM modeling, when required to build a model of the real object.

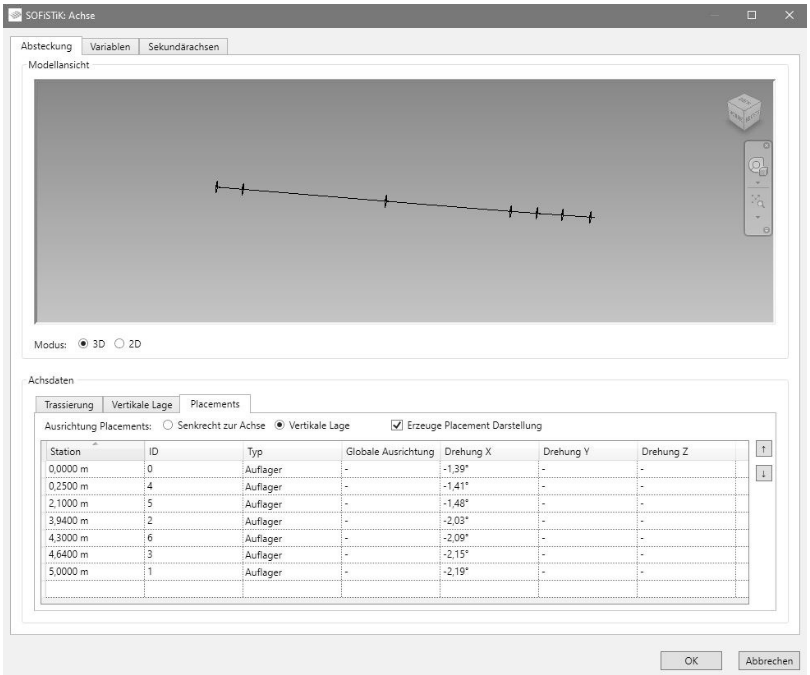


Figure 7.10 Axis of the bridge with a rotation on the placements

In the column “Drehung X” showed the values of an inclination the axis on the placements. The next projected part of a bridge is a body (Fig 7.11). The suitable form is available in the SOFiSTiK families.

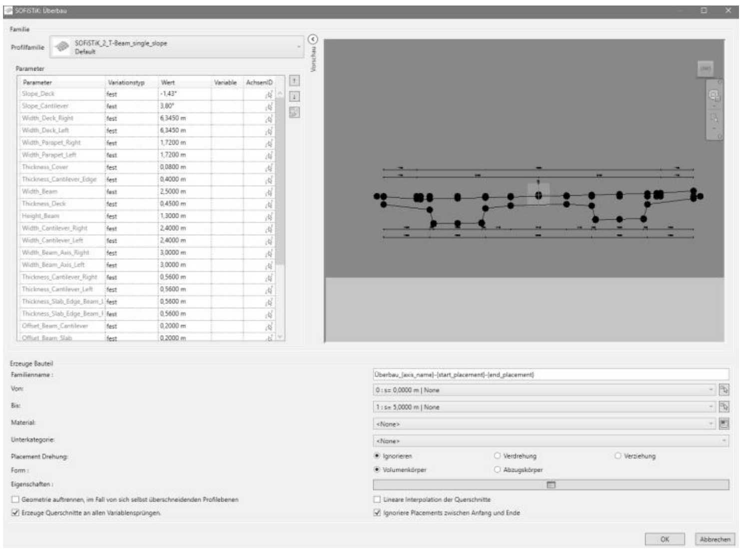


Figure 6.11 Parameters of projected body of the bridge

To set the parameters into the family properties, all dimensions need to be measured manually from the point cloud.

When all components of a bridge are recreated and don't fit precisely, the rotation parameters of the axis placements can be changed and accordingly all components will be changed. To summarize, the advantages of the SOFiSTiK Bridge Modeler are the possibility to recreate the long transportation infrastructure objects (bridges, roads, train lines, path walks, etc), parametrization of the families, and the possibility to create the own family for using inside this add-on. The main disadvantage is low suitability for work with the point cloud data, a user must measure manually the dimensions of the component. All in all, by applying this add-on was reached the goal. The 3D model of a bridge (Fig. 7.12) is created taking into account only visible elements above the ground.

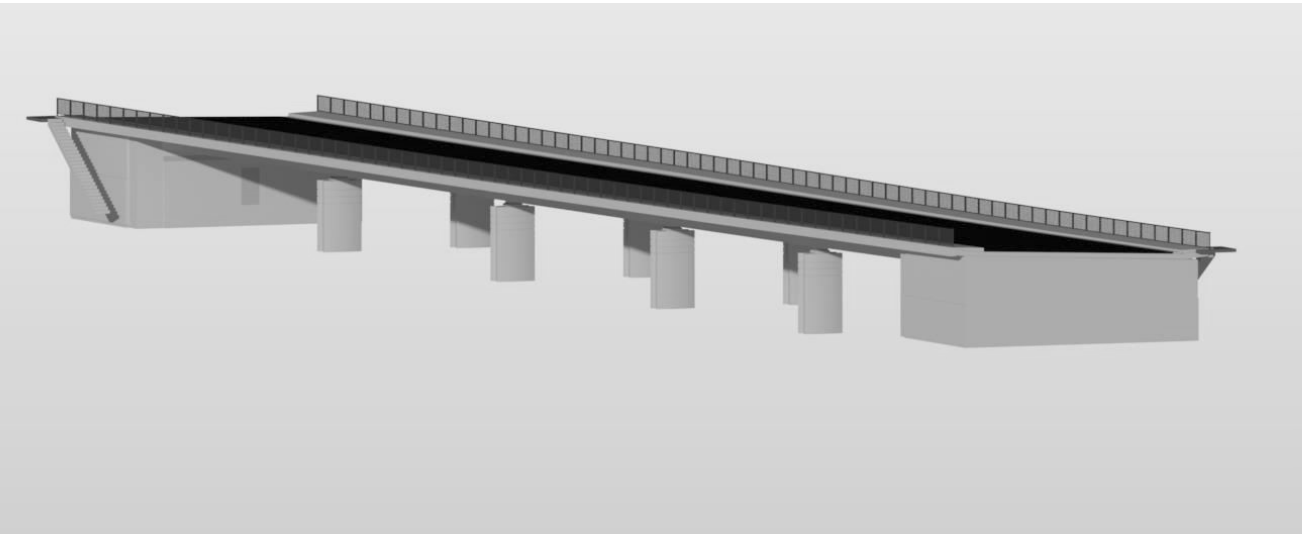


Figure 7.12 3D model of a bridge on new road B96.

At this point modeling of the bridges was successfully finished. The following steps of the investigation are the surface recreation and visualization of the whole project.

7.3. Surface modeling

In order to represent a whole investigated area in a digital format, is required to model a surface. One technique to get an elevation of the coverage is the creation of the Digital Elevation Model. In order to do this, some generated data of the elevation are needed. The following steps were completed: simplification and reducing the density of a point cloud, generation of the height lines, surface generation.

In the software Cloud Compare was done a point cloud processing (Fig. 7.13). The number of the points was reduced from around 146 million to 5,5. Accordingly, the size of the file was reduced from 9 GB to 0,6. Another important thing affecting an elevation representation is the surface of the roads and bridges, and the points located on the trees. To avoid an ambiguity of a DEM, the points belong to the roads were deleted and using the program tools, point cloud was divided onto the ground and not ground points, which were deleted. In order to represent a whole investigated area in a digital format, is required to model the surface. One technique to get an elevation of the coverage is the creation of the Digital Elevation Model. In order to do this, some generated data of the elevation are needed. The following steps were completed: the simplification and reducing the density of a point cloud, generation of the height lines, surface generation.

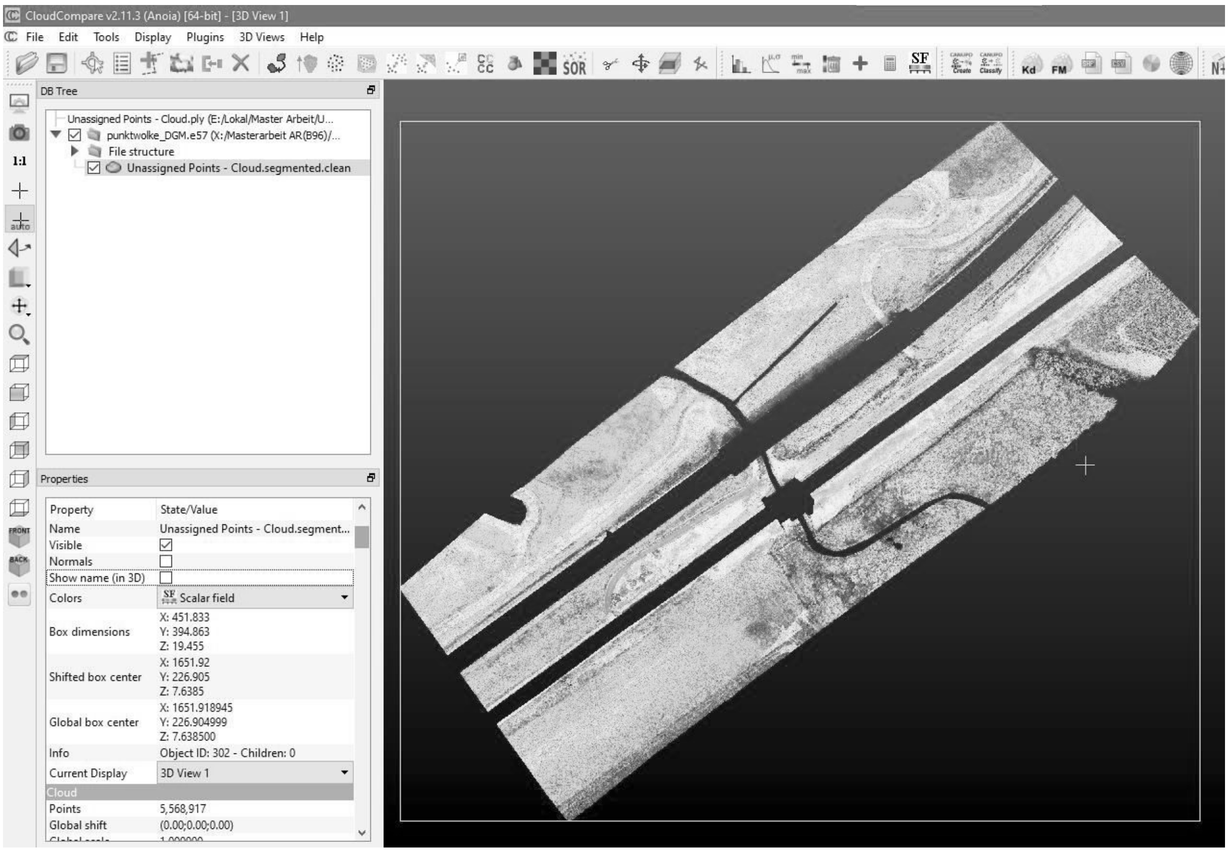


Figure 7.13 Prepared point cloud for the extracting of the height lines

An extracting of the height lines can be completed in the many software such a Cloud Compare, Reshaper, and GeoGraph. The suitable file formats for the Revit are .dxf or .dwg. When required data is available, a further step is an uploading it into the

Revit.

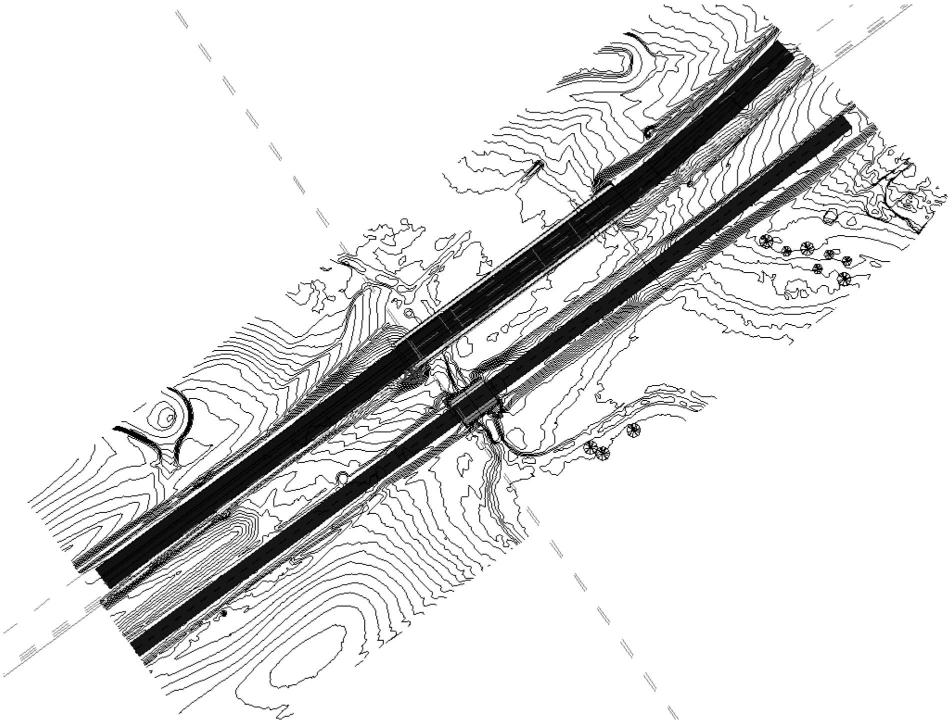


Figure 7.14 Height lines in Revit

The height lines uploaded into the Revit (Fig. 7.14) are presented in 2-dimensional drawings. As the goal of the investigation is a recreation the objects in a 3D, is required to transform the height lines into a 3D format. In Revit it can be done with application the tool "surface creation". Based on the height of the lines, the algorithm generates the coverage in the 3D with the height points of every line. In this view surface is filled with green on the whole area (Fig. 7.15).

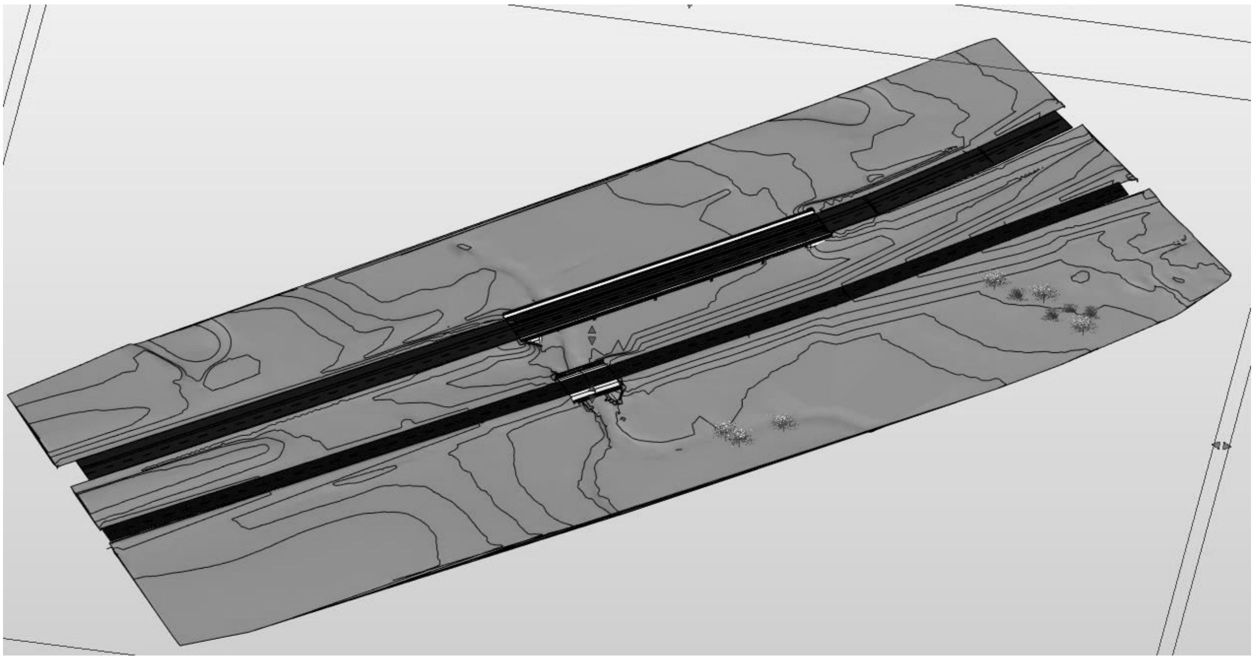


Figure 7.15 Recreated 3D surface of investigated area

7.4. Assessment and visualization

In order to check the quality of the modeling, one simple function was performed. Using the tool of the add-on for the Revit named As-built, the deviation between the model and point cloud was calculated. As shown in the Fig. 6.16, 6.17 an error values are located mostly on the parts of the components located underground and outside of the laser scanner measurement range. It means that this area is not taken into account for the quality control.

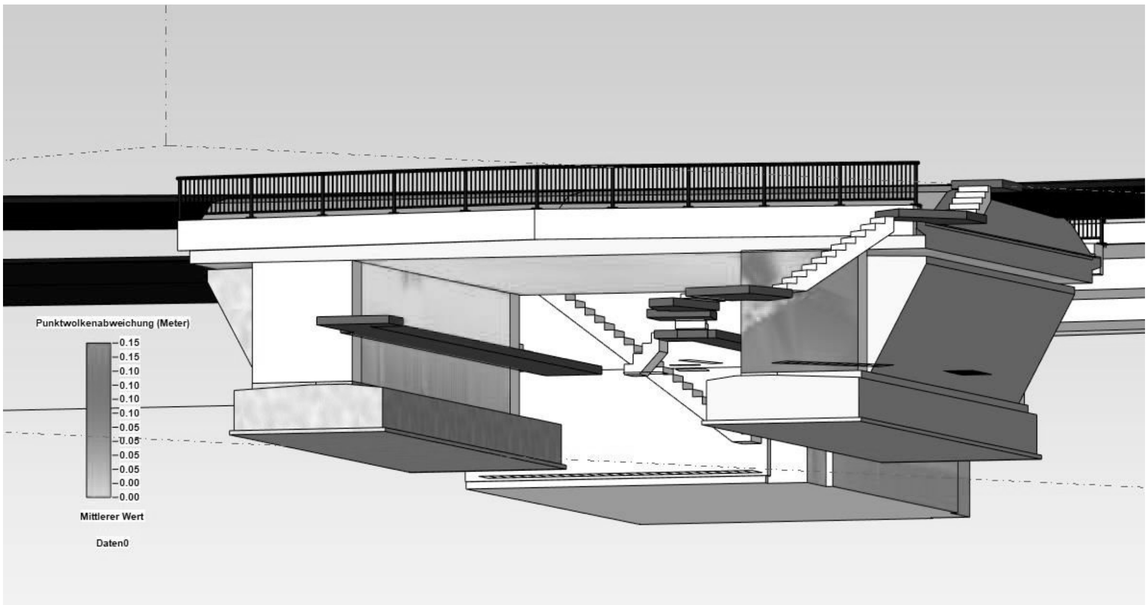


Figure 7.16 Newly built bridge assessment

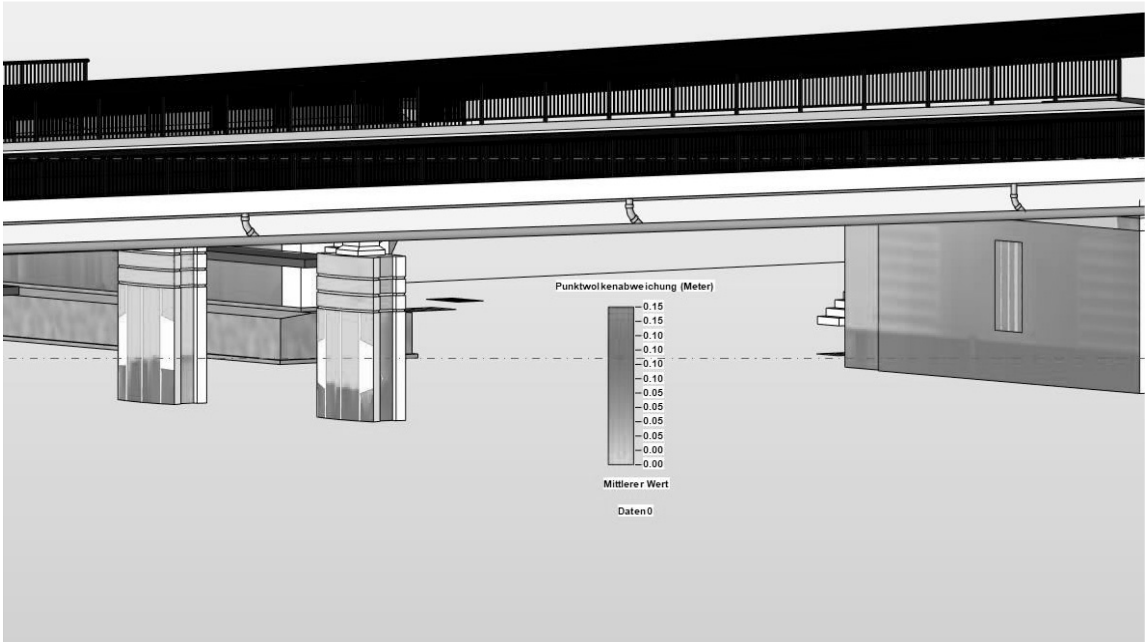


Figure 7.17 Bridge on the national road B96

According to the presented results can conclude, the quality of the modeling is satisfactory. Real error values do not increase the 0.05 meters. That means, the model can be used for further steps of the investigation.

When the modeling process is ended, begins a phase of the visualization and transfers the data into the selected format. During the research, was analyzed some software for the 3D visualization, mostly designed by Autodesk. In each of them were indicated some errors, which did not allow to continue the research until reaching the goal. In Infraworks software with the final version of the project occurred error, which did not allow to visualize the linked project on the preselected coverage. In 3Ds Max was impossible to load a large point cloud for the rendering of the animation. Therefore, were decided to install a student version of the Lumion add-on to visualize the project directly through the add-on.

The main functionality of the Lumion is the visualization improvements and rendering properties. Usage of tools is simple and quick. To open the model from Revit project in the separate program of the Lumion is required to complete the export through add-on in a Revit and save the current model in the .dae file. Afterward, is possible all manipulation with the further view of the model in a

Lumion software.

Figure 7.18 Rendered image of the model of the investigated area

Depending on the author's meaning, the design of the area can be recreated. It is possible to add a layer with an Open Street Map on the background for better recognition of the area. Changing the positioning, elevation, and coverage style are also possible. In Fig. 7.18, 7.19 presented rendered images of the investigated area from different angles.

Figure 7.19 Rendered image of a model of the investigated area

Moreover, the 25 seconds video was rendered, where two bridges showing from different camera positions. Shortly concluding, using a Lumion software can create a visualization in a simple and quick way, what preferring in the commercial organizations.

The last thing in the whole modeling process is the data transfer. For BIM is important to correctly save all relations and properties containing in a project. Therefore, was developed a unique format for a BIM named IFC (Industry Foundation Classes). To export Revit project into IFC format is enough to complete the only transformation to IFC. Then the project will be saved in a selected exporting format.

Summary

To calculate the duration, and in further cost of the investigation, is needed to define how many time were spent for each type of the task. In Table 8.1 presented the following information.

Table 8.1 Duration of each type of the task

Time (working hours)	Type of the task
1 Hour	Exploration of the investigated area. Survey planning
10 Hours 1 Hour 2 Hour	Implementation of the terrestrial laser scanning Implementation of the aerial surveying Georeferencing of the area
8 Hour 8 Hour	Processing and alignment of a TLS data Processing and alignment of an aerial data
12 Hour 24 Hour 8 Hour	Modeling of the new bridge on the old B96 Modeling of the bridge on the new B96 Modeling of the surface of the study area
8 Hour	Visualization and rendering

In a result, were calculated that for a conducting the whole workflow from the field measurements till the visualization, are needed 82 working hours. The part of the field measurements continued 42 hours of the work of the team from two person.

Conclusions

To summarizing, the research is completed. Some questions and tasks are answered and solved, some questions and tasks appeared during the workflow. Several research articles were analyzed, a lot of the technologies in the field of data processing were implemented.

According to the scope of the research, the methodology of a BIM for the infrastructure objects was researched in detail. As a result, were defined some direct conclusions:

- nowadays occurring a spread development of a BIM technologies in the infrastructure, especially for the bridges. In the last years were designed meaning of a BrIM technologies. According to the Trimble Solutions Corporation, (2021) there are the following milestones in a BrIM: 3D visualization, planning and scaffolding, formwork and concrete pours, virtual assembly, automated machine control, smart inventory.
- despite the high relevance of the BIM development, only a few countries already applying a BIM for the infrastructure objects, as well for the bridges instead of the classical 2D CAD drawings: Australia, Norway, Finland, and Sweden.
- from 2020 in Germany began the third phase of the government plan of an implementing of the BIM technologies for all infrastructure objects. That means increasing a demand for a 3D modeling, as well as a capturing the data using a TLS.
- design of a BIM for planned objects and recreation of a BIM for as-built objects are two completely different procedures. As well, as in the case of an investigation, to recreate a BIM of the as-built object needed a cooperation of the competent employees from the field of civil engineering, architecture, and constructions. Only following this way high-quality BIM can be recreated.

In order to complete a 3D modeling of the investigated area was conducted the field measurements such as a TLS, aerial surveying, georeferencing of the area. As a result, were captured data required for the 3D modeling and the beginning of implementing a BIM technology. The workflow was divided into four parts: data preparation, BIM

of the newly built bridge on the old B96 road; 3D modeling of the bridge on the new B96 road; surface modeling, model visualization, quality control and data transformation.
The very important for the BIM is a georeferencing of the model. In order to avoid an ambiguity between the project data and real object dimensions, is recommended to use a scale “1.0”. As in Germany using CRS with the parameters of the UTM, where the scale is “0.99966” was complicated to come out of this situation. After long consideration between experienced employees of Ingenieurteam Nord GbR, for the georeferencing, the area was taken a raw data (distances and directions) for the calculation coordinates of the target. As a result, was proved that a raw data measured by total station do not include the scale corrections.
Thanks to the availability of the additional project documentation for a new bridge on the old B96 road (Fig. 5.8), were designed components not visible from the captured data. Moreover, based on this documentation were added attribute information for every family containing in the model. As a result, may assume that the current data combination allows reaching the level of a BIM.
During a modeling of the bridge on the new B96 road, was conducted recreation of the curved bridge profile along the central axis, with the different angles of an inclination. Applying a specific add-on for the Revit named SOFiSTiK Bridge Modeler for each bridge component were designed families with the correct parameters according to captured data. The suitability of the add-on for design a BIM was proved. For user is allowed to change parameters of available families inside the add-ons library, as well as create their own families for a use in the modeling process.
Applying the software Cloud Compare and Reaschaper, a point cloud was transformed into the height lines, from which was created a 3D height surface in the Revit. Afterward, was conducted visualization improvement and rendering some photos of the model and one video around the whole investigated area in the Lumion software, presented as a separate program and as an add-on for the Revit. The final project version was saved in a IFC format.

The goal of the investigation was reached partially, for one bridge created a BIM, thanks to the availability of the project documentation; for another bridge recreated only a 3D model, because of existing any additional data, which impossible to get from the field measurements. That fact indicates on the demand in a cooperation between the companies working in the field of AEC industries. Unfortunately, surveying companies can not complete the whole procedure of a BIM recreation for the as-built object.

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