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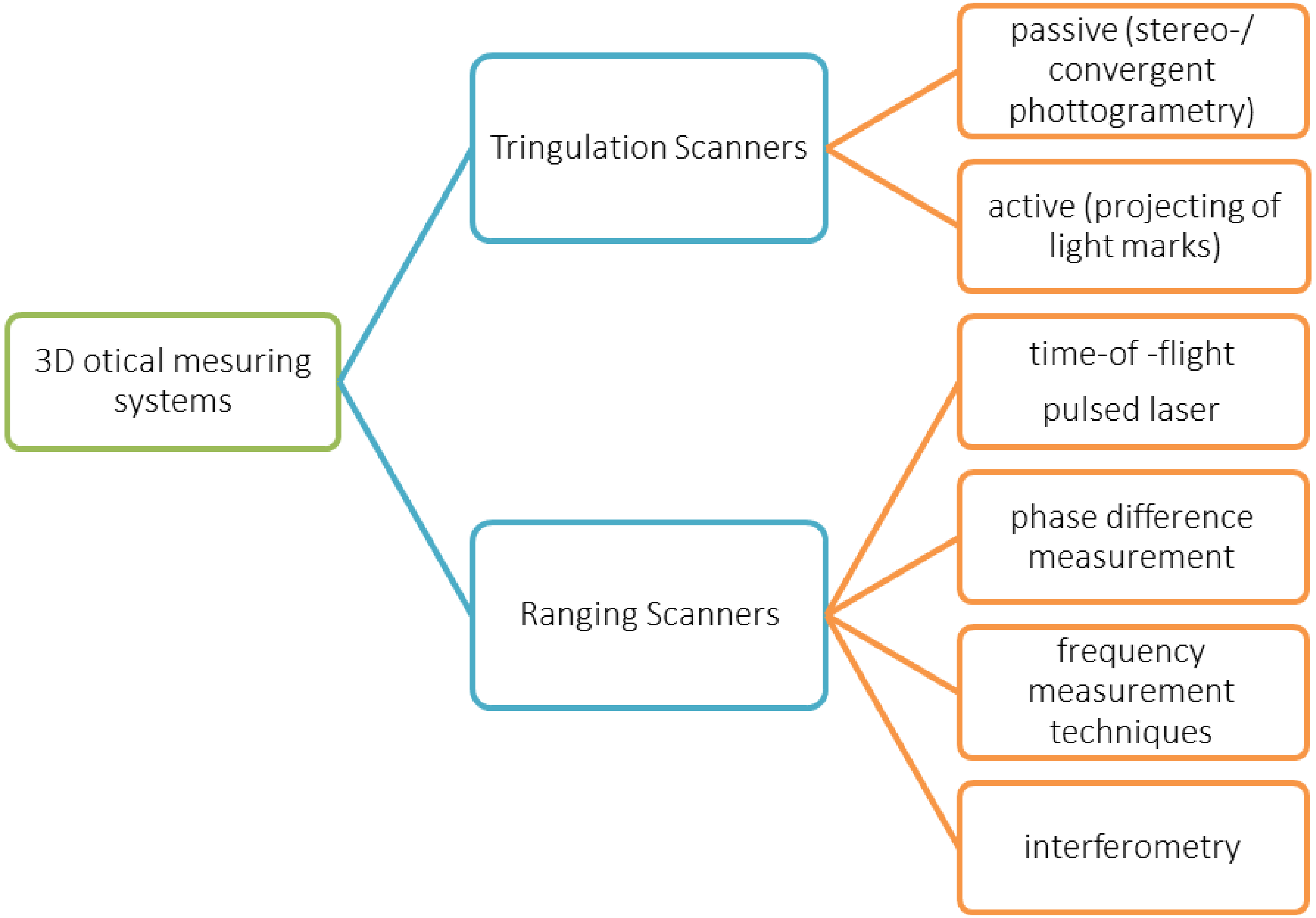
FACULTY OF CIVIL ENGINEERING

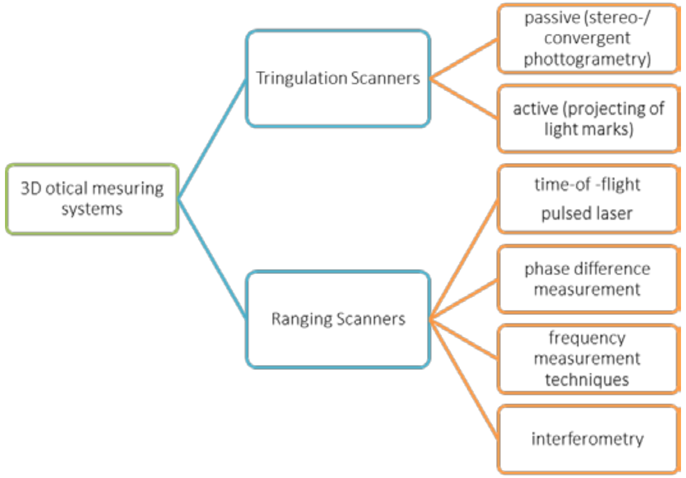
TERRESTRIAL LASER SCANNING AND ITS USE IN ENGINEERING SURVEYING

JÁN ERDÉLYI

3D optical measurement systems



3D optical measurement systems



convergent close-range photogrammetry (bitfab.io, 2020)

3D optical measurement systems

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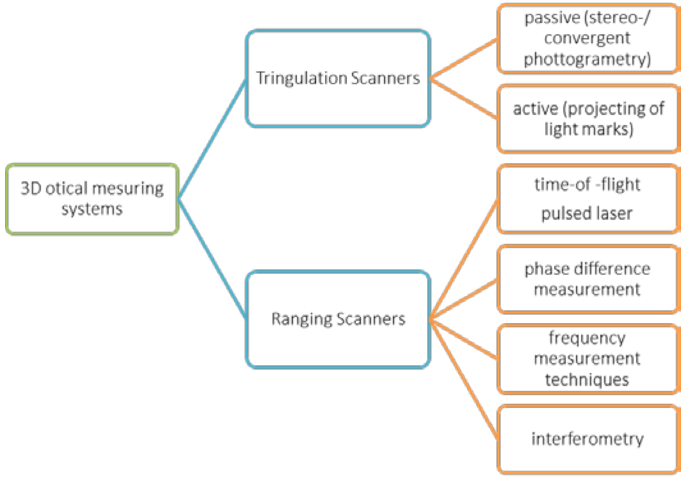
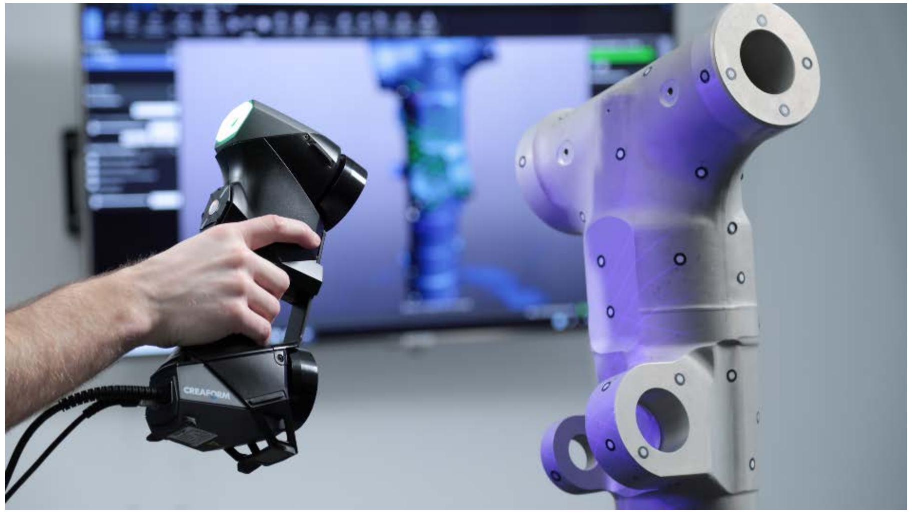
- 3D otical mesuring systems
  - Tringulation Scanners
    - passive (stereo-/ convergent phottogrametry)
    - active (projecting of light marks)
  - Ranging Scanners
    - time-of -flight pulsed laser
    - phase difference measurement
    - frequency measurement techniques
    - interferometry

RPAS prhotogrammetry (Buczkowski, 2018)

3D optical measurement systems





HandySCAN 3D
(creaform.com, 2020)

accuracy: 0,025 mm
Measurement range: 0,05 m – 4,00 m

HP 3D structured light scanner PRO S3
(hp.com, 2020)

accuracy: až 0.05% (až 0,05 mm)
Measurement range: 60 mm – 500 mm

3D optical measurement systems

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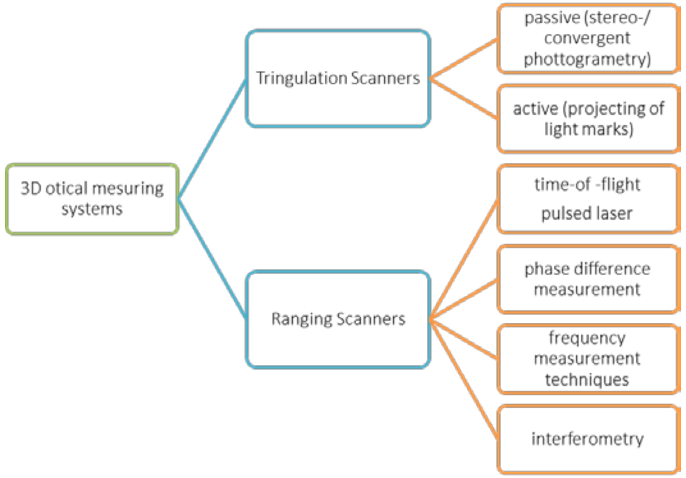
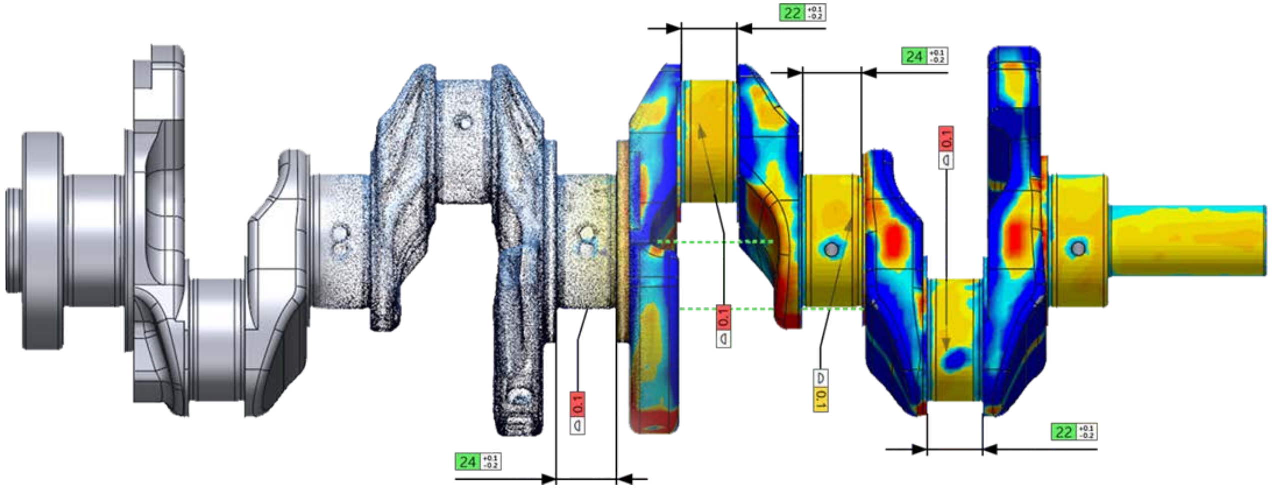


Leica T-SCAN
(Hexagon, 2015)

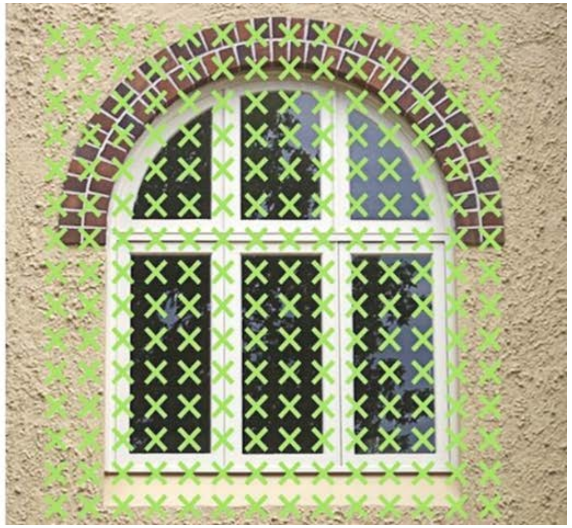
accuracy (dist.): ± 26 µm + 4 µm/m
accuracy (plane): ± 80 µm + 3 µm/m
Measurement range: Φ 60 m



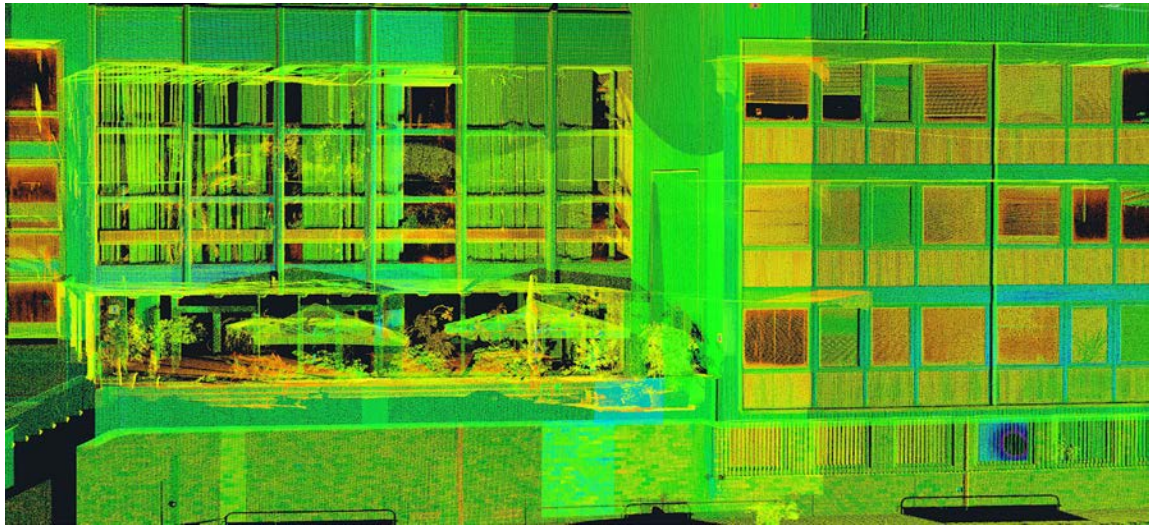
Quality inspection
(artec3D.com, 2020)

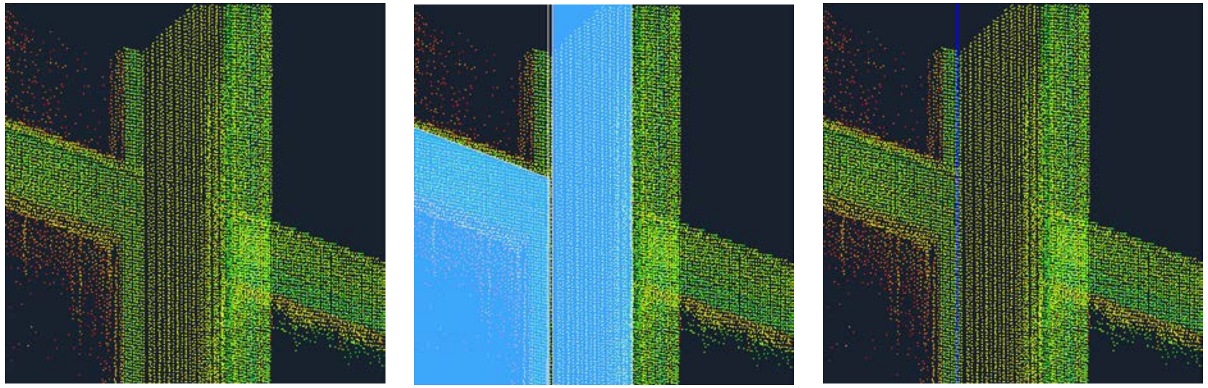
Laser scanning systems

- Non- selective method



- Point cloud

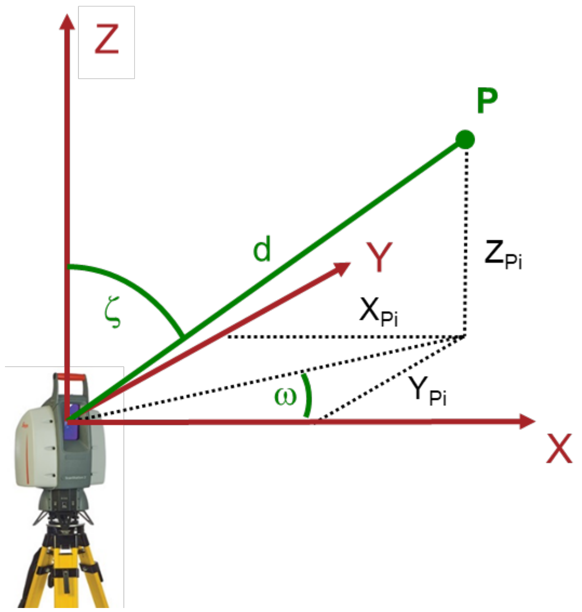




Modeling of the edge of a frame

Laser scanning systems

- Polar method



- Distance measurement
  - Pulse time-of-flight
  - Phase difference measurement
  - Frequency measurement, Interferometry

Laser scanning systems

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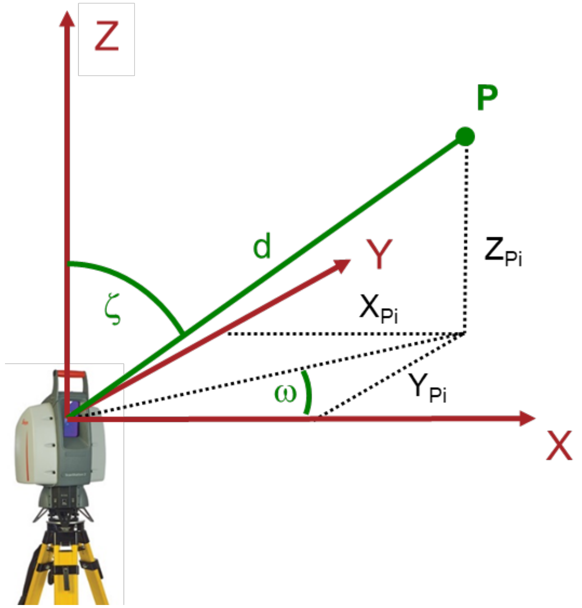
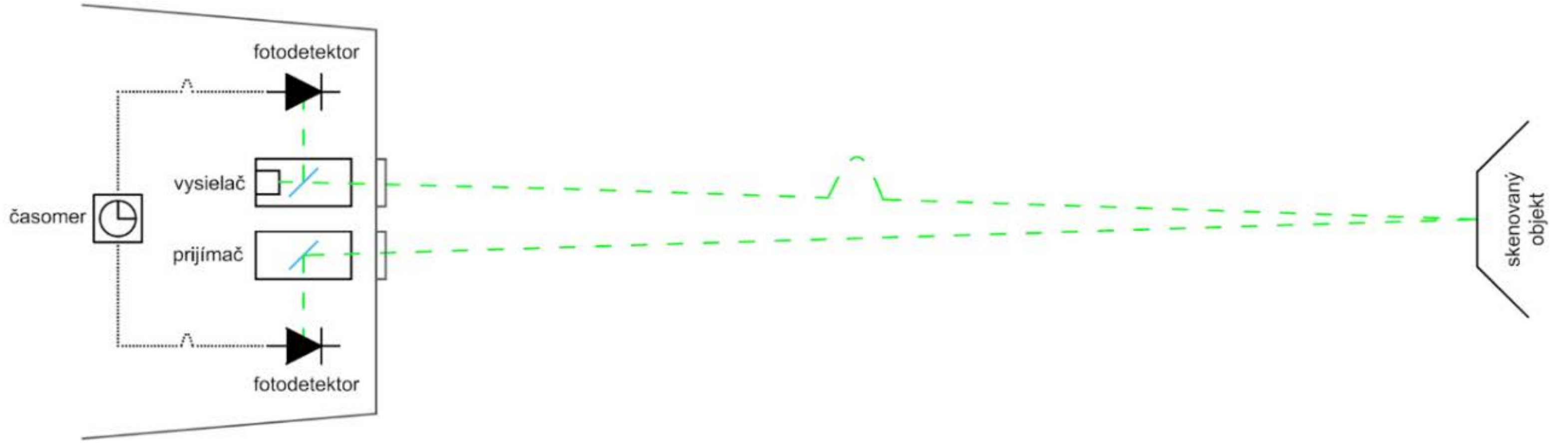
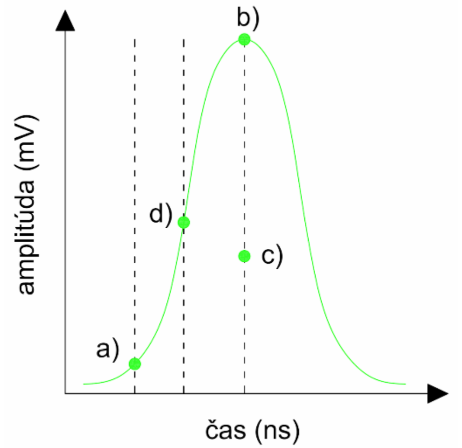
- Polar method





- Distance measurement
  - **Pulse time-of-flight**
  - Phase difference measurement
  - Frequency measurement, Interferometry

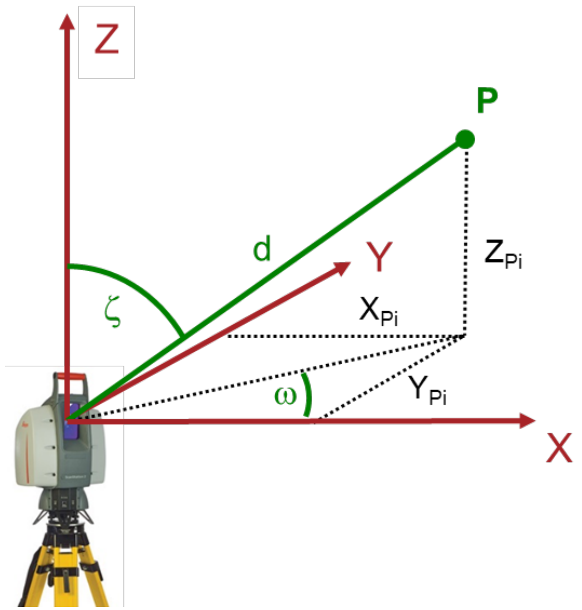


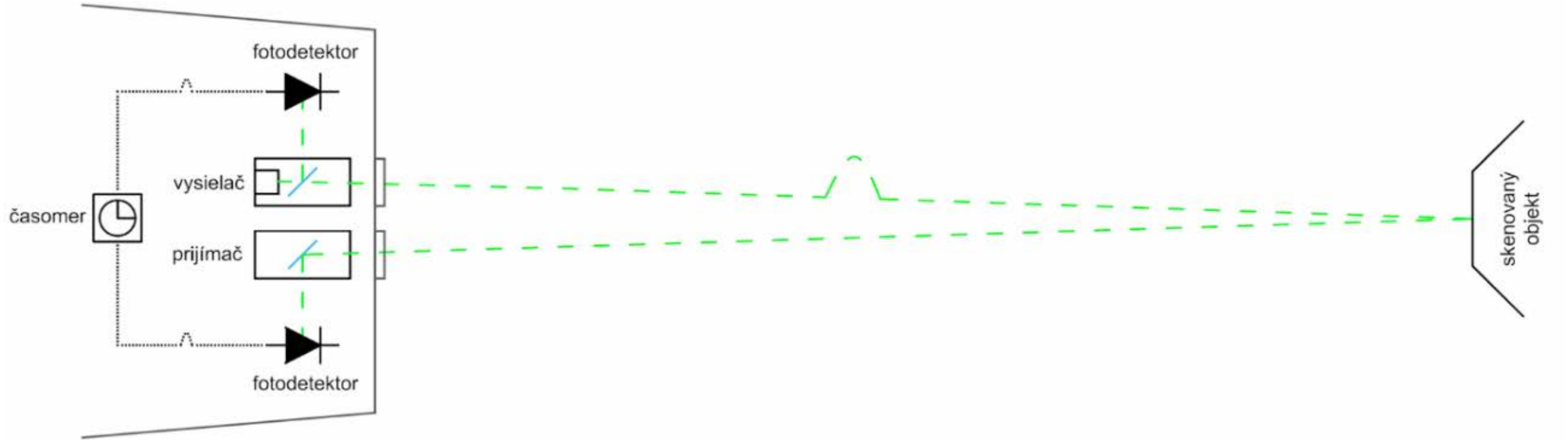
Pulse detection:

a) leading edge, b) peak c) center of grav. d) constant fraction

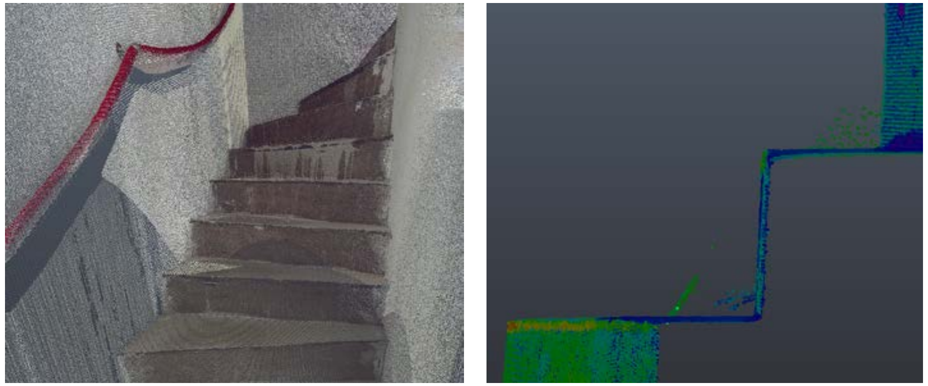
Laser scanning systems

- Polar method

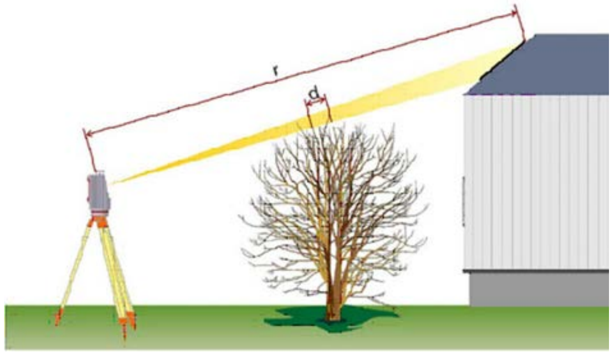




- Distance measurement
  - **Pulse time-of-flight**
  - Phase difference measurement
  - Frequency measurement, Interferometry



multiple reflection – edge effect



multiple reflection

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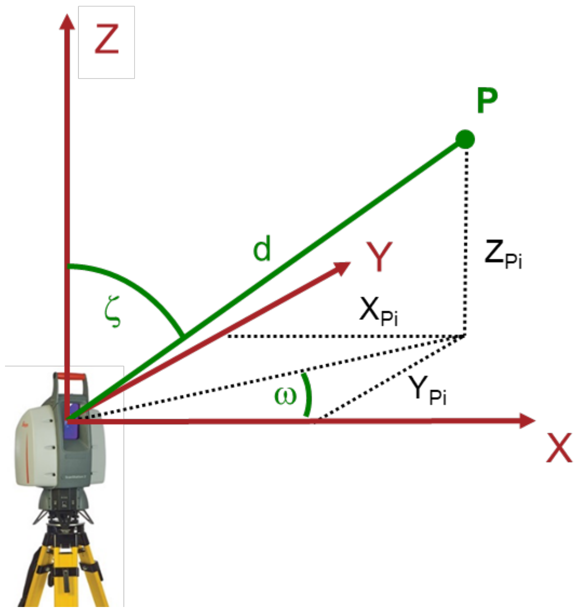
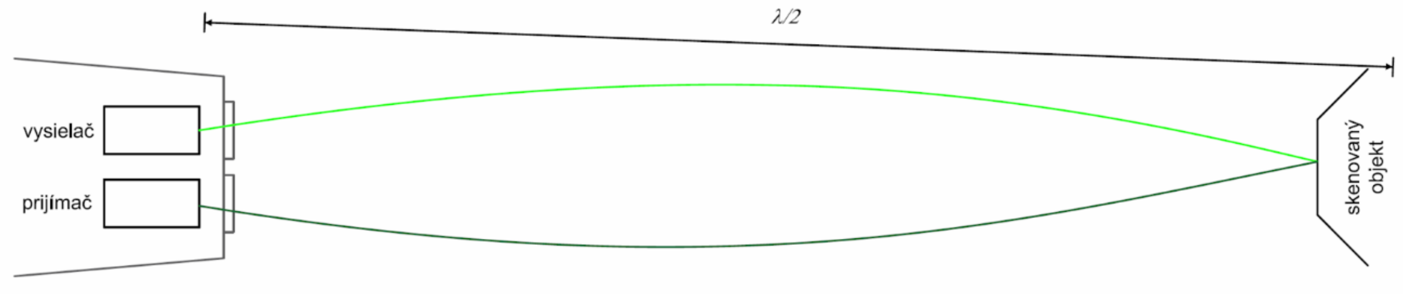
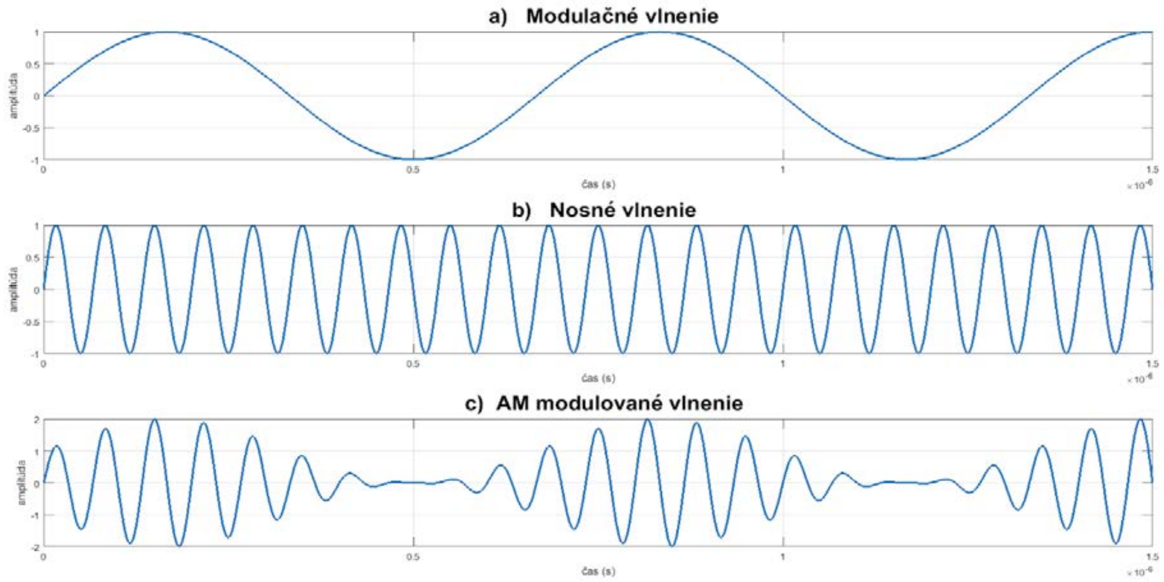
- Polar method





- Distance measurement
  - Pulse time-of-flight
  - **Phase difference measurement**
  - Frequency measurement, Interferometry

$$d = \frac{v}{4 \cdot \pi} \cdot \frac{\Delta \varphi}{f_m}$$



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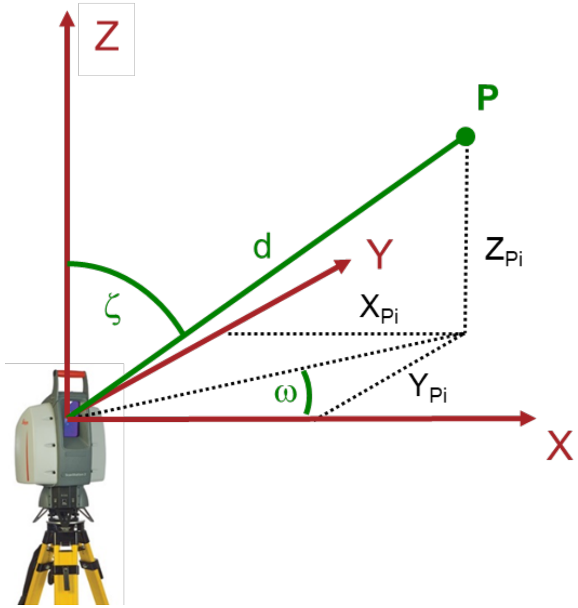
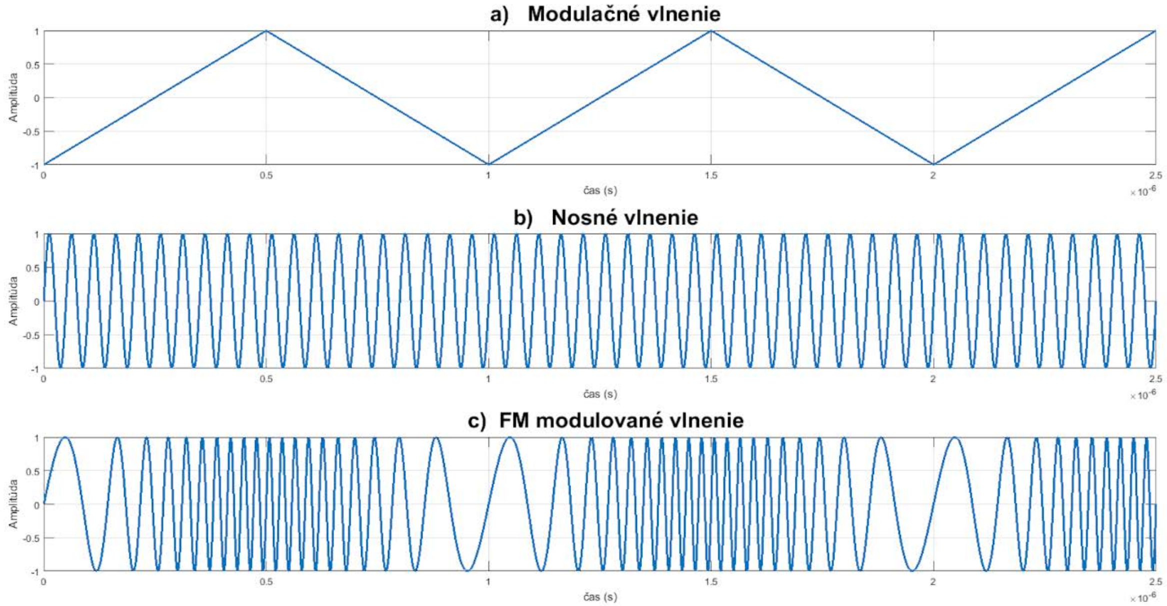
- Polar method



$$d = \frac{v \cdot \Delta F}{8 \cdot f_m \cdot \Delta f}$$



- Distance measurement
  - Pulse time-of-flight
  - Phase difference measurement
  - **Frequency measurement, Interferometry**

Laser scanning systems

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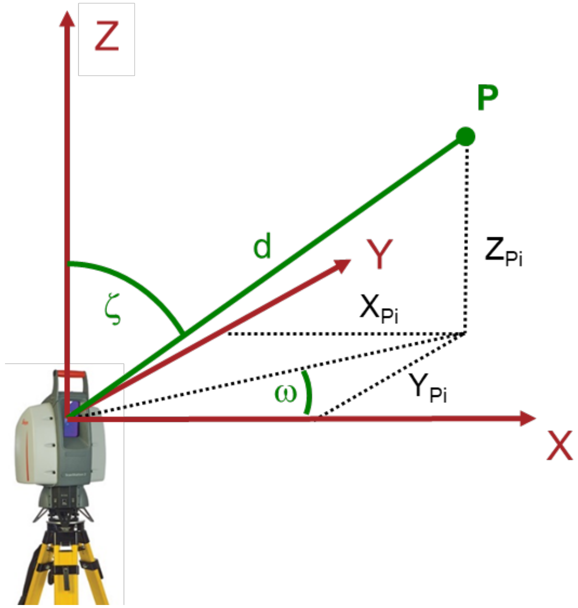
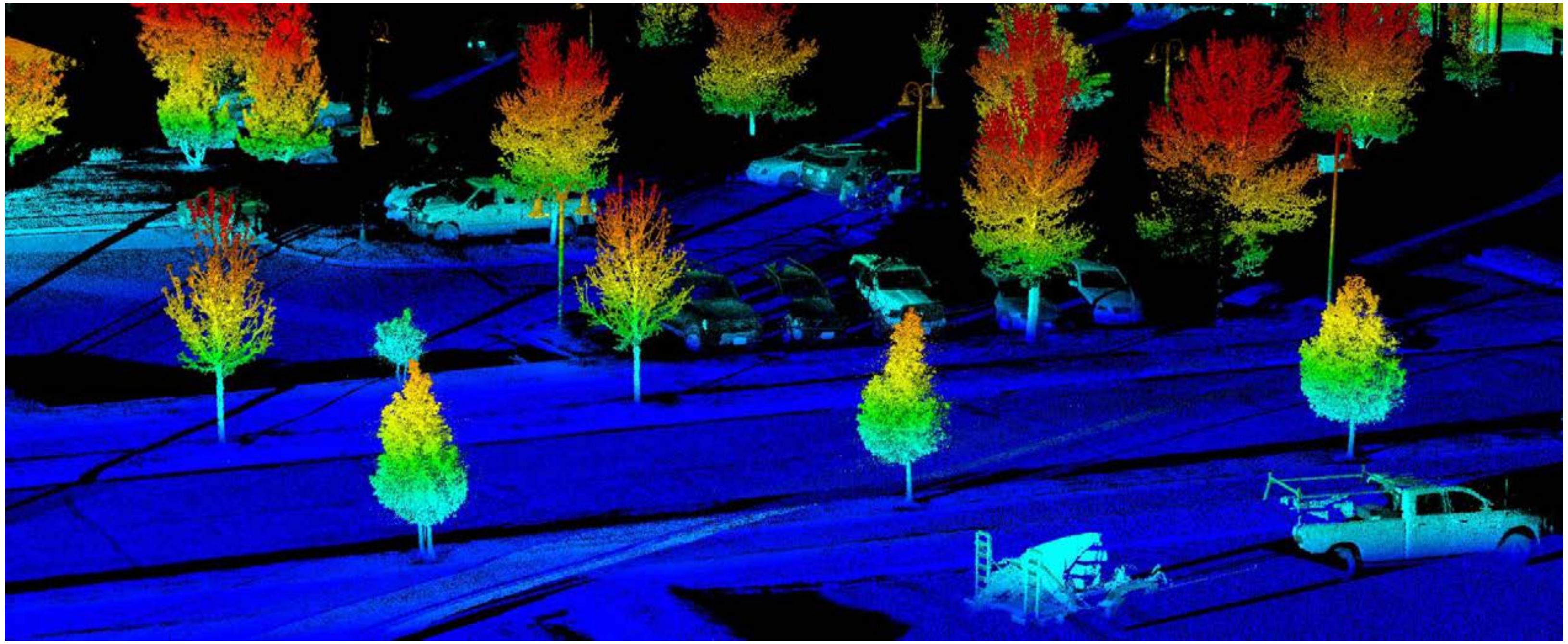
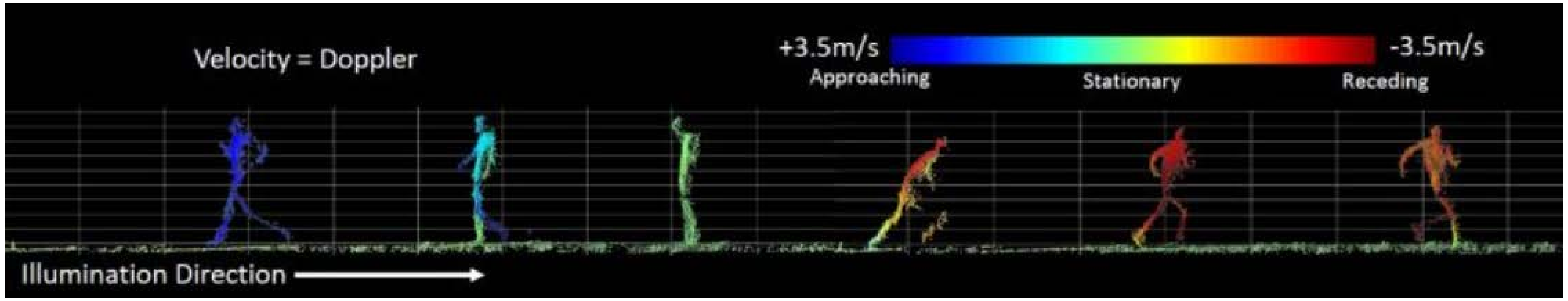
- Polar method



- Distance measurement
  - Pulse time-of-flight
  - Phase difference measurement
  - **Frequency measurement, Interferometry**





Laser scanning systems

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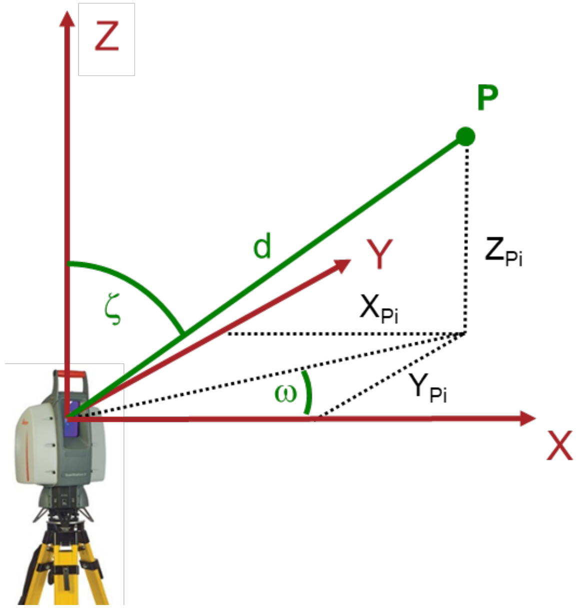
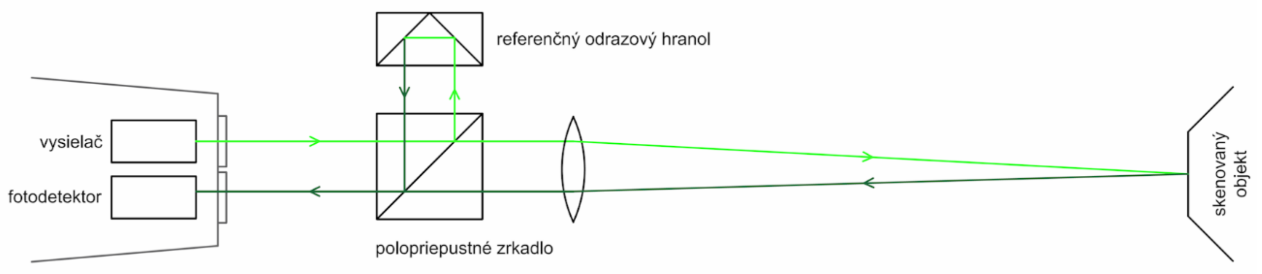
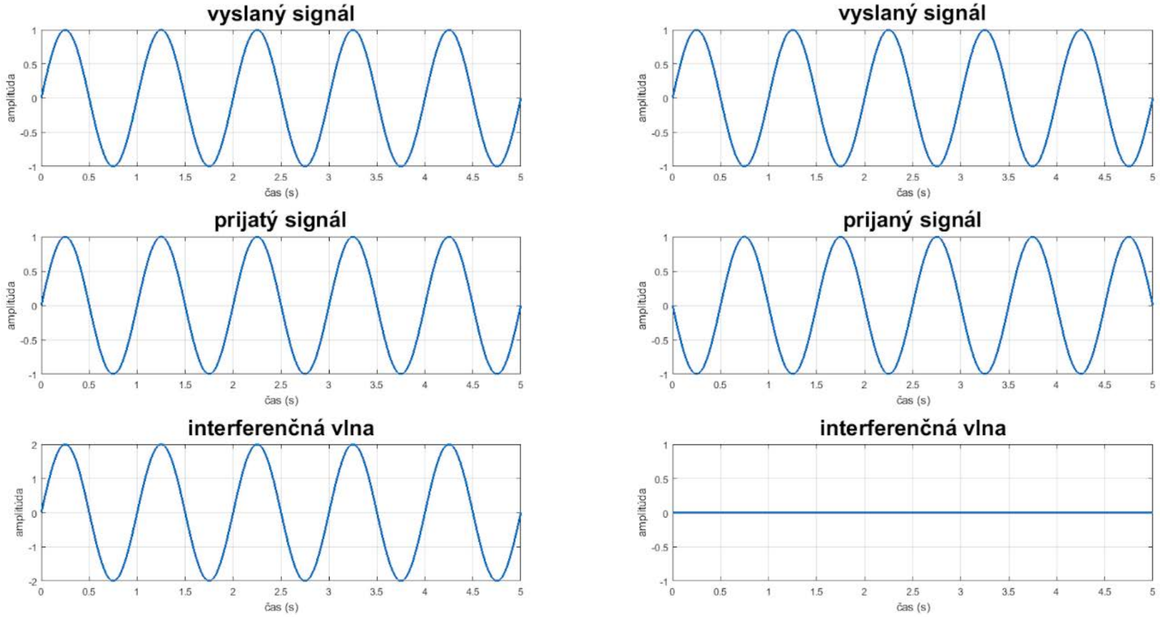
- Polar method







- Distance measurement
  - Pulse time-of-flight
  - Phase difference measurement
  - **Frequency measurement, Interferometry**

$$\Delta d = N \cdot \frac{\lambda}{2}$$

Laser scanning systems

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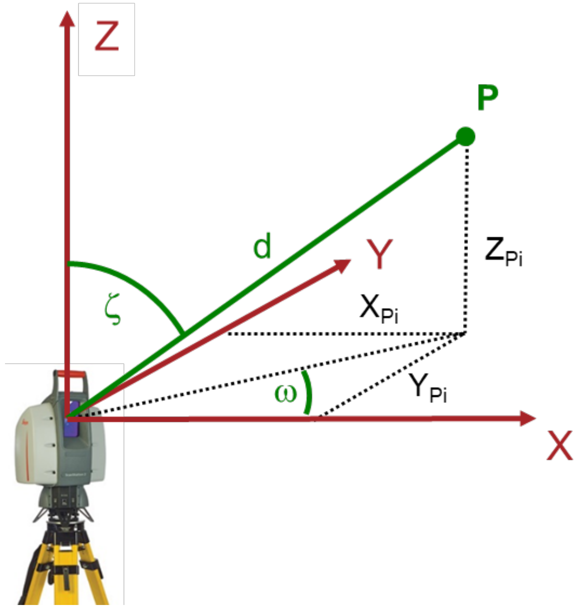
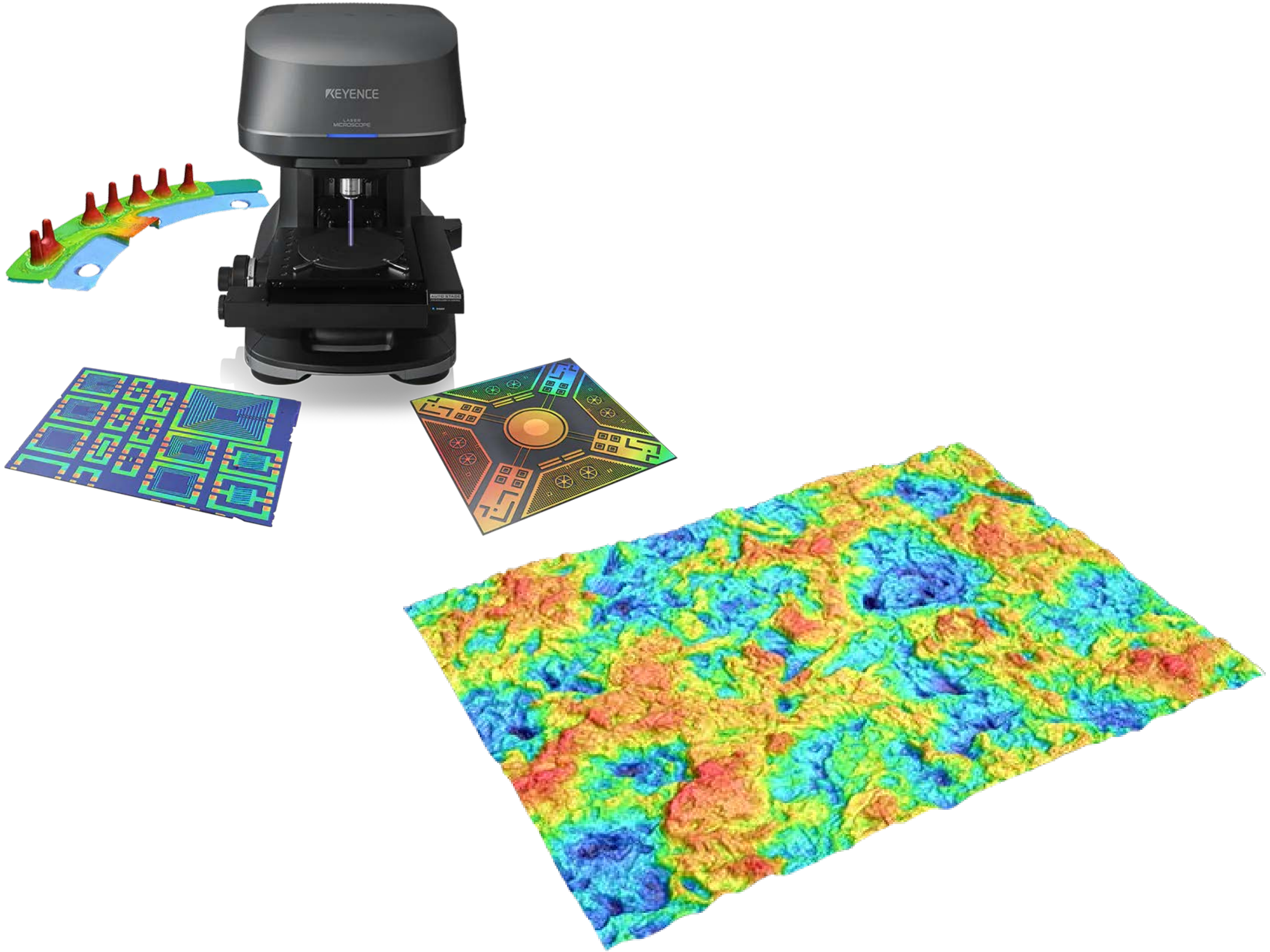
- Polar method

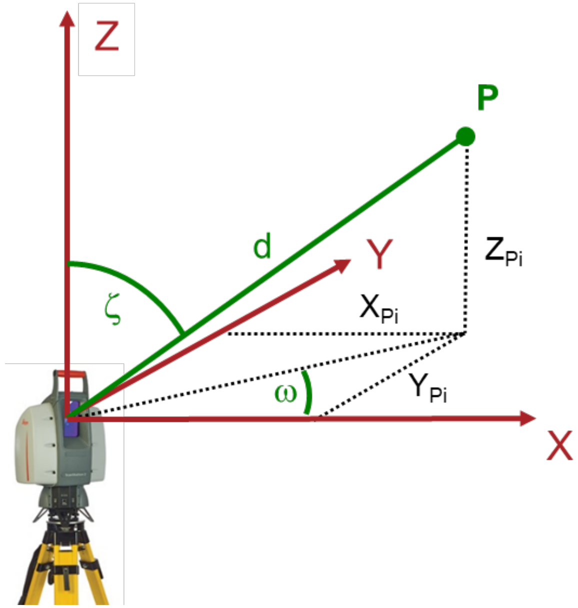


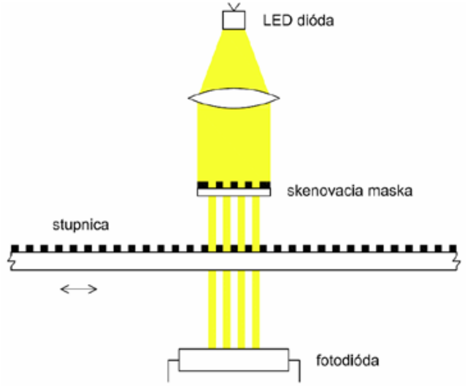


- Distance measurement
  - Pulse time-of-flight
  - Phase difference measurement
  - **Frequency measurement, Interferometry**

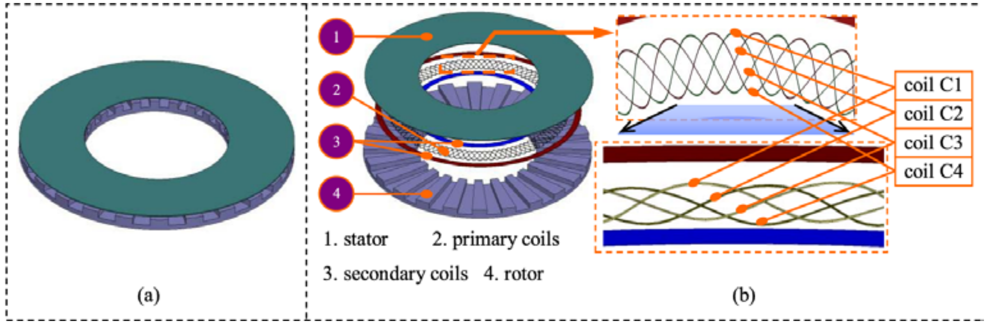
Laser scanning systems

- Polar method





- Angle measurement
  - Electro-optical – incremental, coded, combination of both
  - Electro-inductive



Categorization of laser scanning systems

- According to location
  - Terrestrial (ground-based)

Skener placed on the Earth's surface, it's close surroundings or on a device moving on the Earth's surface

(Leica Geosystems.com, 2020)

(laserinst.com, 2020)

(Topconcare.com, 2020)

(riegl.com, 2020)

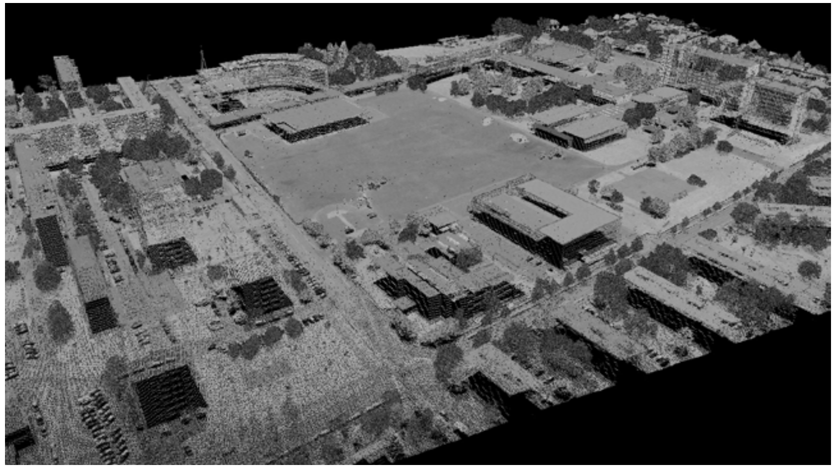
(faro.com, 2020)

  - Airborne

Instrument placed on a flying carrier (aircraft, helicopter, drone)

(lidaretto.com, 2020)

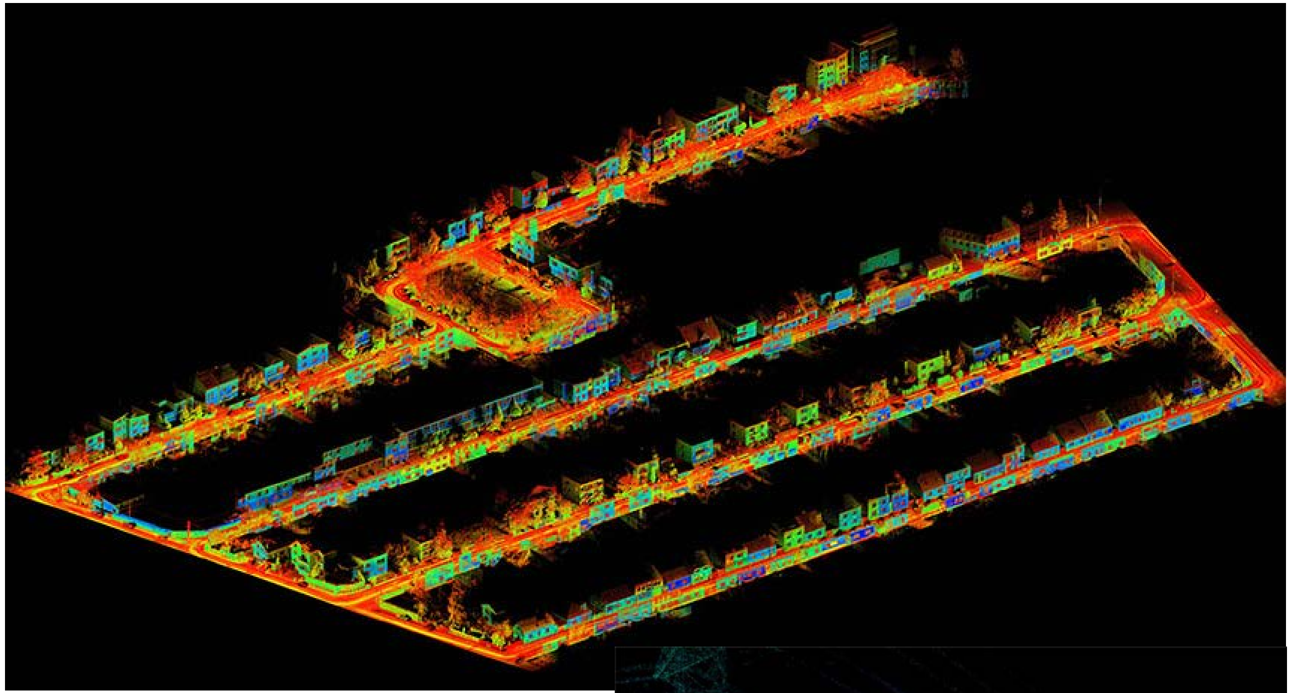
(riegl.com, 2020)



Categorization of laser scanning systems

- Static
- Kinematic

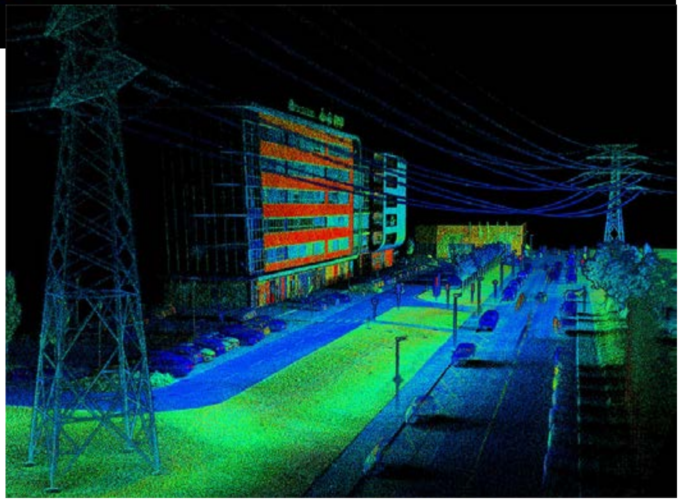
(Leica Geosystems.com, 2020)



(Amberggroup.com, 2020)

(navvis, 2018)

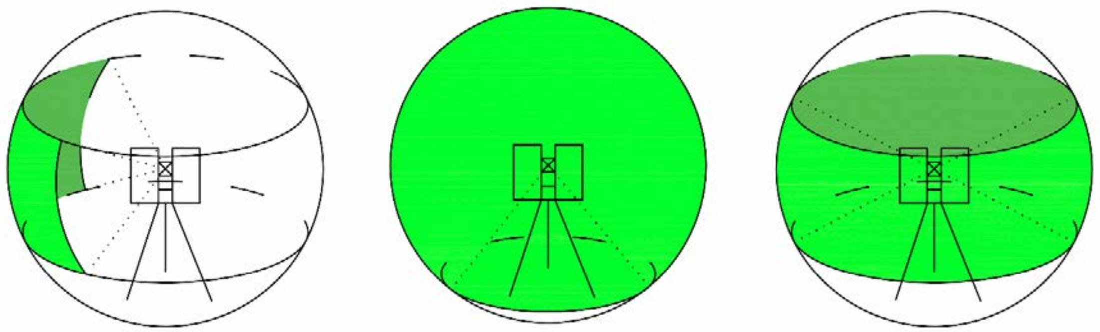
(geoslam, 2018)



(lidaretto.com, 2020)

Categorization of laser scanning systems

- Field of view
  - camera, panoramic, hybrid



- Range
  - Short range up to 150 m,
  - Middle range from 150 m to 450 m,
  - Long range up to several kilometers.
- Accuracy (full range)
  - with accuracy better than 1 mm (most often triangulation scanners),
  - with accuracy from 1 mm to 10 mm (most often short range and middle range scanners),
  - with accuracy worst than 10 mm up to several centimeters (middle range and long-range scanners).

- Inaccuracy (deviation) of the position of a measured point

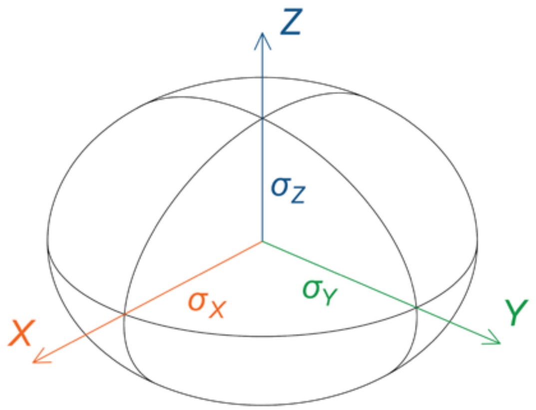
$$\sigma_{X_P} = \sqrt{\left(\cos\omega \cdot \sin\zeta\right)^2 \cdot \sigma_d^2 + \left(d \cdot \left(-\sin\omega\right) \cdot \sin\zeta\right)^2 \cdot \sigma_\omega^2 + \left(d \cdot \cos\omega \cdot \cos\varsigma\right)^2 \cdot \sigma_\zeta^2}$$

$$\sigma_{Y_P} = \sqrt{\left(\sin\omega \cdot \sin\zeta\right)^2 \cdot \sigma_d^2 + \left(d \cdot \cos\omega \cdot \sin\zeta\right)^2 \cdot \sigma_\omega^2 + \left(d \cdot \sin\omega \cdot \cos\varsigma\right)^2 \cdot \sigma_\zeta^2}$$

$$\sigma_{Z_P} = \sqrt{\left(\cos\zeta\right)^2 \cdot \sigma_d^2 + \left(d \cdot \left(-\sin\zeta\right)\right)^2 \cdot \sigma_\zeta^2}$$

$$\sigma_{XYZ_P} = \sqrt{\sigma_{X_P}^2 + \sigma_{Y_P}^2 + \sigma_{Z_P}^2}$$

$$\Sigma_{XYZ_P} = \begin{bmatrix} \sigma_{X_P}^2 & cov_{XY} & cov_{XZ} \\ cov_{XY} & \sigma_{Y_P}^2 & cov_{YZ} \\ cov_{XZ} & cov_{YZ} & \sigma_{Z_P}^2 \end{bmatrix}$$



$$\frac{X_P^2}{a^2} + \frac{Y_P^2}{b^2} + \frac{Z_P^2}{c^2} = 1$$

covariance error ellipsoid

Testing and calibration of TLS

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- Inaccuracy (deviation) of the position of a measured point
- Systematic error sources and their mathematical models
  - Range error correction model,
  - Correction model for errors in horizontal direction ,
  - Correction model for errors in zenith angles,
  - Influence of the environment.

$$\Delta d = A_0 + A_1 \cdot d + A_2 \cdot \cos\zeta + \sum_{k=1}^{n}\left(A_{2k+1} \cdot \sin\left(\frac{2\cdot\pi\cdot k\cdot d}{U_1}\right) + A_{2k+2} \cdot \sin\left(\frac{2\cdot\pi\cdot k\cdot d}{U_1}\right)\right)$$

$$\Delta\alpha = B_1 \cdot \alpha + B_2 \cdot \sin\alpha + B_3 \cdot \cos\alpha + B_4 \cdot \sin 2\alpha + B_5 \cdot \cos 2\alpha + B_6 \cdot \frac{1}{\sin\zeta} + B_7 \cdot \cot\zeta + \frac{B_8}{d} + \sum_{k=1}^{n}\left(B_{2k+7} \cdot \cos(k\cdot\zeta) + B_{2k+8} \cdot \sin(k\cdot\zeta)\right)$$

- Calibration of terrestrial laser scanners
  - Calibration of individual TLS components (range finder, horizontal circle, vertical circle)
  - Self-calibration (autocalibration) of the whole system as a whole – system calibration

Testing and calibration of TLS

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- Calibration of terrestrial laser scanners
  - Calibration of individual TLS components (range finder, horizontal circle, vertical circle)

Testing and calibration of TLS

- Calibration of terrestrial laser scanners
  - Self-calibration (autocalibration) of the whole system as a whole – system calibration

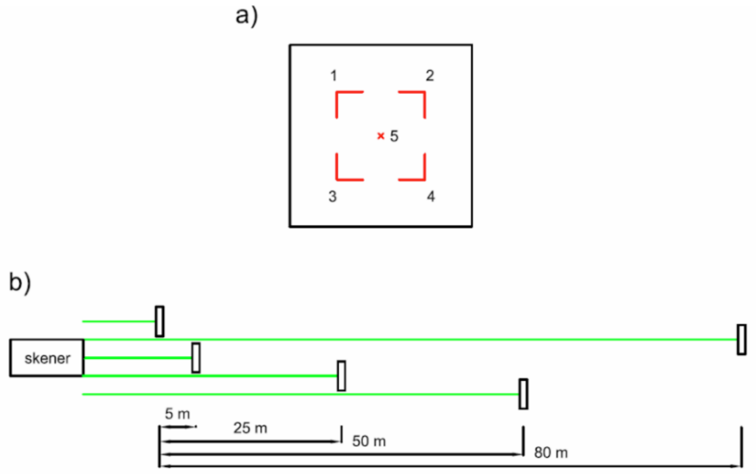
$$d_{ij} = \sqrt{X_{ij}^2 + Y_{ij}^2 + Z_{ij}^2} + \Delta d$$

$$\alpha_{ij} = arctg\left(\frac{Y_{ij}}{X_{ij}}\right) + \Delta\alpha$$

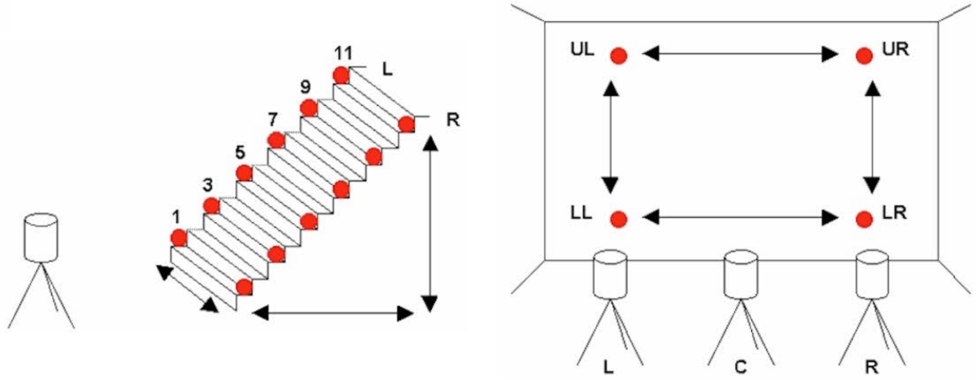
$$\zeta_{ij} = arctg\left(\frac{\sqrt{X_{ij}^2 + Y_{ij}^2}}{Z_{ij}}\right) + \Delta\zeta$$

Testing and calibration of TLS

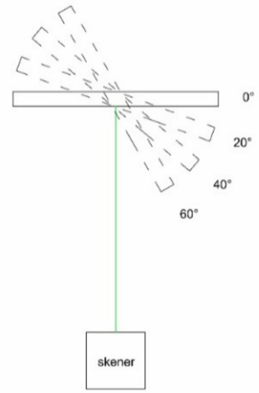
- Testing of terrestrial laser scanners
  - Analytical tests, global tests



Testing the accuracy of distance determination using planar targets



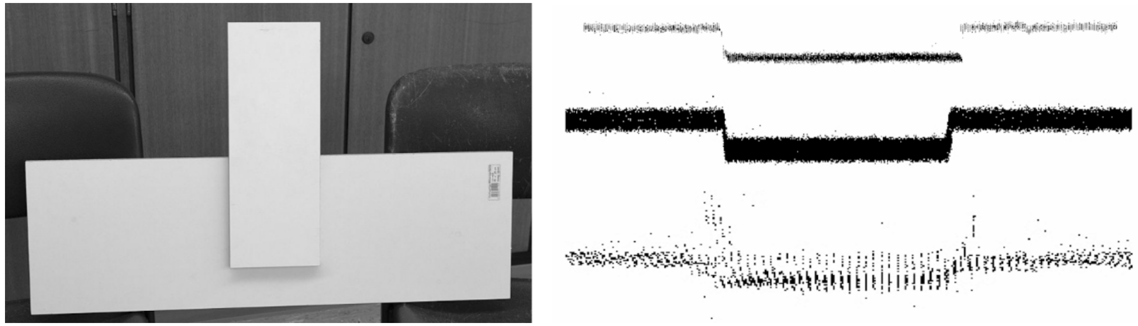
Point network for testing the accuracy of angle measurements



GretabMacbeth color test scheme (left), rotation of the color scheme during testing (right)

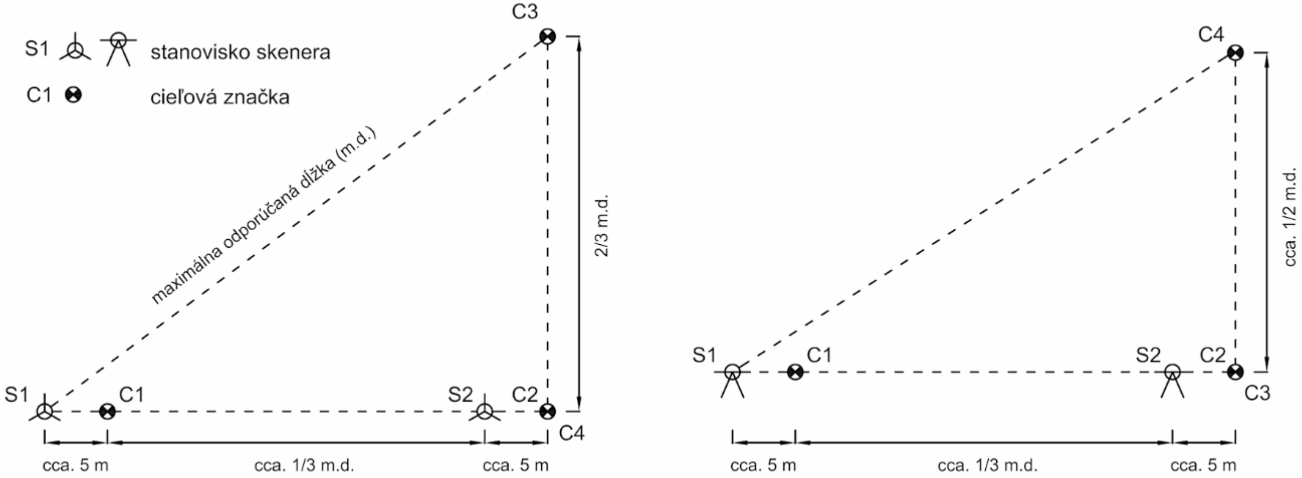
Testing and calibration of TLS

- Testing of terrestrial laser scanners
  - Analytical tests, global tests



Edge scan quality testing

Test bodies for complex TLS testing



TLS testing based on ISO standard:
left - floor plan, right - front view of the position of points and scanner during the test measurement

- *ISO 17123-9 Optics and optical instruments – Field procedures for testing geodetic and surveying instruments – Part 9: Terrestrial laser scanners*

Measurement using TLS

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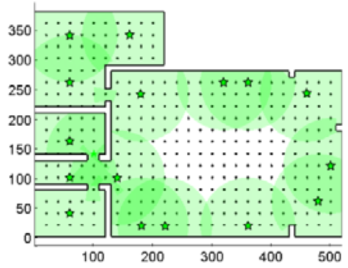
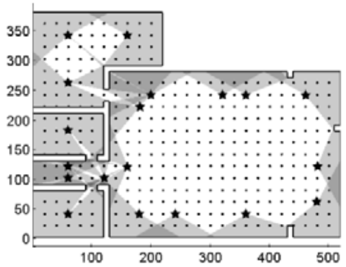
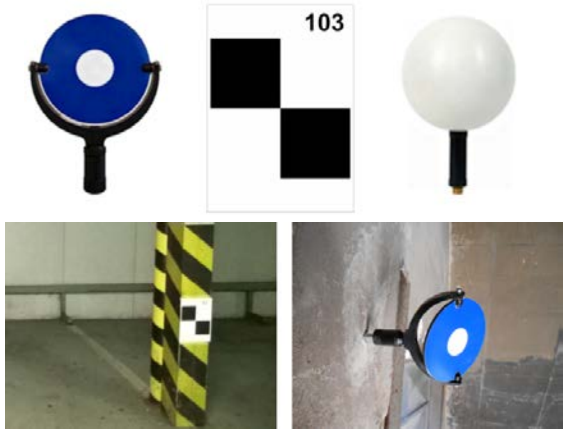
- Preparation for measurement





optimization of the position of TLS



signaling and stabilization of reference points

Measurement using TLS

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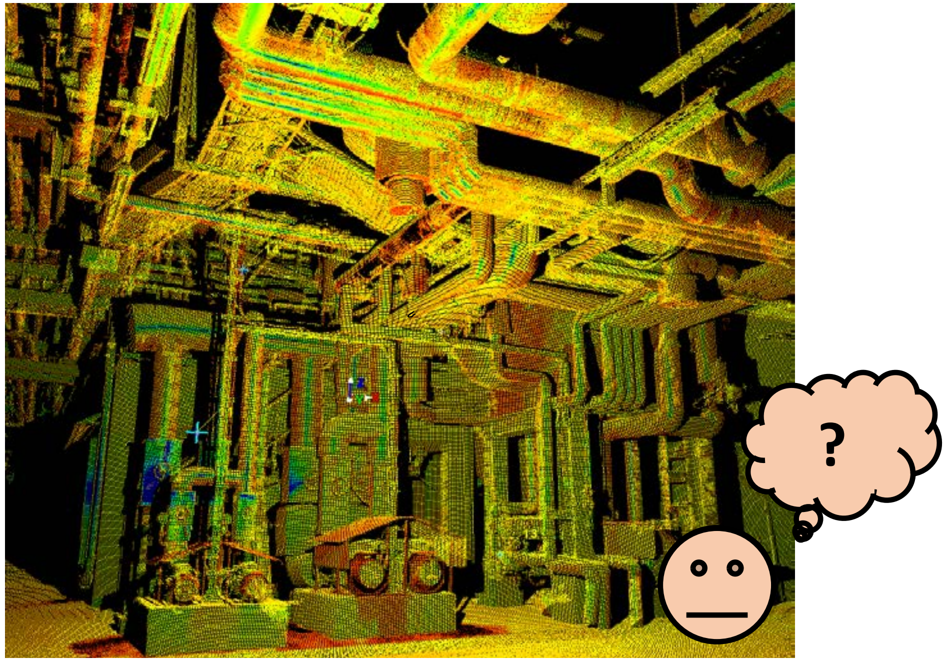
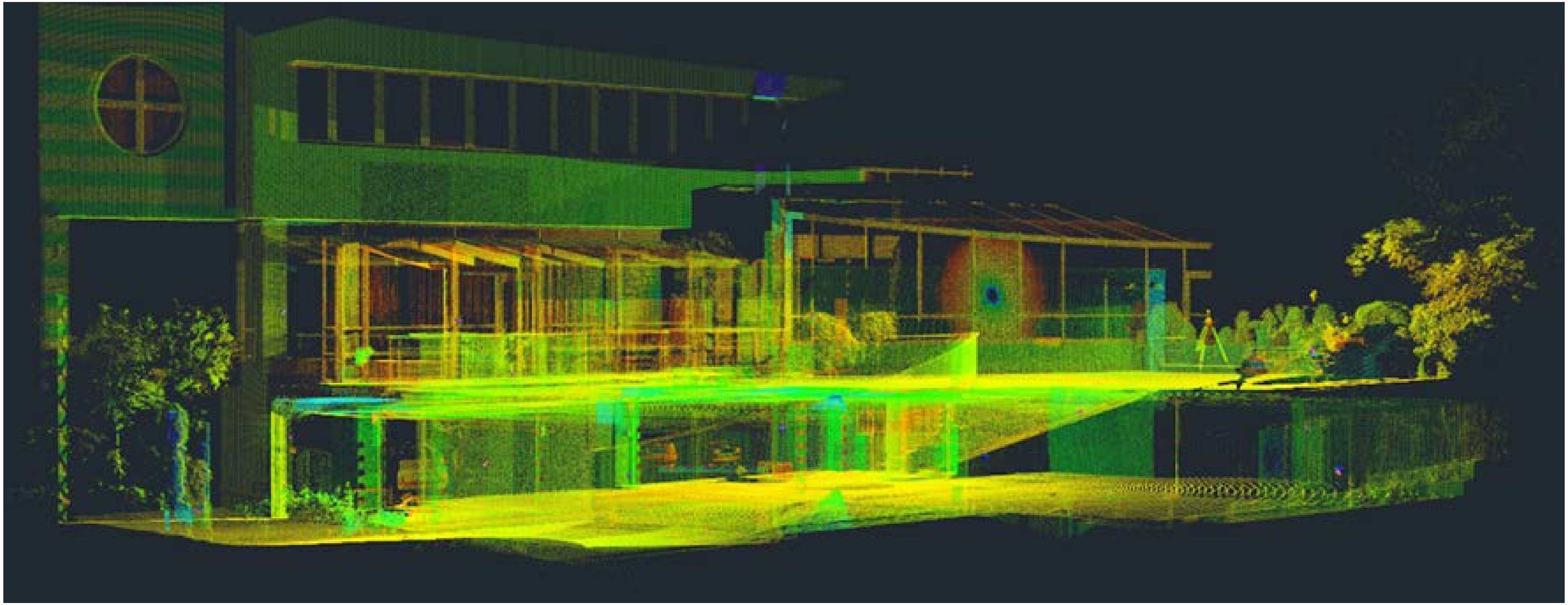
- Scanning



Measurement using TLS

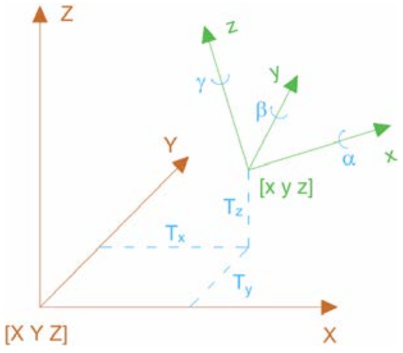
- Scanning



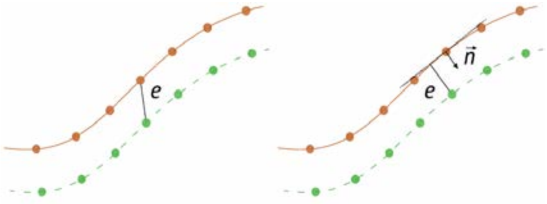
Result of scanning – point cloud

TLS data processing

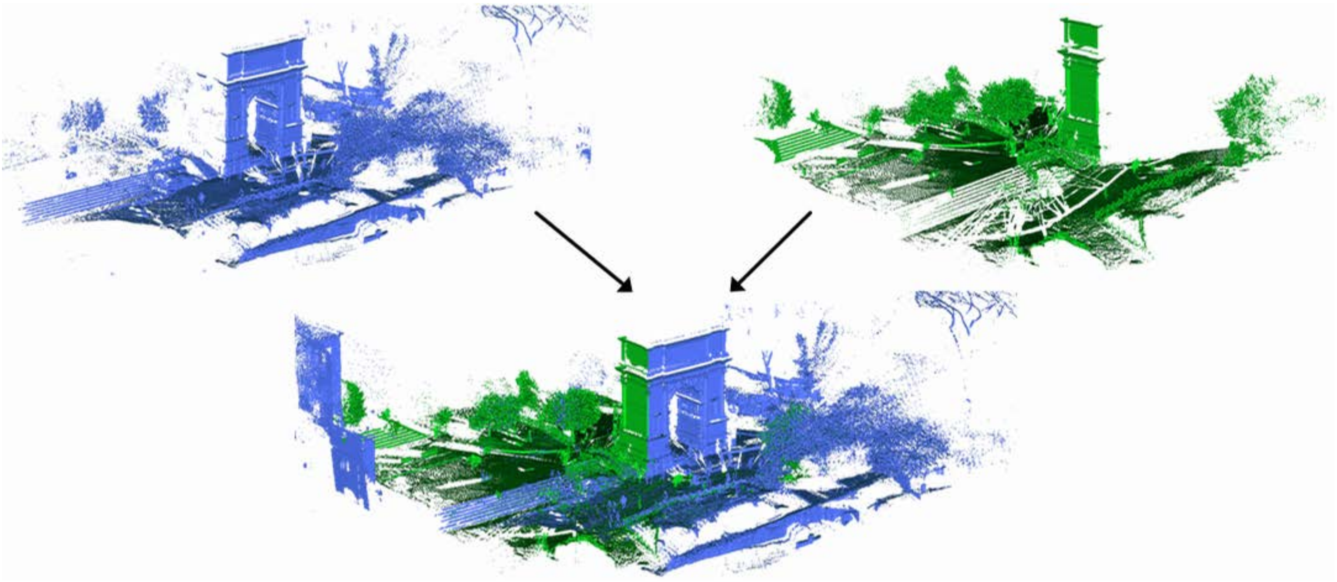
- Adjustment of point clouds
  - Transformation of point clouds (registration)
    - Direct georeferencing,
    - Target-based registration,
    - Surface-based registration,
    - Feature-based registration

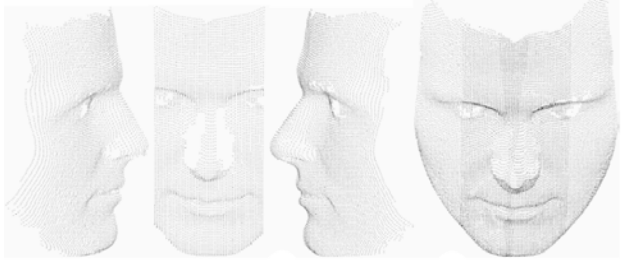


spatial identity transformation



calculation of Euclidean distances between clouds for ICP





Transformation using LS3D algorithm

(prs.igp.ethz.ch, 2020)

non-rigid transformation

TLS data processing

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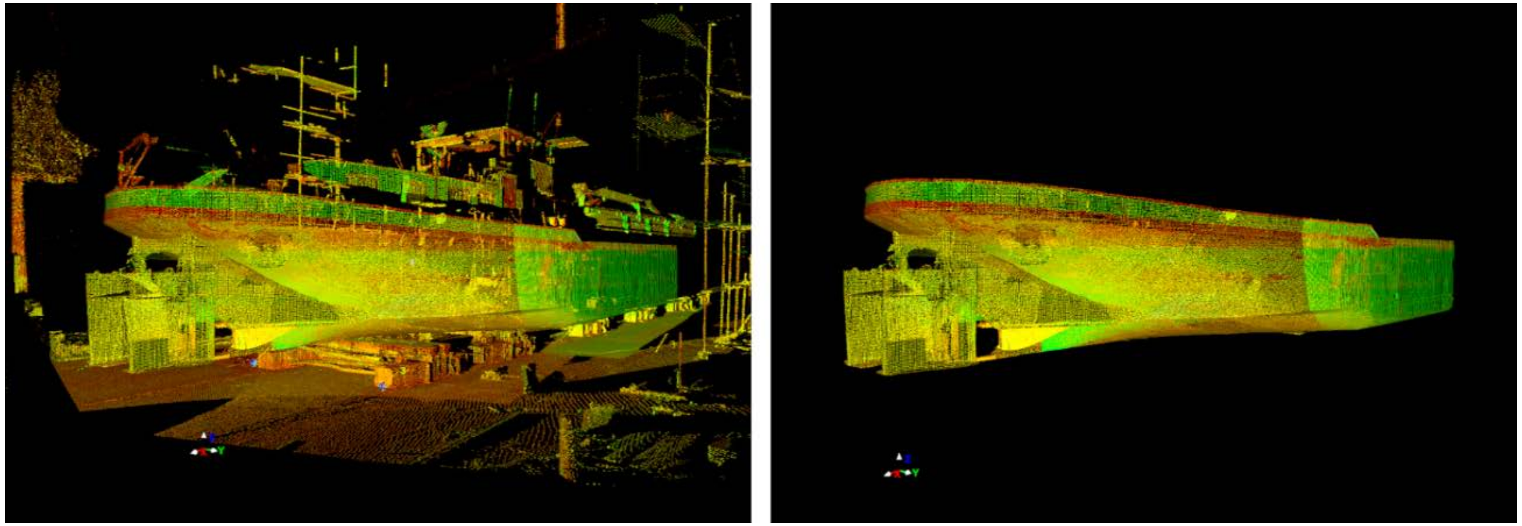
- Adjustment of point clouds
  - Other adjustments
    - **Deleting of outliers, deleting of redundant points not on the surface of the measured object,**
    - Coloring of the point cloud,
    - Data reduction – noise attenuation (data dispersion), density reduction (decimation) of the point cloud,
    - conversion of clouds into required data structures



Deleting of redundant points

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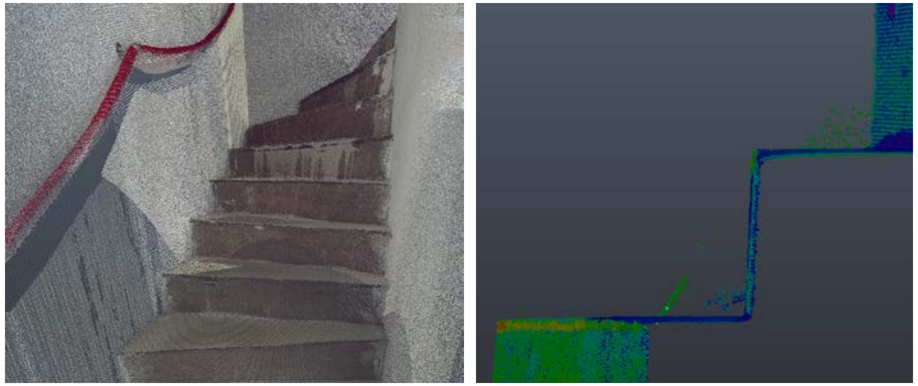
- Adjustment of point clouds
  - Other adjustments
    - Deleting of outliers, deleting of redundant points not on the surface of the measured object,
    - **Coloring of the point cloud,**
    - Data reduction – noise attenuation (data dispersion), density reduction (decimation) of the point cloud,
    - conversion of clouds into required data structures

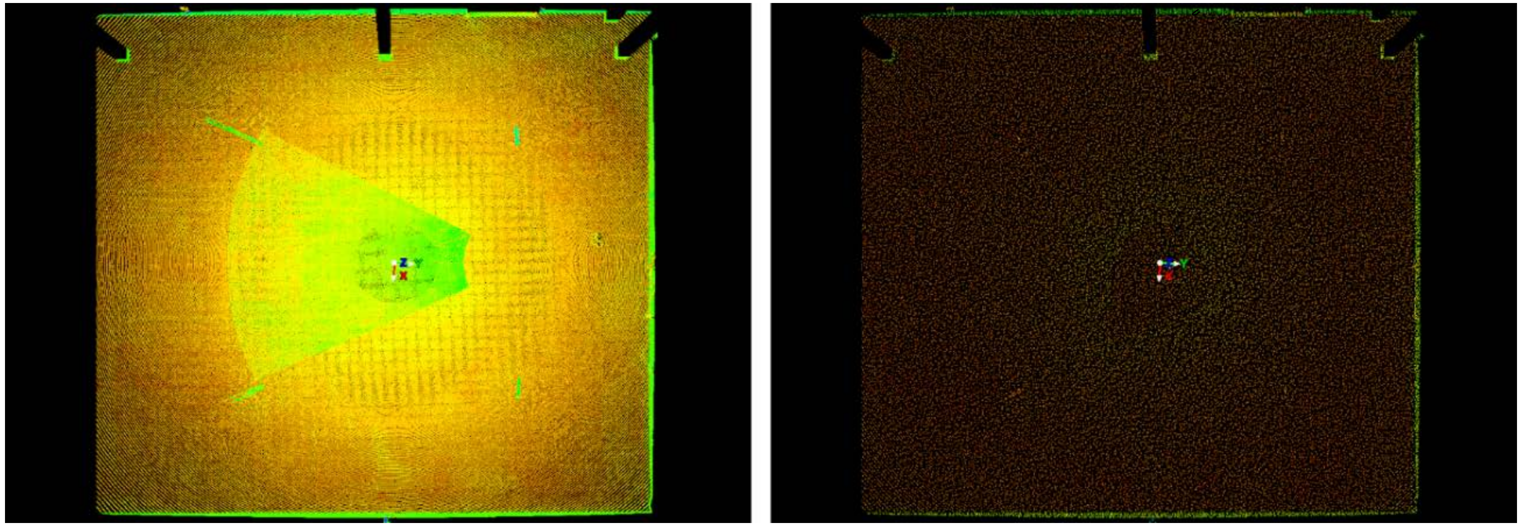
coloring

TLS data processing

- Adjustment of point clouds
  - Other adjustments
    - Deleting of outliers, deleting of redundant points not on the surface of the measured object,
    - Coloring of the point cloud,
    - **Data reduction – noise attenuation (data dispersion), density reduction (decimation) of the point cloud,**
    - conversion of clouds into required data structures



Multiple reflection – edge effect



Data reduction

TLS data processing

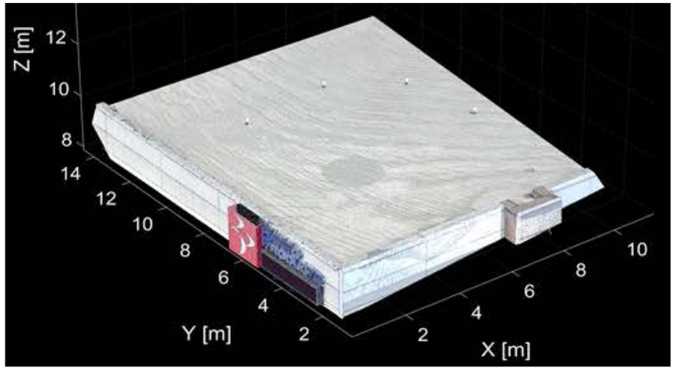
- Adjustment of point clouds
  - Other adjustments
    - Deleting of outliers, deleting of redundant points not on the surface of the measured object,
    - Coloring of the point cloud,
    - Data reduction – noise attenuation (data dispersion), density reduction (decimation) of the point cloud,
    - **conversion of clouds into required data structures**

    - **ASCII text format**
    - Most often: *.ptx (Leica), *.pts (Leica), *.csv, *.txt, *.xyz

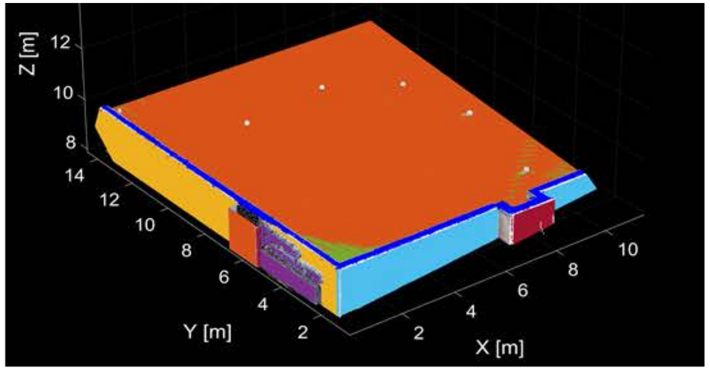
    - **Binary format**
    - Most often: *.clr (Topcon), *.cl3 (Topcon), *.fls (Faro/Trimble), *.fws (Faro/Trimble), *.ptg (Leica), *.zfs (Zoller&Fröhlich), *.rds (Riegl), *.rxp (Riegl), *.las (American Society of Photogrammetry and Remote Sensing), *.e57 (ASTM International), *.rcs (Autodesk), *.rcp (Autodesk)

TLS data processing

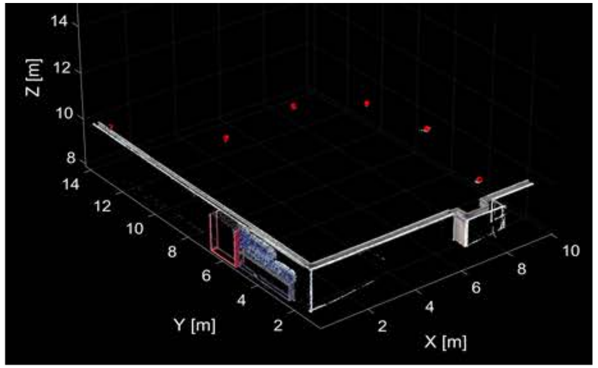
- Modeling and analysis
  - Point cloud segmentation
    - Edge-based methods,
    - Model-based methods,
    - Surface-based methods, Region-based methods,
    - Clustering-based methods,
    - Graph-based methods.



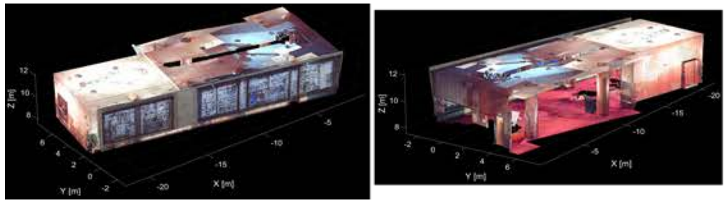
Original point cloud

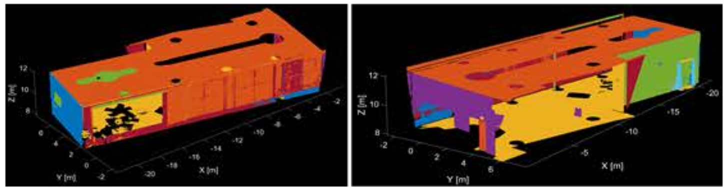


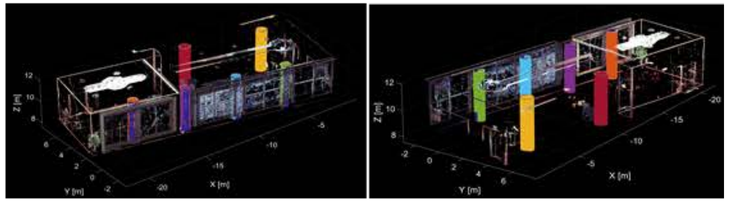
Segmented planes



Segmented spheres


Original point cloud


Segmented planes


Segmented cylinders

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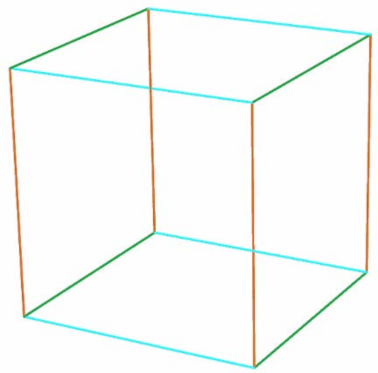
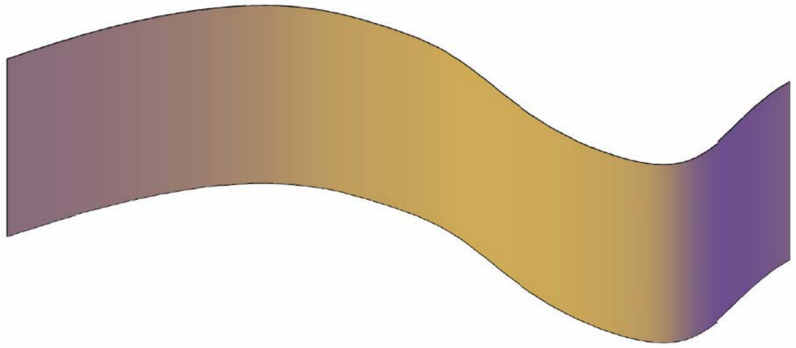
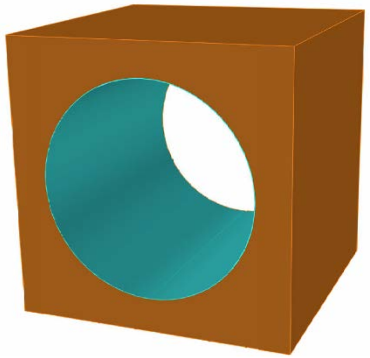
- Modeling and analysis
  - 3D model creation
    - Wireframe model
    - Surface model – *plane, various types of rotating surfaces (spherical surface, ellipsoid, cylindrical surface, etc.), polygonal networks, triangular networks (also TIN), Bézier surface, B-spline (Basis-spline) surfaces or NURBS (Non-Uniform Rational B-Spline) surface*
    - Solid model - *Boundary representation (B-rep.), Constructive Solid Geometry (CSG), sweeping, or decomposition model*



Wireframe of a cube



B-spline surface



3D model created by CSG

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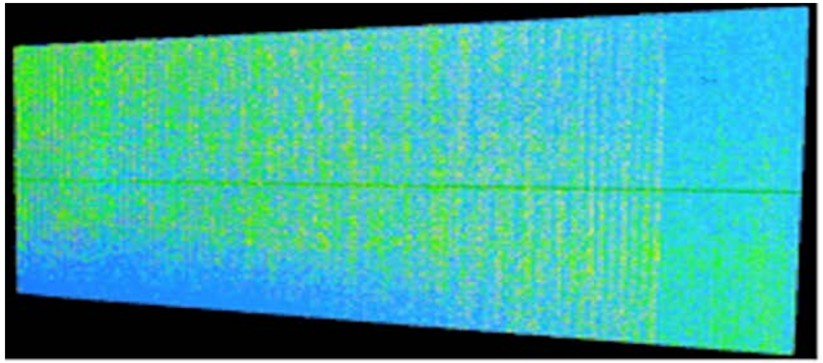
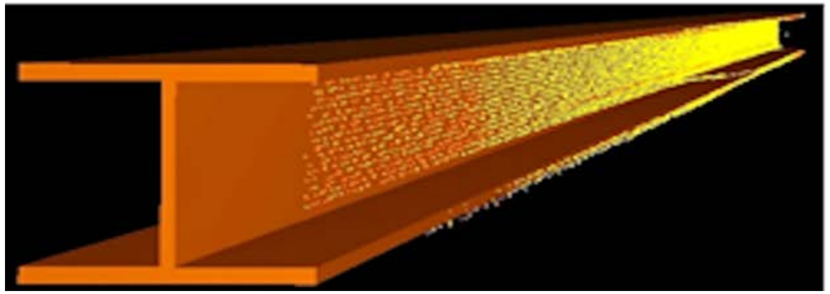
- Modeling and analysis
  - 3D model creation
    - **Approximation of point clouds or their parts by surfaces of geometric primitives (plane, cylindrical surface, spherical surface, etc.) and solids**
    - Modelling by lines and curves (creation of a wireframe model)
    - Approximation by irregular surfaces





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- Modeling and analysis
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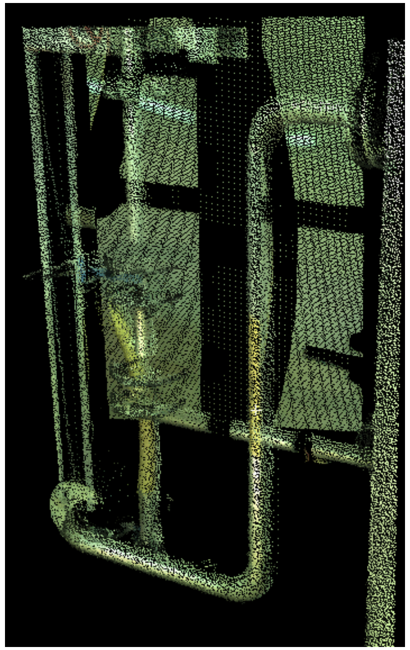
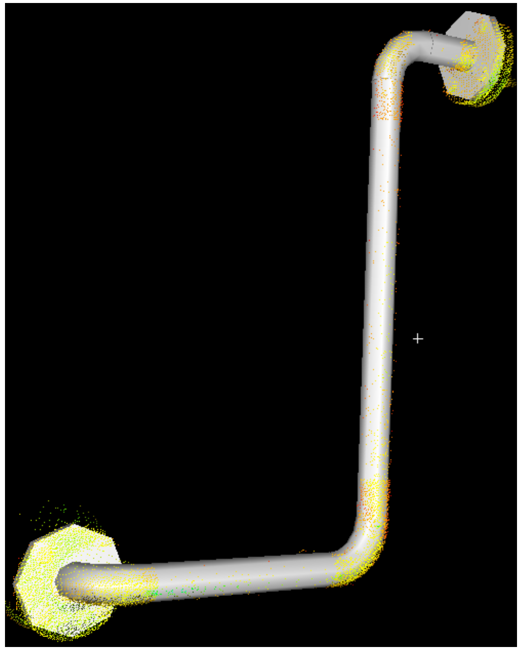
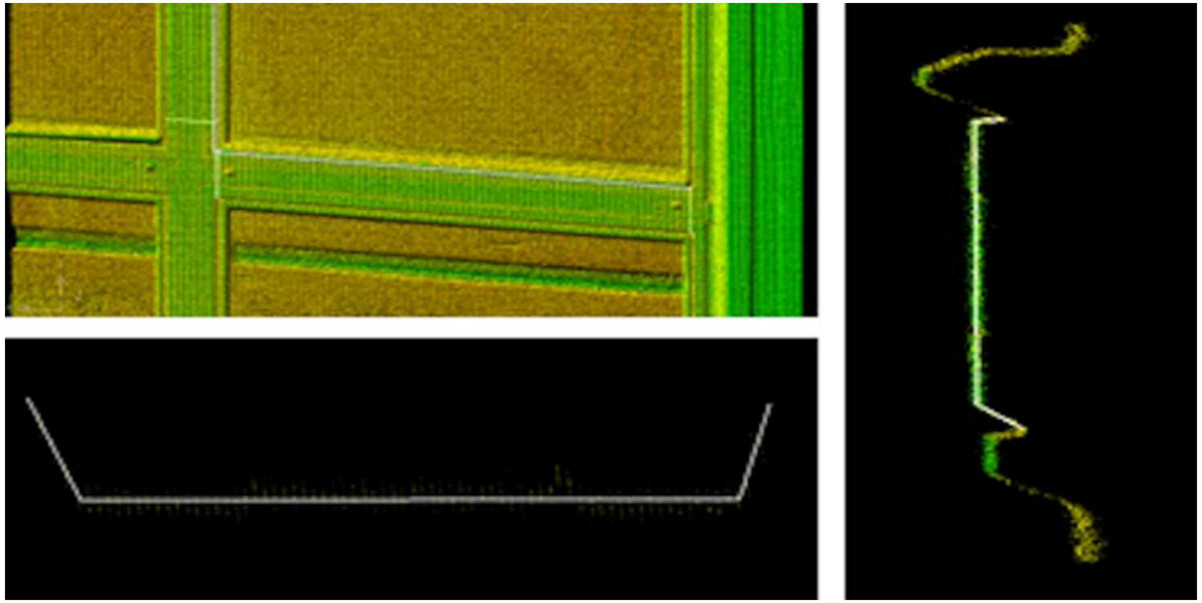




TLS data processing

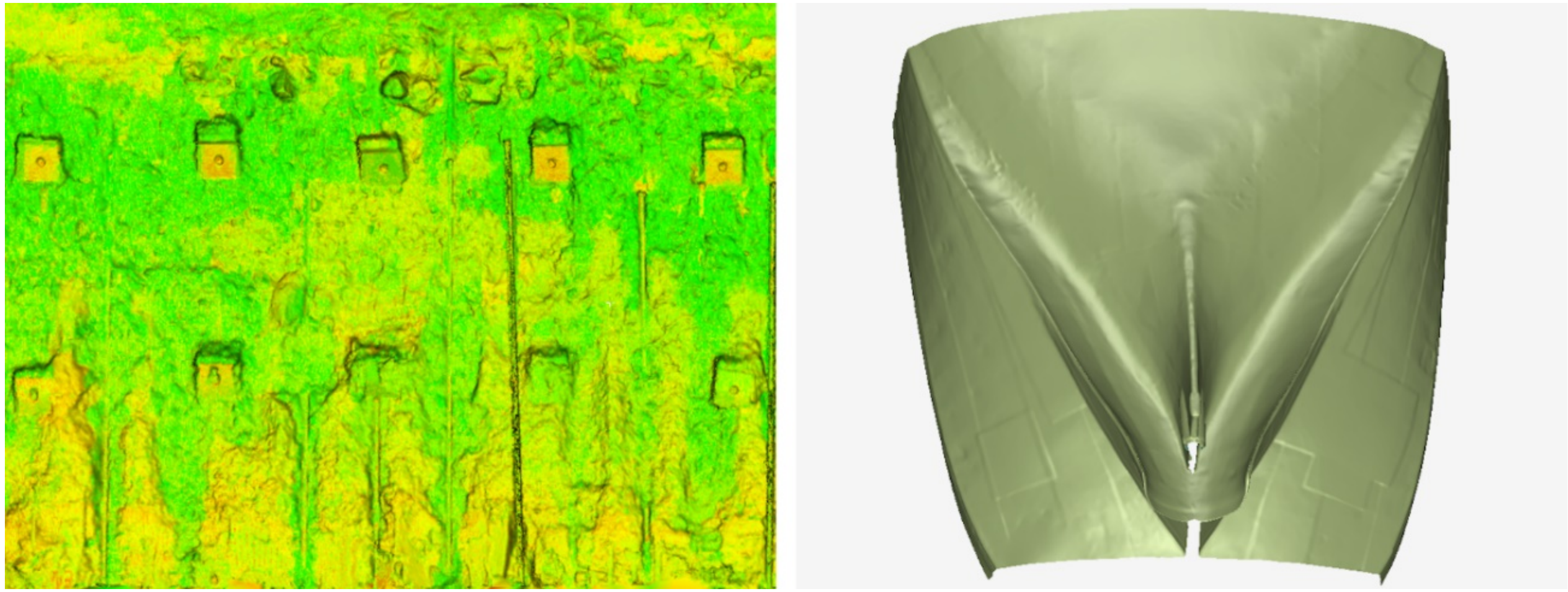
- Modeling and analysis
  - 3D model creation
    - Approximation of point clouds or their parts by surfaces of geometric primitives (plane, cylindrical surface, spherical surface, etc.) and solids
    - **Modelling by lines and curves (creation of a wireframe model)**
    - Approximation by irregular surfaces



Modelling by lines (modelling of a window frame)

TLS data processing

- Modeling and analysis
  - 3D model creation
    - Approximation of point clouds or their parts by surfaces of geometric primitives (plane, cylindrical surface, spherical surface, etc.) and solids
    - Modelling by lines and curves (creation of a wireframe model)
    - **Approximation by irregular surfaces**



Approximation by surfaces TIN (left) NURBS (right)

Creation of a 3D model of polder Holombek II

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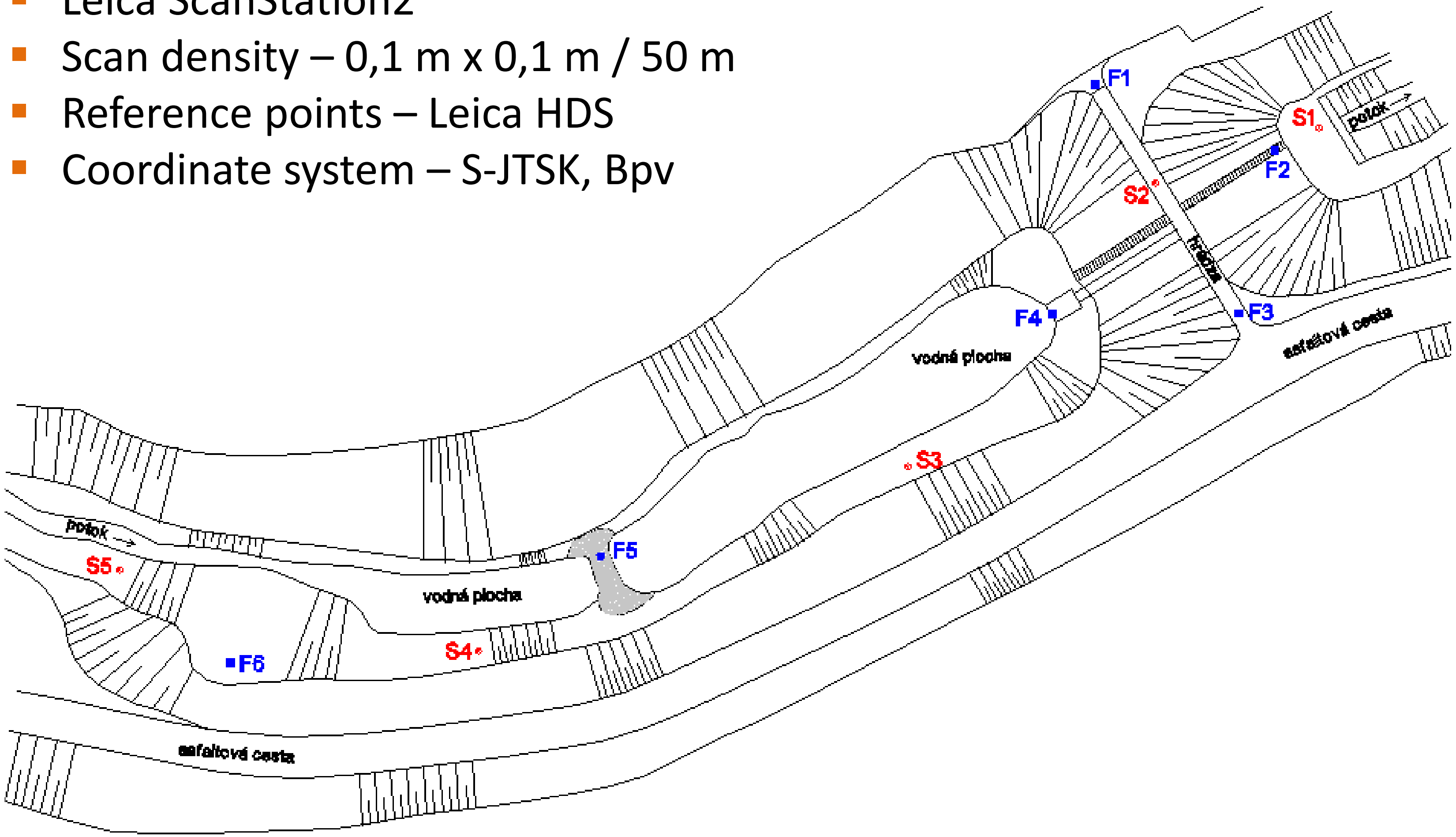
- Polder Holombek II
  - Formed by natural hillslopes
  - Soil-filled dam with a concrete outlet – 41,7 m x 3,0 m
  - Altitude of the edge of the outlet – 247,8 m

Location

polder Holombek II

Creation of a 3D model of polder Holombek II

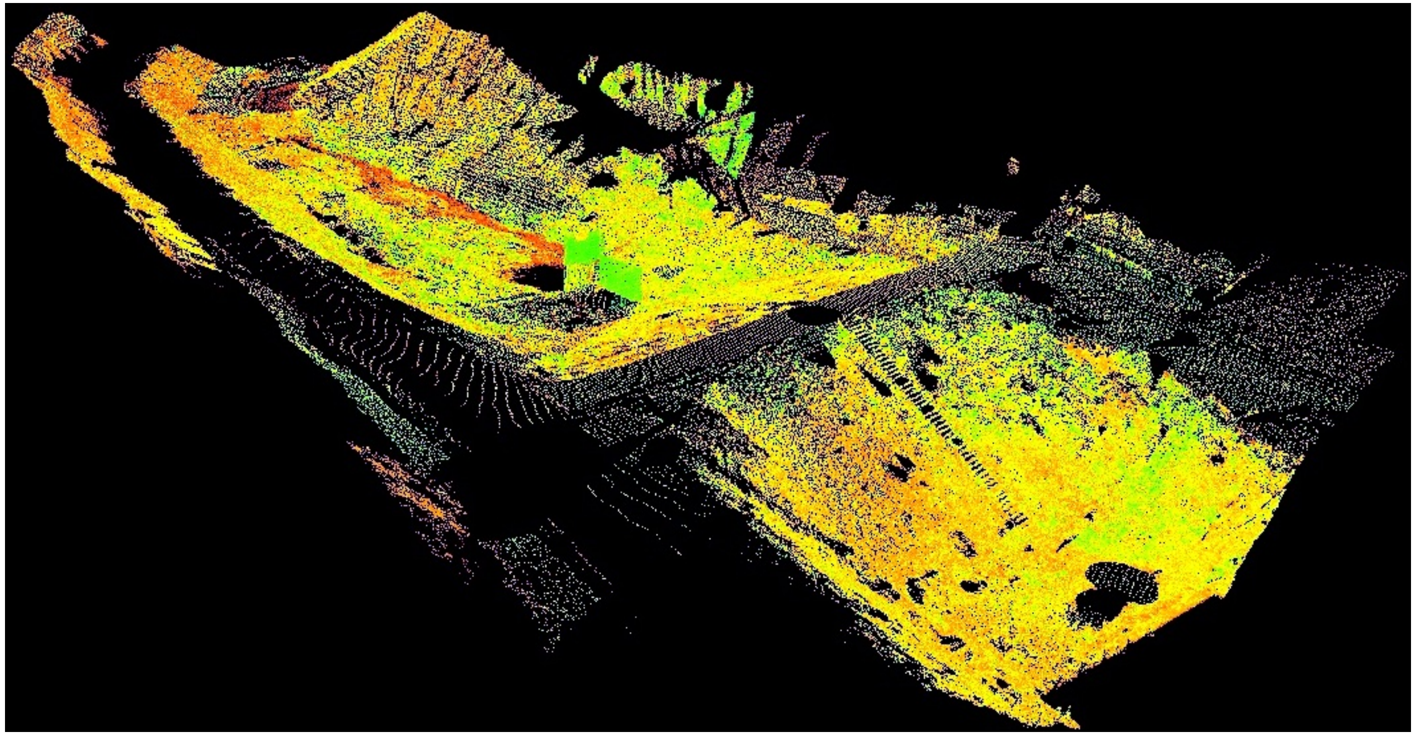
- Polder Holombek II
  - Leica ScanStation2
  - Scan density – 0,1 m x 0,1 m / 50 m
  - Reference points – Leica HDS
  - Coordinate system – S-JTSK, Bpv



Location

Creation of a 3D model of polder Holombek II

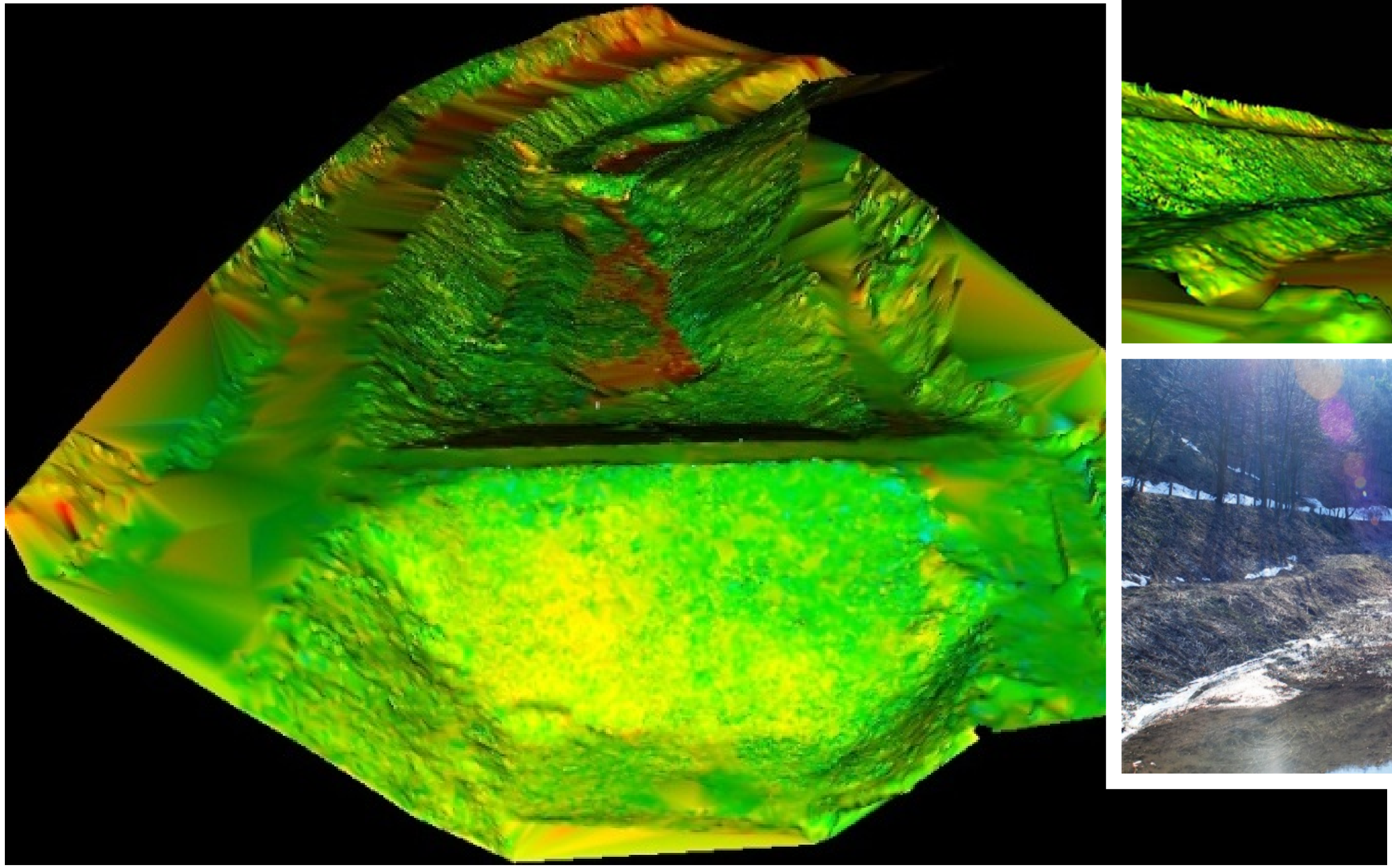
- Polder Holombek II
  - Georeferencing – Target based transformation
  - 14,5 mil. of point before removing of redundancy
  - 4,5 mil. of point after removing of redundancy

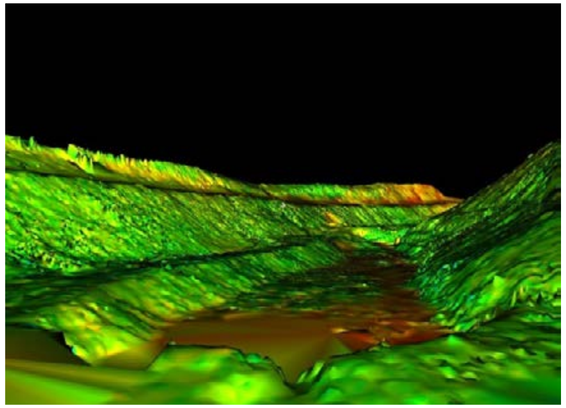


Location

Creation of a 3D model of polder Holombek II

- Modelling
  - TIN model

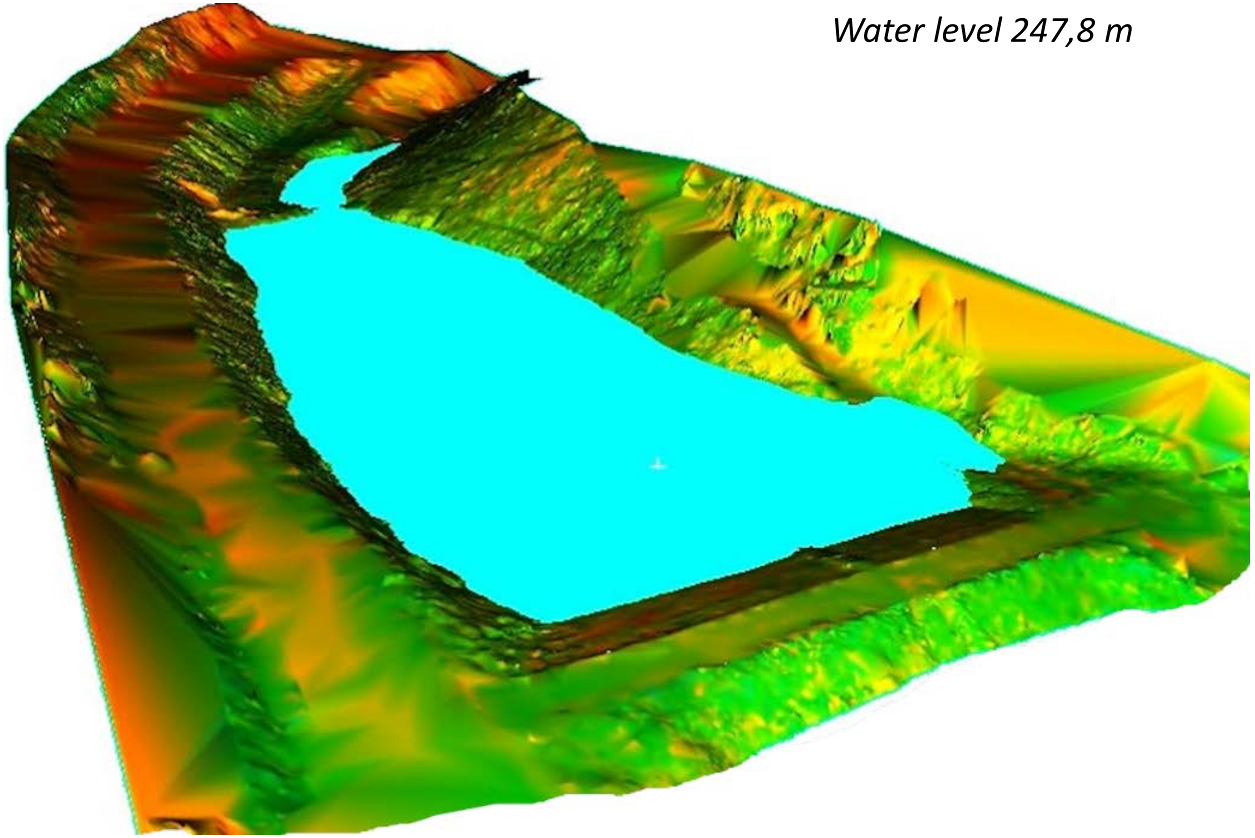




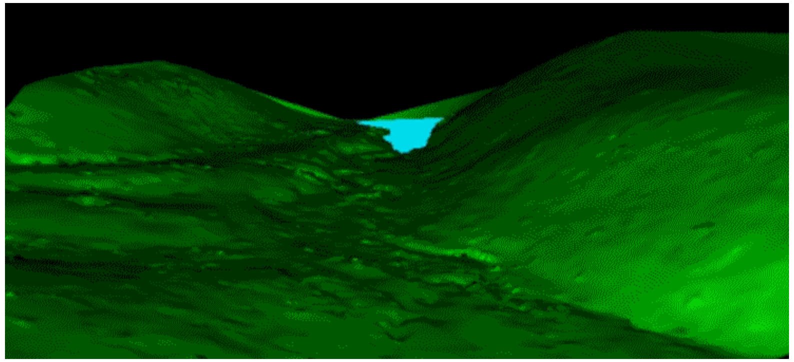
Creation of a 3D model of polder Holombek II

- Modelling
  - Flood range
  - Volume at different water level heights
  - Volume of the polder at 247, 8 m – 5 457 m^3

Water level 247,8 m



polder Zochova chata



As-built documentation of anchor blocks of buildings Panorama City

- Multifunctional complex Panorama City
- Substructure (1UF and 4OF) 15 m height
- 2 identical high-rise buildings
  - equilateral triangle 51,34 m, 110,65 m total height

Panorama City

Panorama City – Tower 2

As-built documentation of anchor blocks of buildings Panorama City

- Anchor blocks
  - Stabilized in the concrete slabs of balconies
  - 4 threaded rods of type M20, 2 pairs of rods – steel plates
  - Designed horizontal distance 260 mm, vertical distance 165 mm

originally designed brackets with 65 mm holes

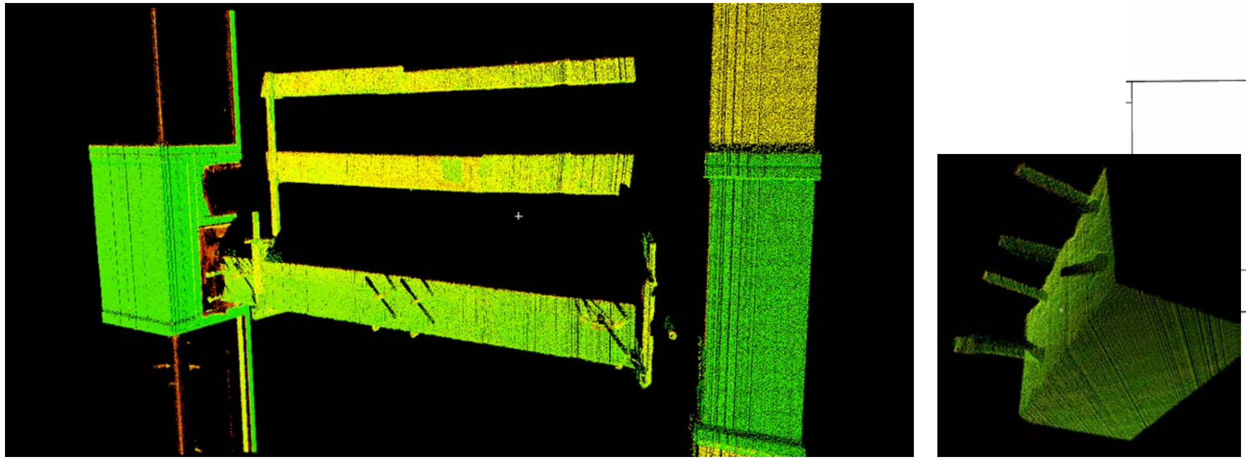
balcony – Tower 1 SW facade

mounting brackets

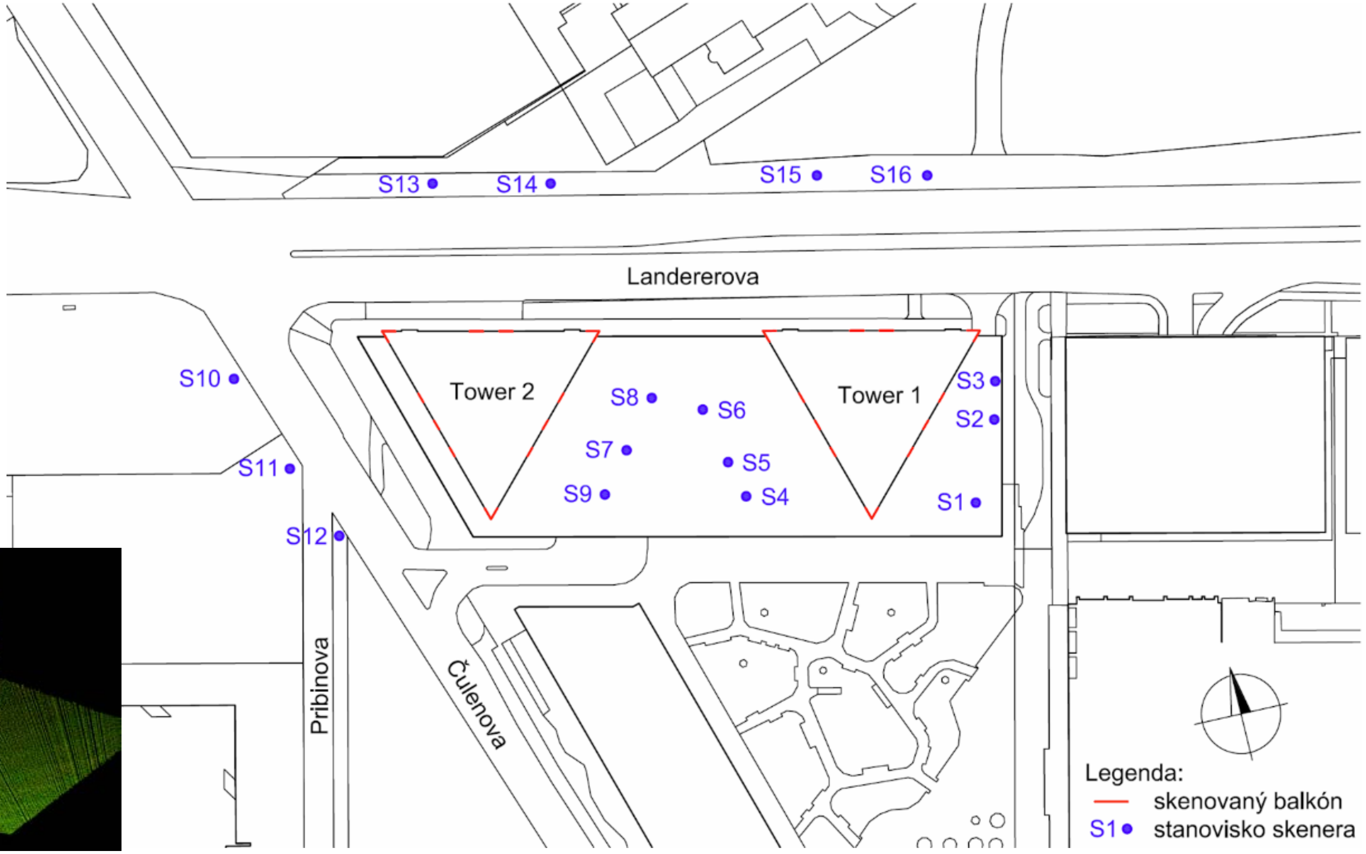
balcony railing

As-built documentation of anchor blocks of buildings Panorama City

- Scanning
  - Leica ScanStation2
  - Distance from the scanner: 20 m to 110 m
  - Scan density: 3 mm x 3 mm
  - Number of positions: 3 to 5 for each facade



Point cloud of balcony



Positions of the scanner

As-built documentation of anchor blocks of buildings Panorama City

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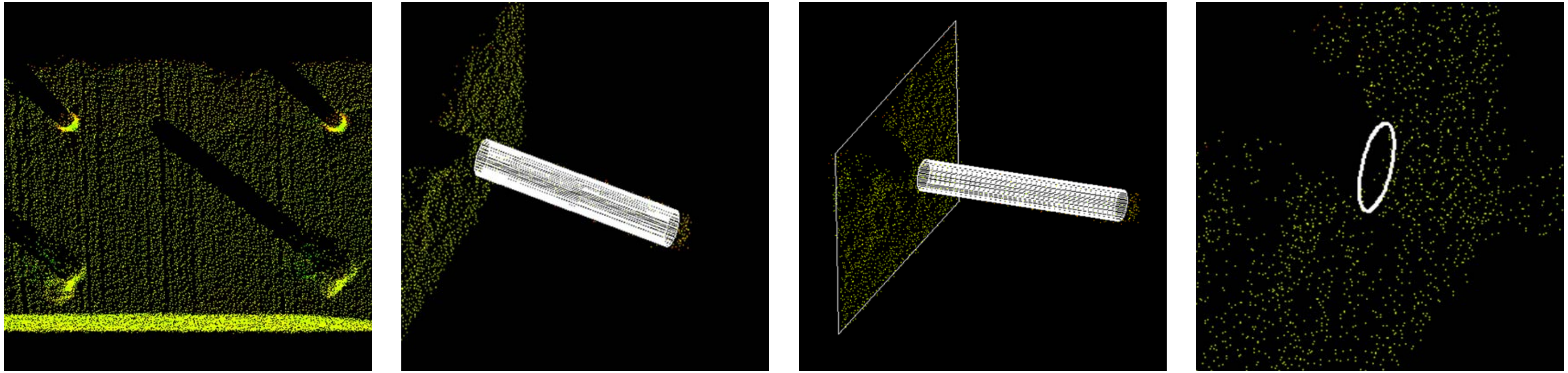
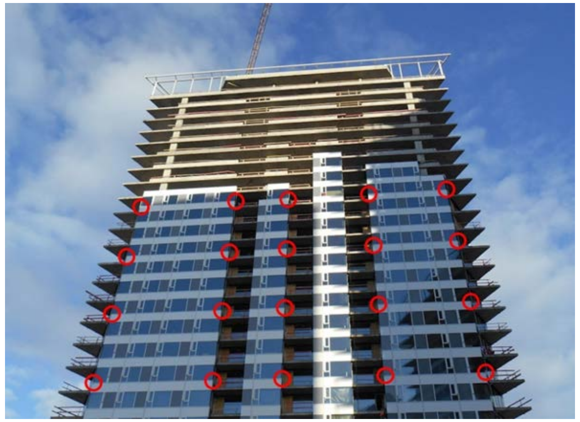


Modelling of threaded rods

- Modelling of anchor blocks
  - Regression planes on the front of the concrete slabs
  - Regression cylinders – diameters (15 mm to 20 mm)
  - 3D coordinates of the center of the intersecting ellipses
  - Modelling of reference points – corners of aluminum strips
  - Transformation to the coordinate system of the CAD design



modeling the position of reference points

As-built documentation of anchor blocks of buildings Panorama City

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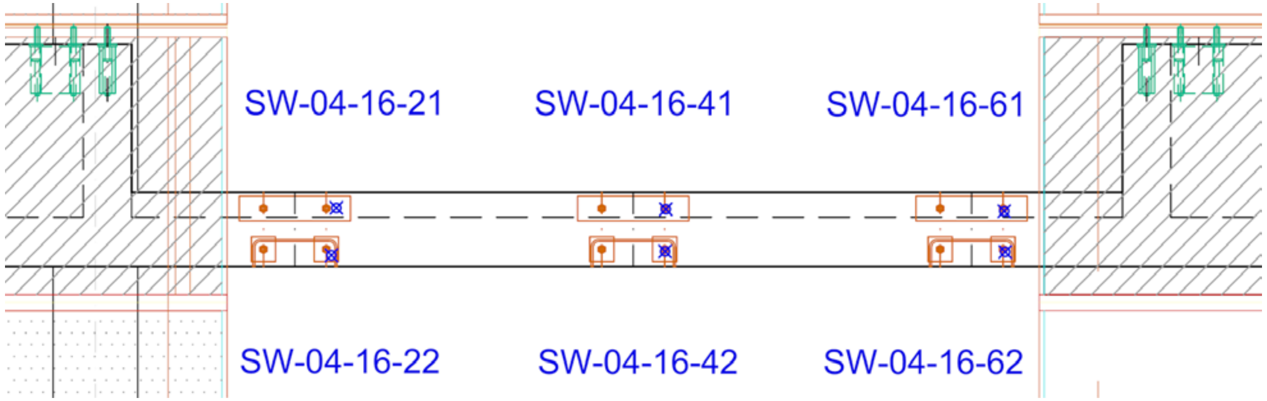
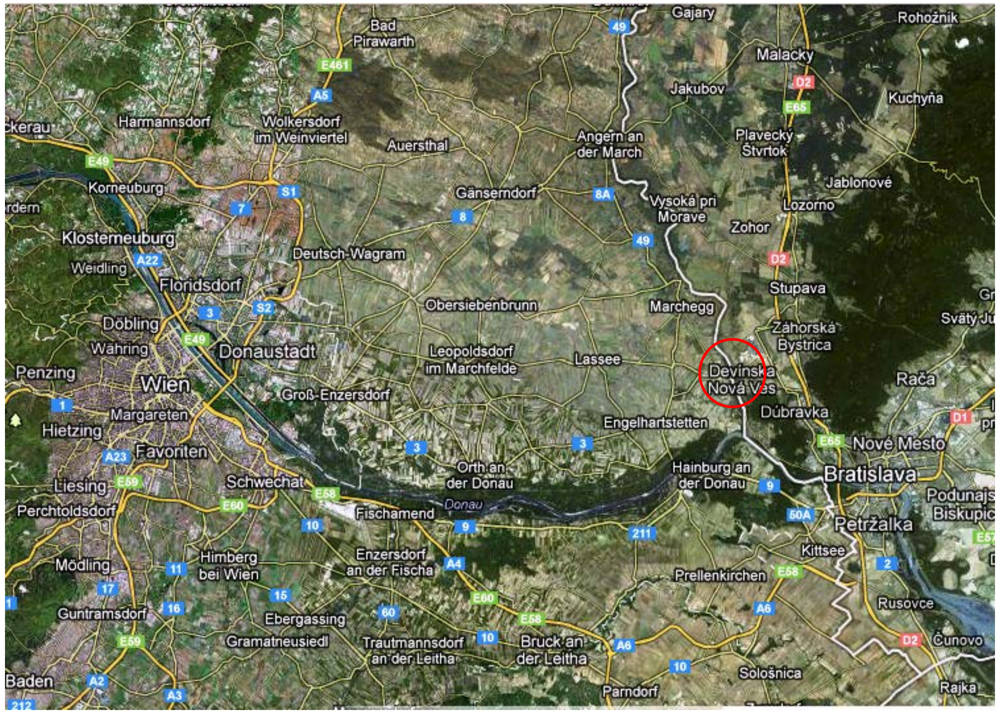
- Results of as-built documentation
  - Deviation from the design less than 15 mm – 10%
  - Deviation from the design less than 30 mm – 40%
  - In some cases, more than 100 mm



- Verification of the results
  - Distances between randomly selected pairs of rods – every second floor
  - The axial distance differed from the design (260 mm) within ± 3 mm
  - Distances between the rods along the balconies – measuring tape, error less than ± 5 mm
- Transformation error
  - Differences ΔX, ΔY between the identical reference points
  - Contains the accuracy of the measurement and the construction deviation
  - Values from 4 mm to 6 mm

Deformation monitoring of the Cycling Bridge “Most Slobody”

- The bridge allows join for pedestrians and cyclists between Bratislava city district Devínska Nová Ves (SVK) and Schlosshof (AUT), (river kilometer 4.31)
- Build over inundation area, total length 525.0 m



Deformation monitoring of the Cycling Bridge “Most Slobody”

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- Suspended construction with 3 sections, 30.0 m +120.0 m +30.0 m
- Reinforcing beam – tubular, triangle, clearance 50.0 m x 8.0 m, curvature 376.35 m
- Bridge deck – metal sheet, traverse beams, longitudinal reinforcing

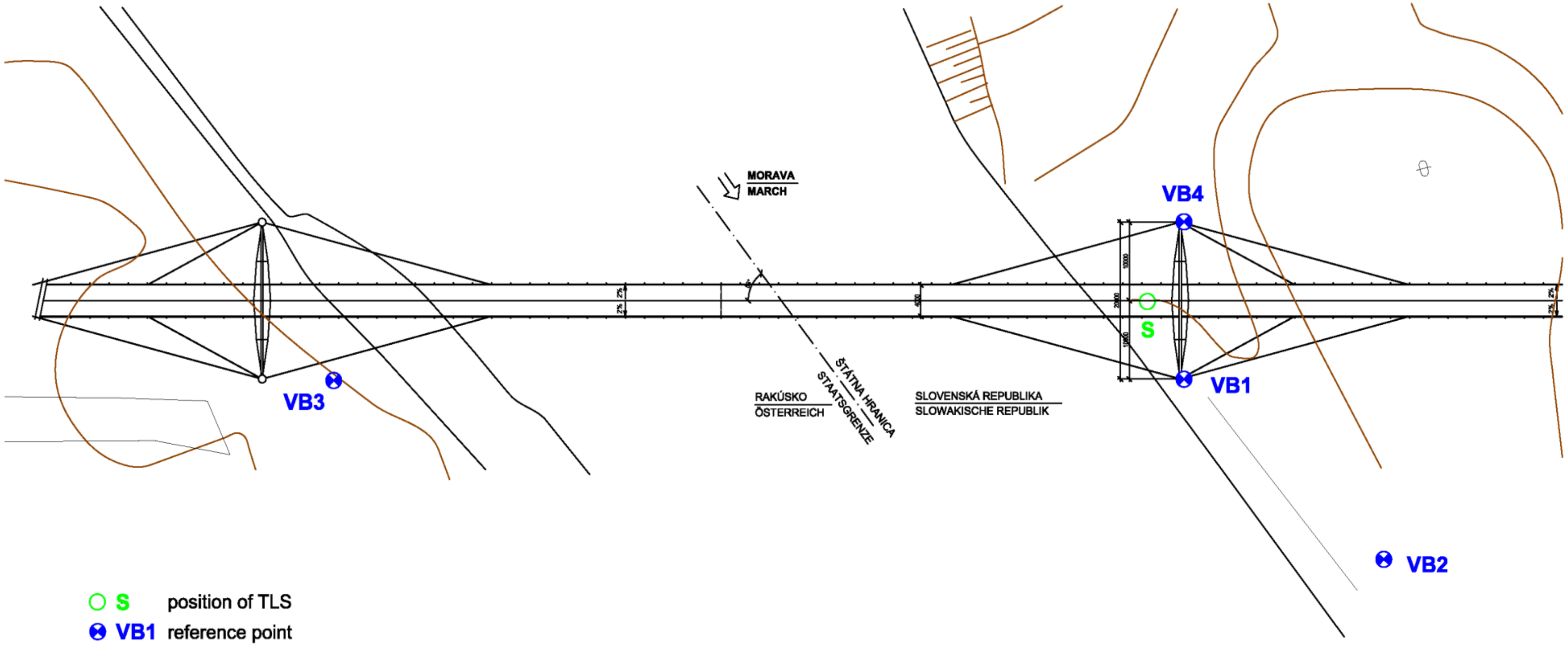
  cross slope of the deck 2.0 %, deck clearance 4.0 m, axial distance of cross beams 2.5 m
- Pylons – rectangular frames, number of pylons 4

Deformation monitoring of the Cycling Bridge "Most Slobody"

- Scanning of the main bridge section
  - Scanned in 3 epochs: November 2012, March 2013, November 2013
  - Leica ScanStation2
  - Scan density: 3 mm x 3 mm
  - Number of positions: 1

Position of the scanner

Reference points



Position of the reference points and the scanner

Deformation monitoring of the Cycling Bridge "Most Slobody"

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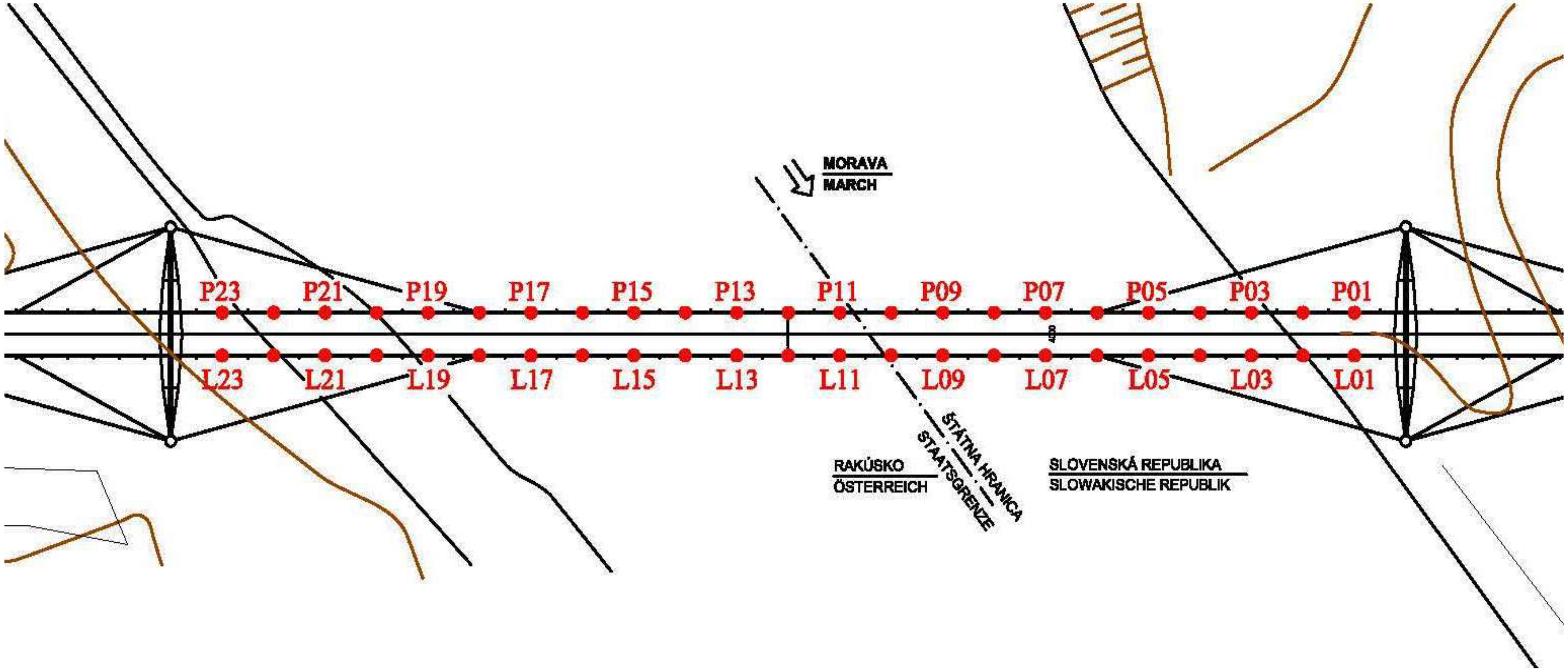
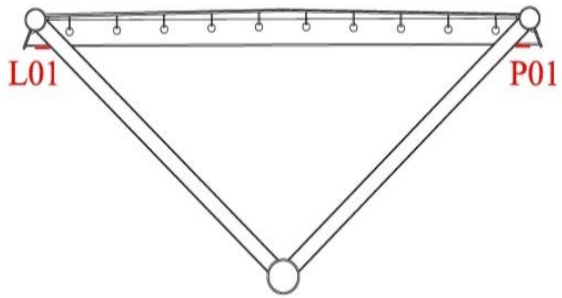
- Determination of the displacements
  - Regression planar surfaces 75 mm x 75 mm
  - Determination of the height of the monitored points
  - Determination of the vertical displacements
  - Calculation of standard deviation



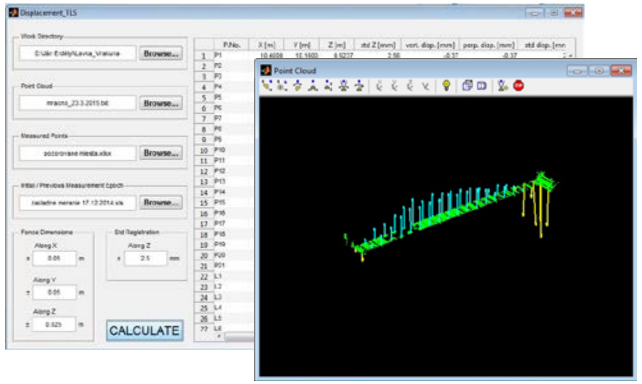
Position of monitored points

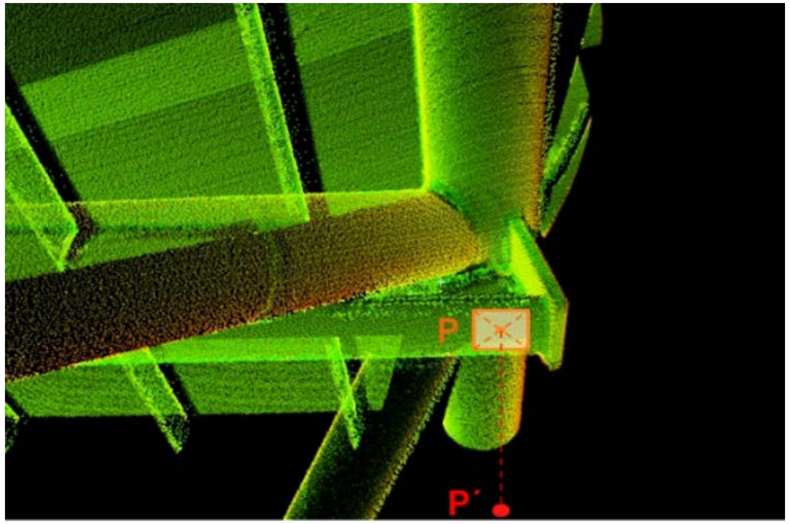


Deformation monitoring of the Cycling Bridge “Most Slobody”

- Determination of the displacements
  - Regression planar surfaces 75 mm x 75 mm
  - Determination of the height of the monitored points
  - Determination of the vertical displacements
  - Calculation of standard deviation

APP
Displacement TLS





Determination of the position of monitored points

Deformation monitoring of the Cycling Bridge “Most Slobody”

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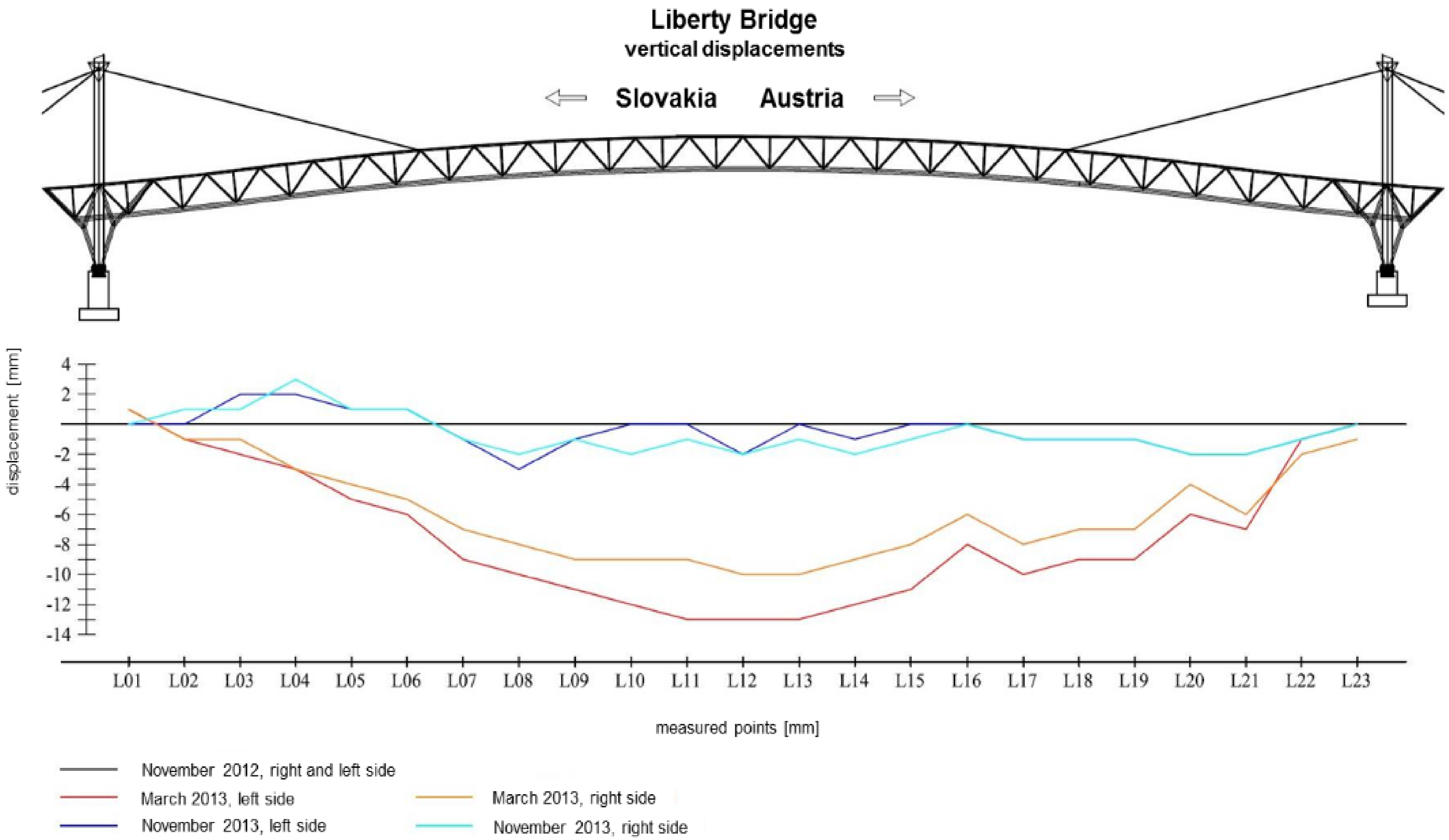
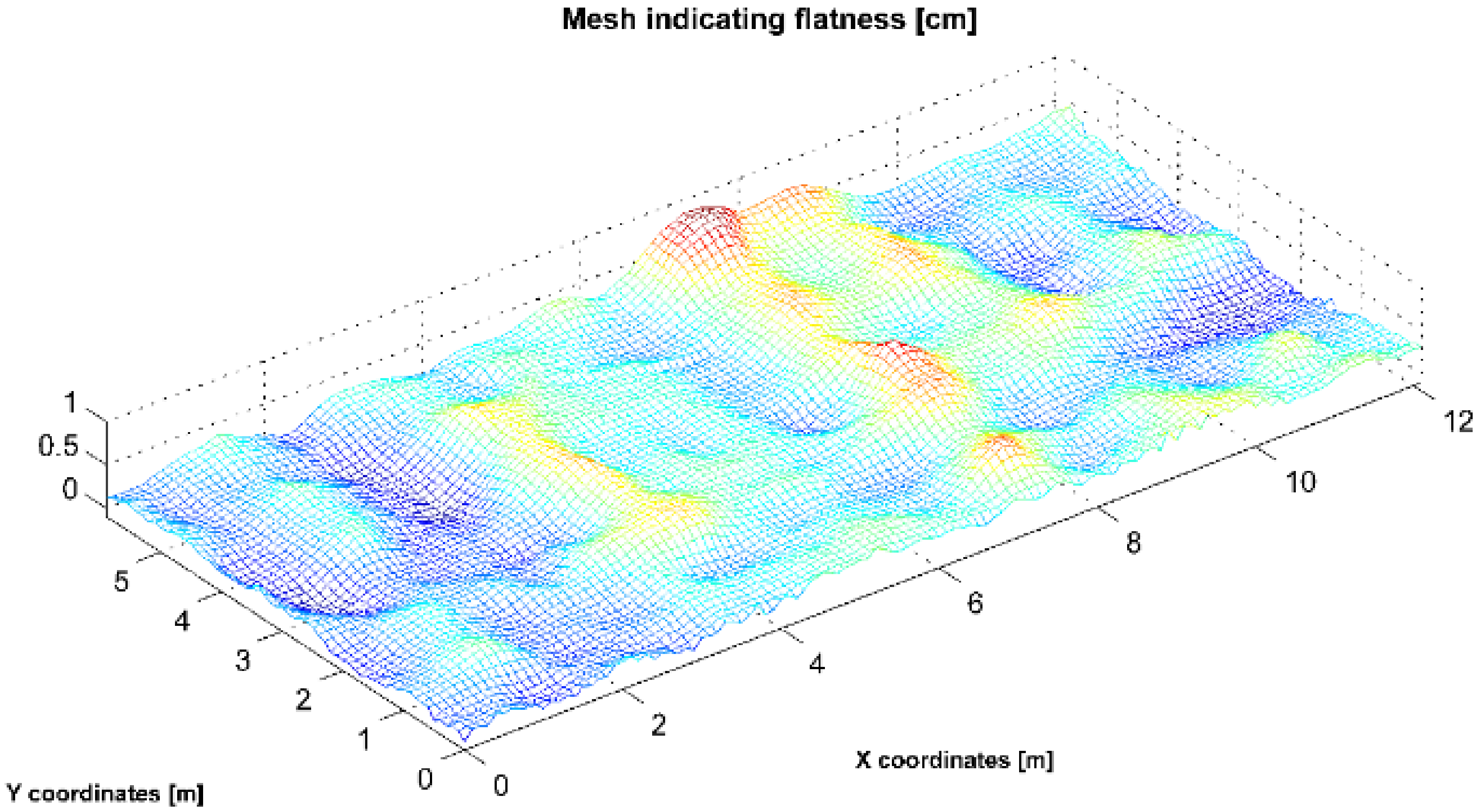
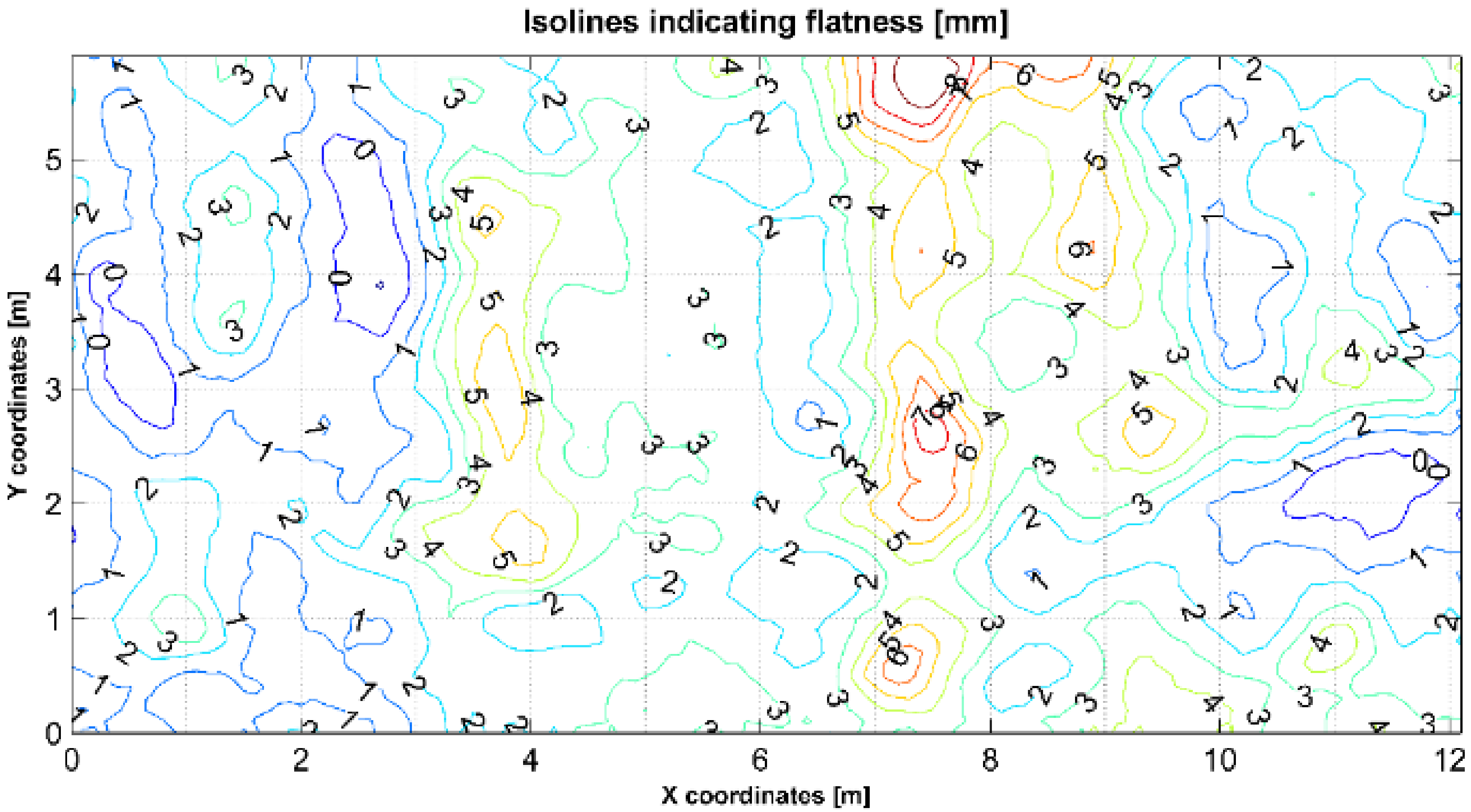


Determination of flatness of industrial floors



Determination of flatness of industrial floors



Information Model of Industrial Plants

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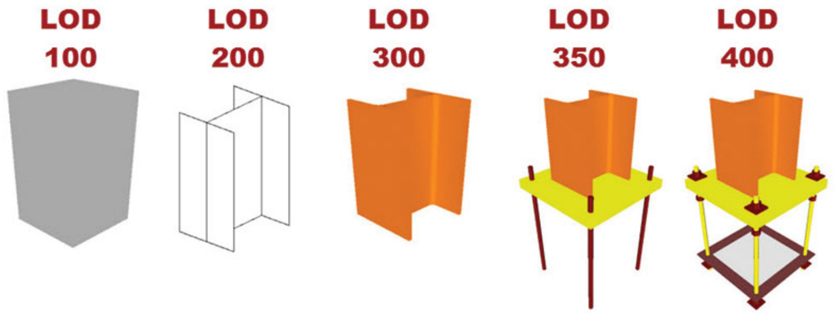
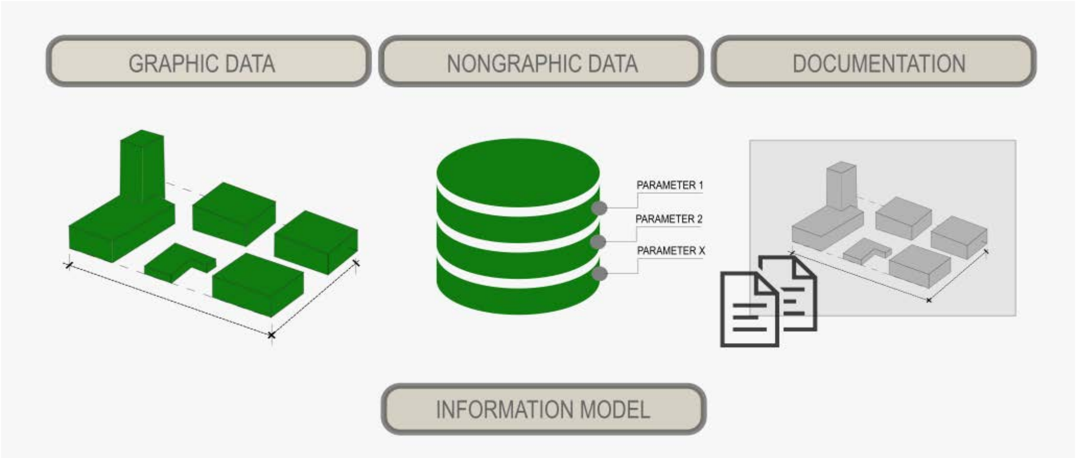
- BEP – BIM Execution Plan
  - Proposal of data structure for information modeling
  - Proposal of information model content
    - Graphic data – the smallest detail, accuracy and representation of the elements
    - Nongraphic data – identification of information that the BIM model should contain (attributes)
    - Documentation – definition of documents (production documentation, manuals, inspection reports, photographs, etc.)



BIM Forum



Information Model of Industrial Plants

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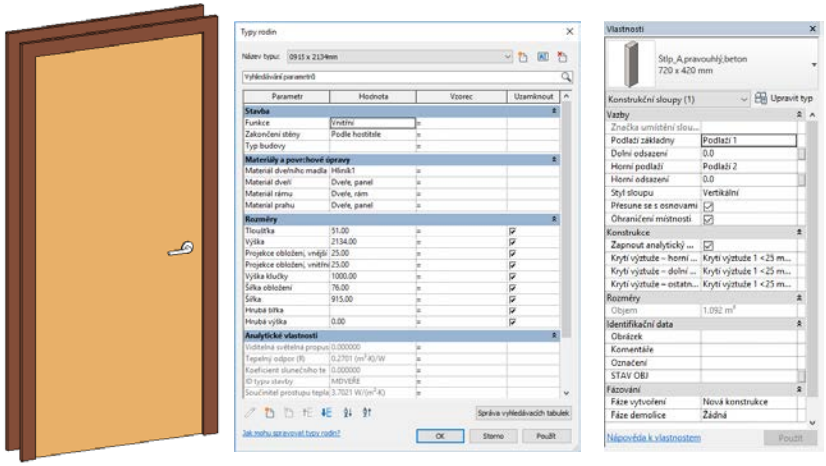
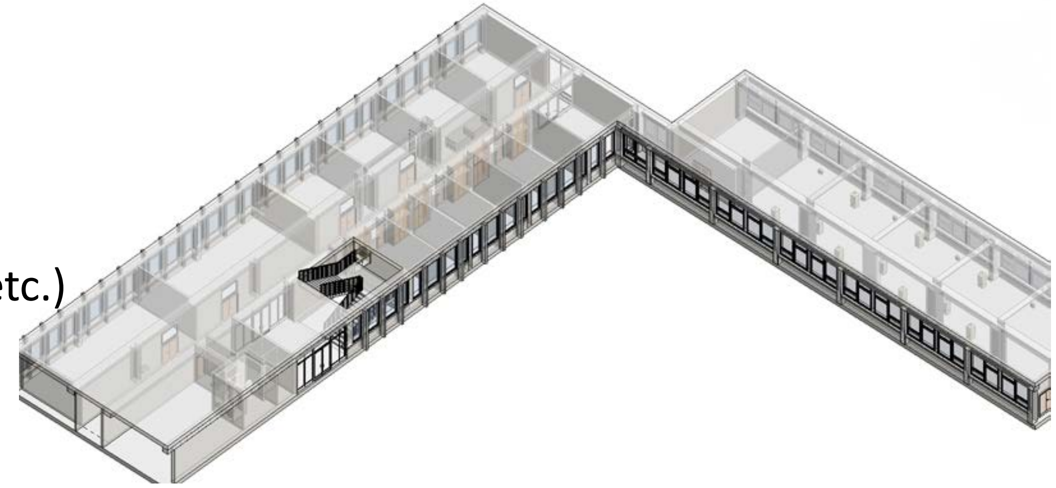
- BIM of plants
  - Machinery, production lines, conveyors, pipeline, etc. in addition to the buildings
  - Each forms a separate unit

  - Buildings
    - Architectural, structural, electrical, plumbing and other building services (HVAC etc.)
    - Volume models – object libraries or user defined models (Category-Family-Type-Instance)

  - Machinery
    - Close cooperation with their manufacturers
    - Space associations (relationship to production lines, halls, etc.)

  - Pipeline bridges, pipeline routes





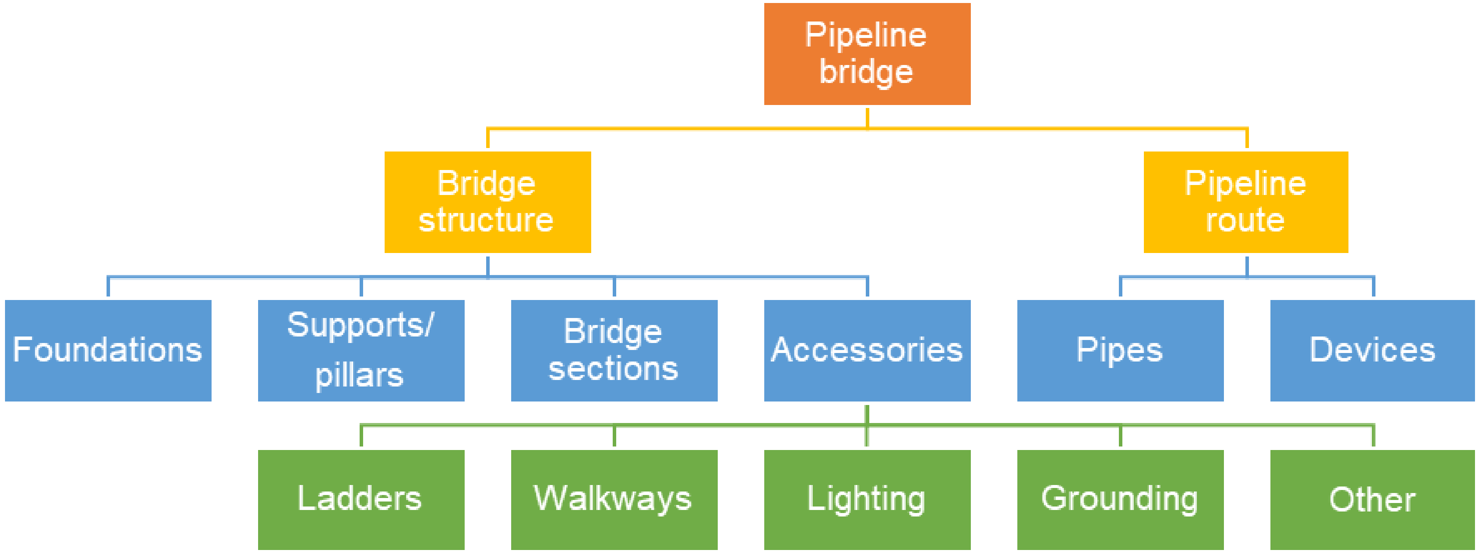
Information Model of Pipeline Bridges

- Pipeline bridge, pipeline route

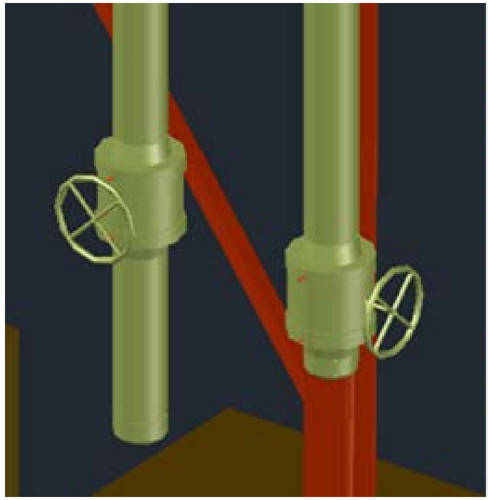
- 3 main parts of pipeline bridges: foundations, supports (pillars) and bridge sections
- The operators need:
  - Information about pipeline routes, their characteristics, substance, who is the purchaser of the transported substance (which operating unit within the plant), ID of the pipeline route manager, condition of the pipes, as well as info about other facilities
  - Information about the operational status of pipeline bridge structures

Information Model of Pipeline Bridges

- Pipeline bridge
  - Bridge structure
    - Foundations, supports, bridge sections, accessories
  - Pipeline route
    - Pipes, devices on pipeline rotes



- LOD 300 - the element is graphically represented in the model as a separate system, object, or device, defined by quantity, size, shape, location, and orientation,



- Documents - photographs (*.jpg, *.tiff, etc.), 300 dpi 1920 x 1080 pix. (or panoramic) TrueColor

Information Model of Pipeline Bridges

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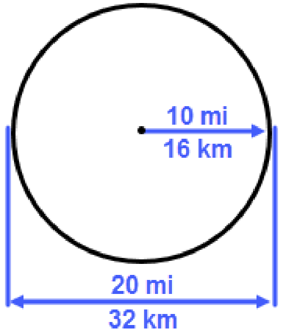
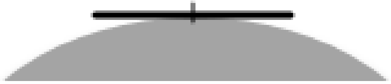
- Limitations of the software platforms for BIM
  - Objects displayed 1:1
  - Not taking into the account the map projection (Earth's surface curvature, cartographic distortion).
  - Only allow the placement of the object at one point and the orientation of the object towards the initial direction (north) - ***IfcMapConversion***
  - Limited virtual environment (limited numerical coordinate values)





  - Division of the model into parts in a local horizon
  - If necessary, transformation of characteristic points

Information Model of Pipeline Bridges – Duslo, a.s. Šaľa, Slovakia

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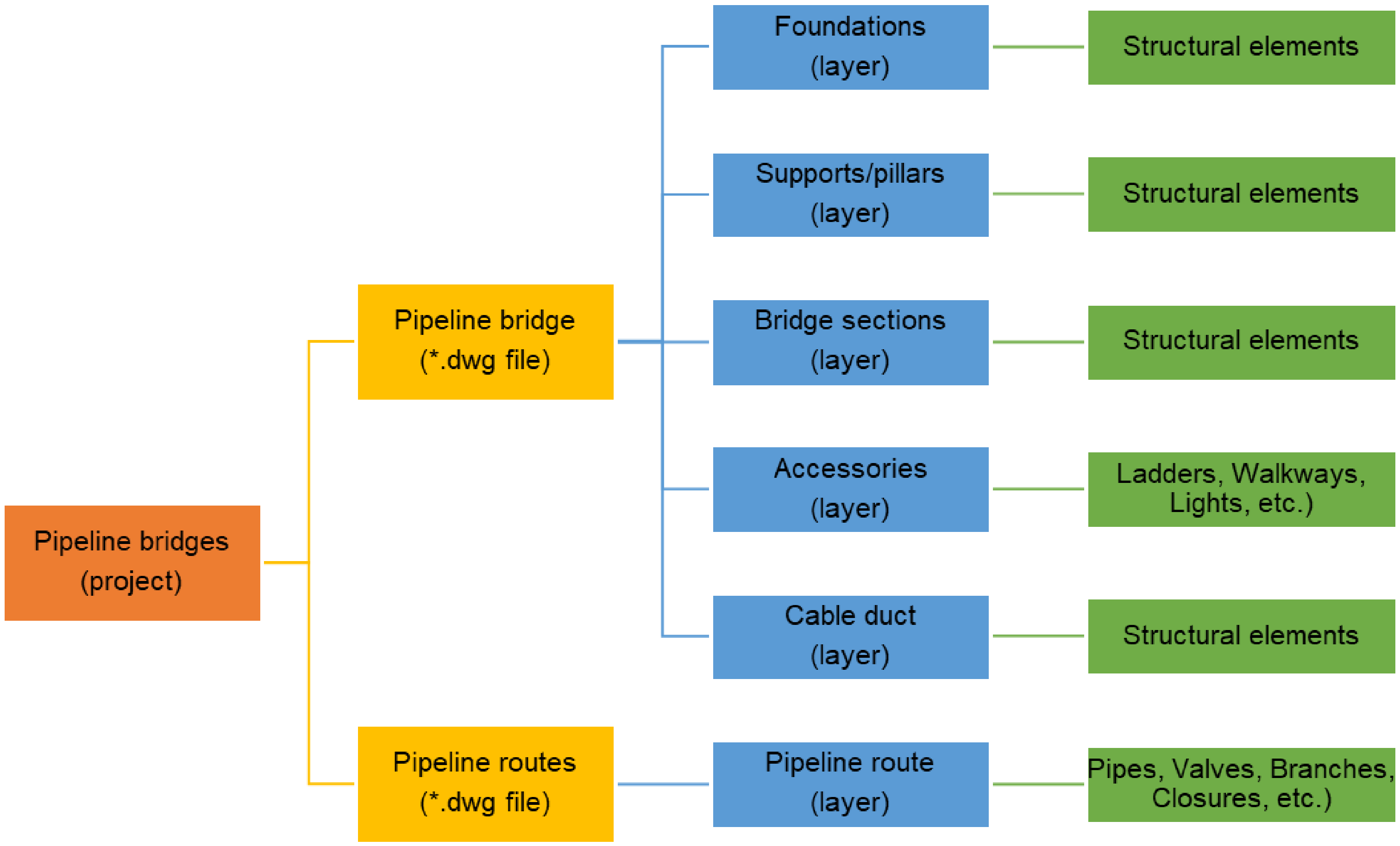
- Pipeline bridge M1 - length 184 m, height 9 m a width 5 m
- Measurement – terrestrial laser scanning

  - Trimble TX5
  - 3 mm / 10 m
  - 20 positions

  - Software used AutoCAD Plant 3D

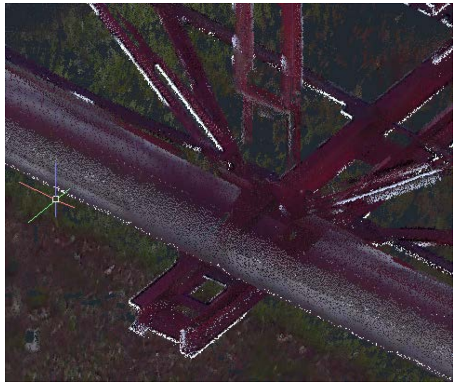
Information Model of Pipeline Bridges – Duslo, a.s. Šaľa, Slovakia

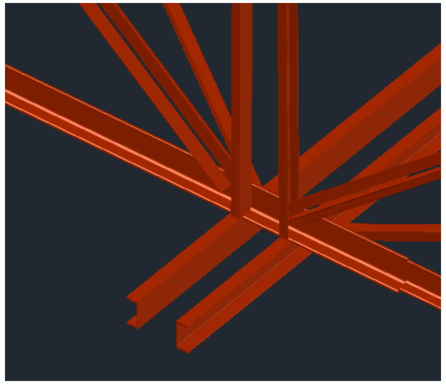
- Structure of the information model in AutoCAD Plant 3D



Information Model of Pipeline Bridges – Duslo, a.s. Šaľa, Slovakia

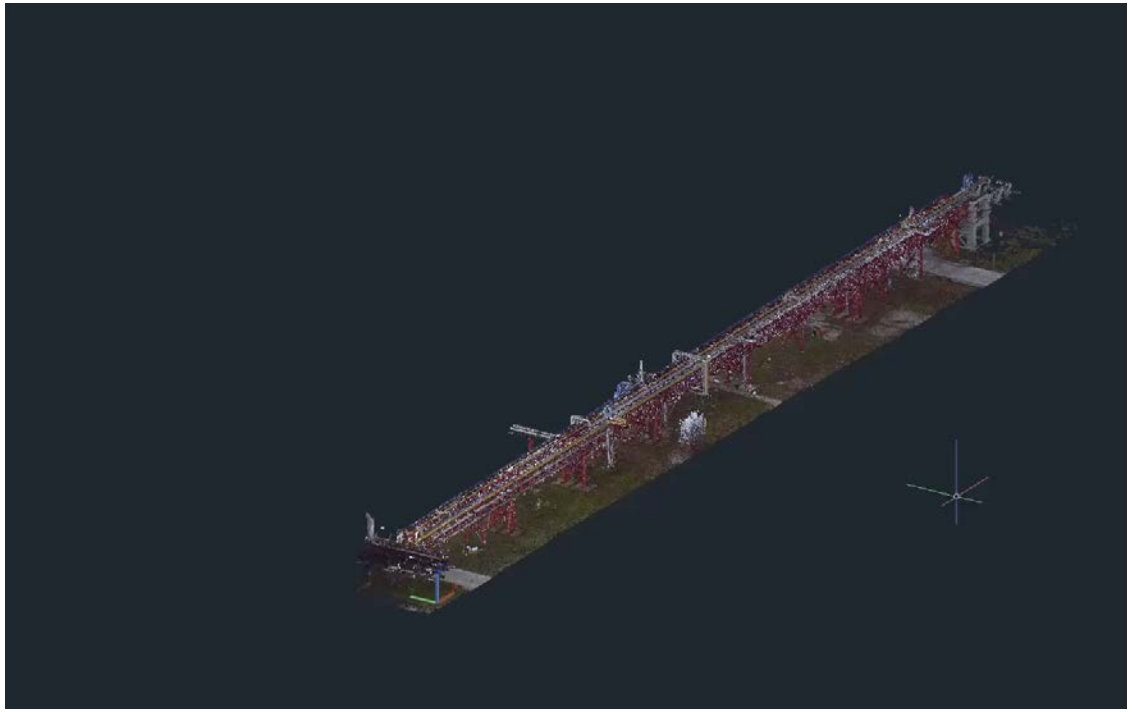
- Modeling of the pipeline bridges
  - Modeling of bridge sections using structural beams from library
  - Modeling of supports
  - Modeling of foundations
  - Modeling of accessories (ladders, lights, walkways, etc.)



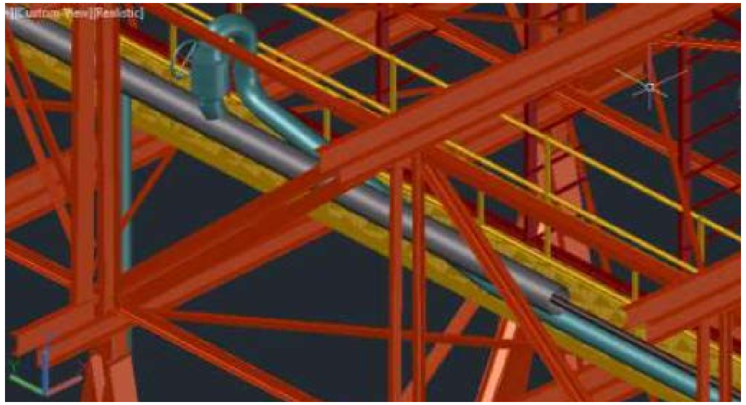


- In the attribute tables
  - Definition of the parameters
  - Definition of ID of the pipeline bridge – M1
  - Unique ID of the elements:

    Bridge sections – BS_XX_L_NN
    Supports/pillars– S_XX_L_NN
    Foundations – F_XX_L_NN
    Cable ducts – M1_CNNN
    Other accessories– M1_NN



Information Model of Pipeline Bridges – Duslo, a.s. Šaľa, Slovakia

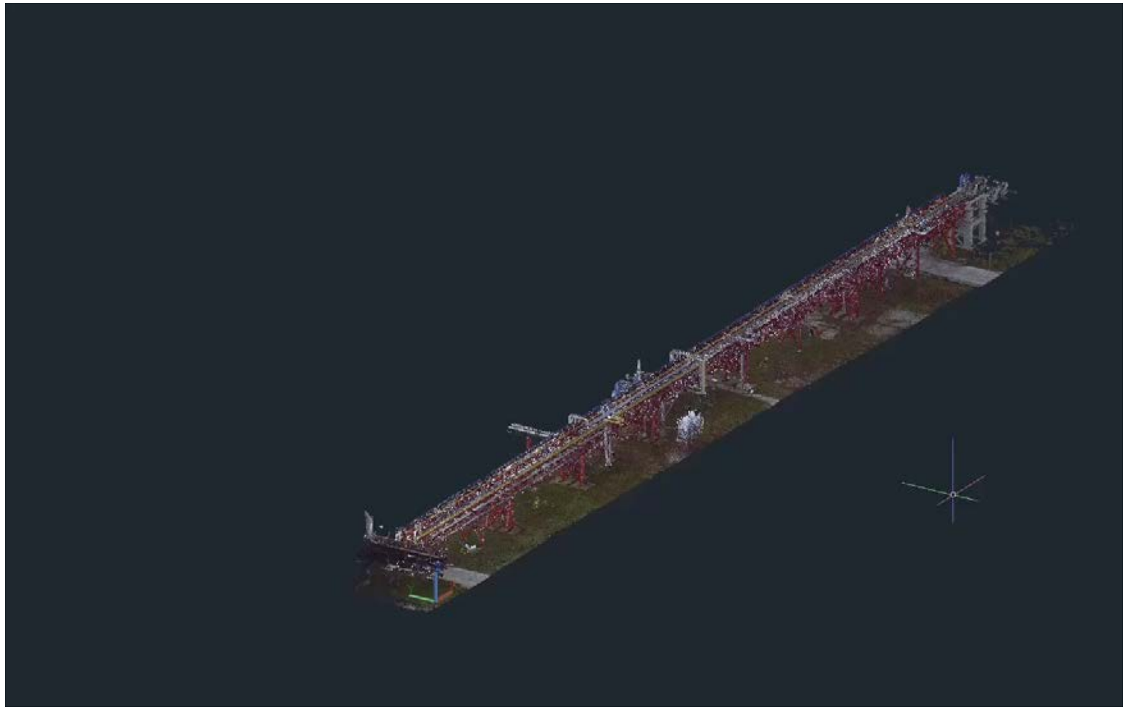


- Modeling of the pipeline routes
  - Modeling of the pipeline routes using object library
  - Modeling of the outer diameter of the pipes (incl. insulation)
  - Heating pipes and the pipelines modeled separately
- In the attribute tables
  - Definition of the parameters
  - Definition of the ID of pipeline route

  RRRR_SS_DDD_MMMM_II

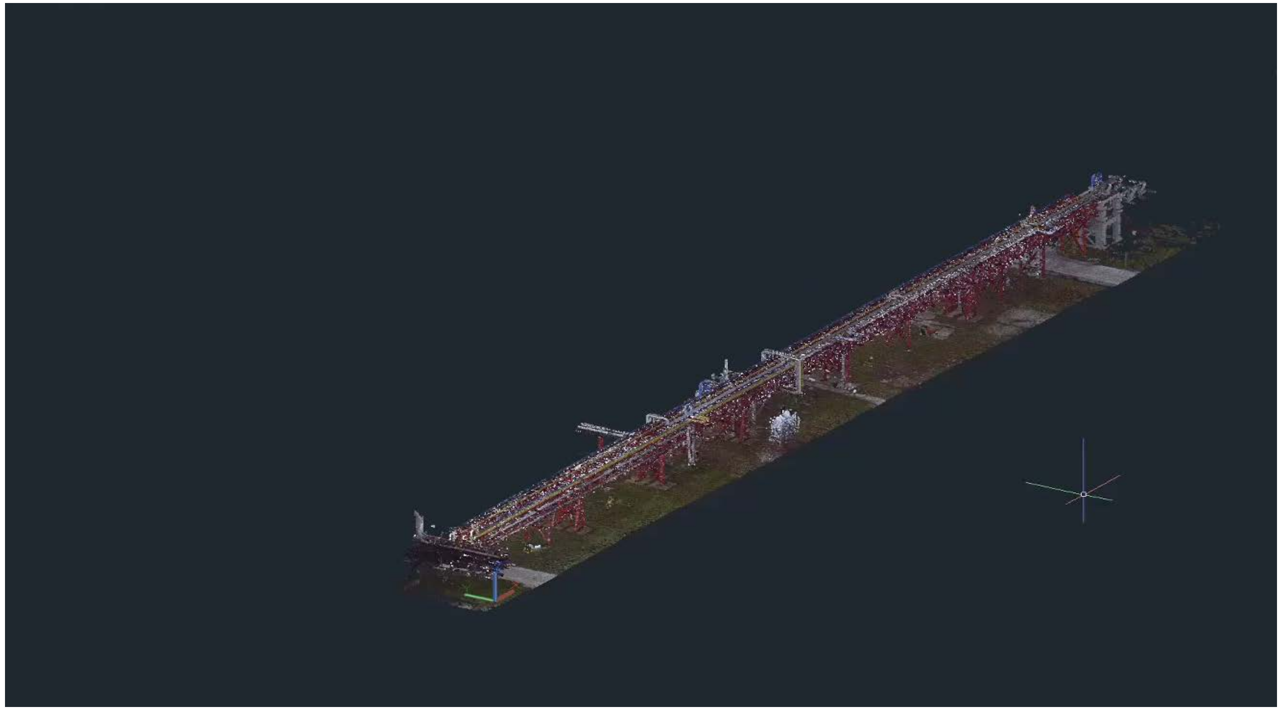
PnPID	Typ a norma	Vonkajší priemer (mm)	Dĺžka (mm)	Médium	Evidenčné číslo trasy	Vnútorný priemer (DN)	Maximálny tlak (PN)	Materiál-
13898	Pipe DIN 2448	250	111637.5...	Vodk	018-H-250-TR11-	250		oceľ, tr. 11
14026	Pipe DIN 2448	150	68588.9...	Metanol - prívod	0028-82-50-TR11-DE	50		oceľ, tr. 11
14135	Pipe DIN 2448	150	68358.4...	Metanol - odvod	0027-82-50-TR11-DE	50		oceľ, tr. 11

Hrúbka steny (mm)	Izolácia	Hrúbka izolácie (mm)	Prevádzkový tlak	Teplota v °C	Kapacita	Farba potrubia	Smer prúdenia	Vstupy	Výstupy	Vyhradené technické zariadenie
	Nie			okolia		RAL1018		44-12	34-06	Nie
3	Áno	50	0,3 MPa	50				44-05	34_06	Nie
3	Áno	50	0,3 MPa	50				34_06	44-05	Nie



Information Model of Pipeline Bridges – Duslo, a.s. Šaľa, Slovakia

- LOD, accuracy, generalization
  - LOD 300 for most of the elements,
  - LOD 200 for the objects with complex geometry,
  - Generalization – less than 50 mm
  - Accuracy – depends on the accuracy of the measured points and the generalization



Verification of the as-built geometry of structures

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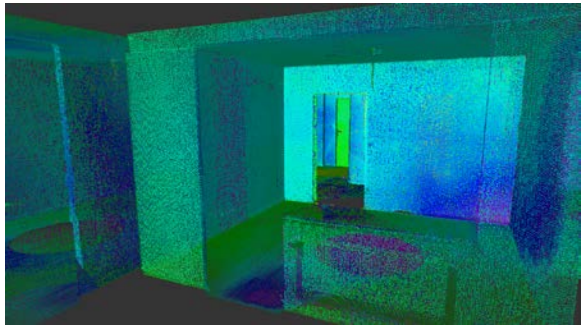
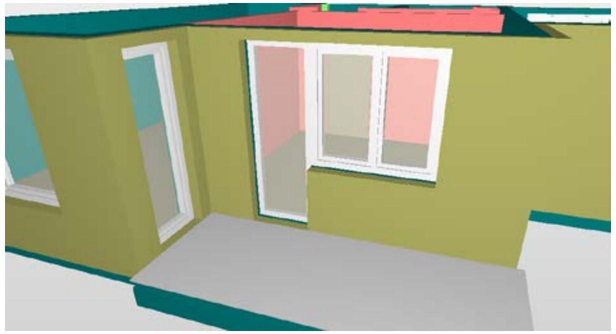
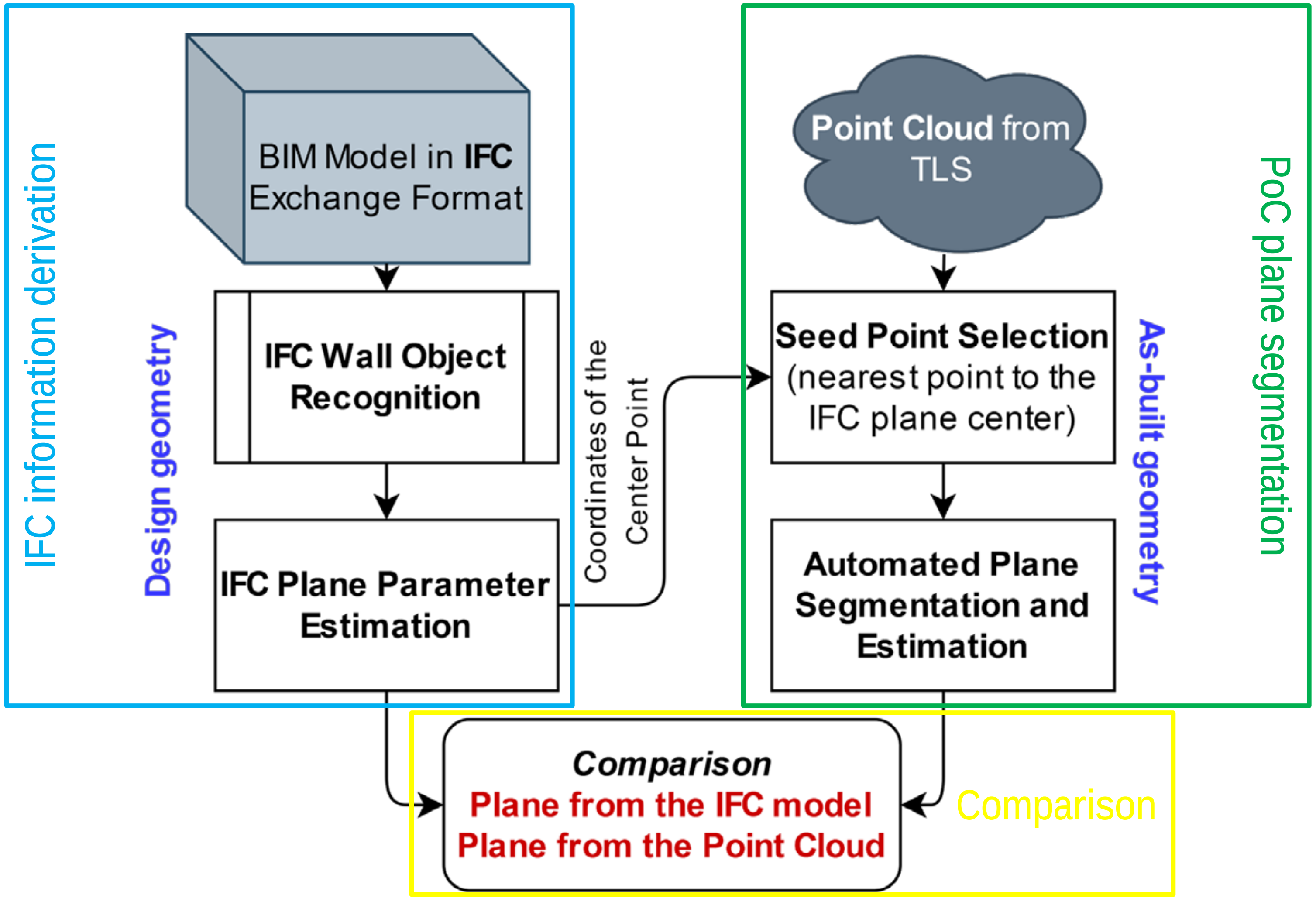
- Automated geometry check based on the comparison of the designed geometry from the BIM model (IFC) with the as-built geometry from the point clouds3D model creation
  - use of point clouds (TLS, photogrammetry) and BIM models
  - monitoring at all points of the building
  - automation of the evaluation of the quality check of the execution using a standalone app





Verification of the as-built geometry of structures



Verification of the as-built geometry of structures

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#156= IFCSURFACESTYLE('Betonov\X2\00E9\X0\ Tv\X2\00E1\X0\rnice',.BOTH.,(#155));
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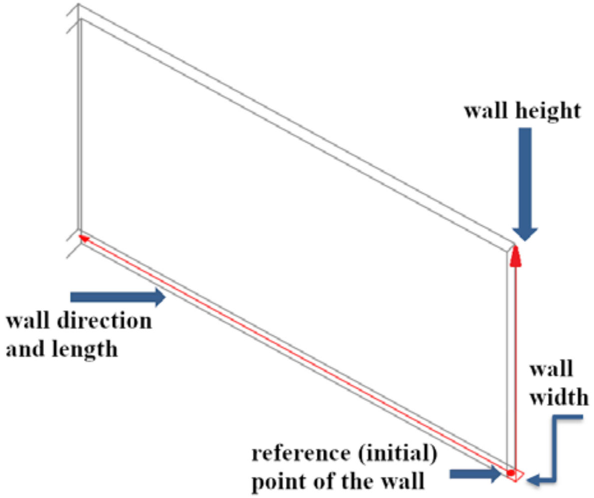
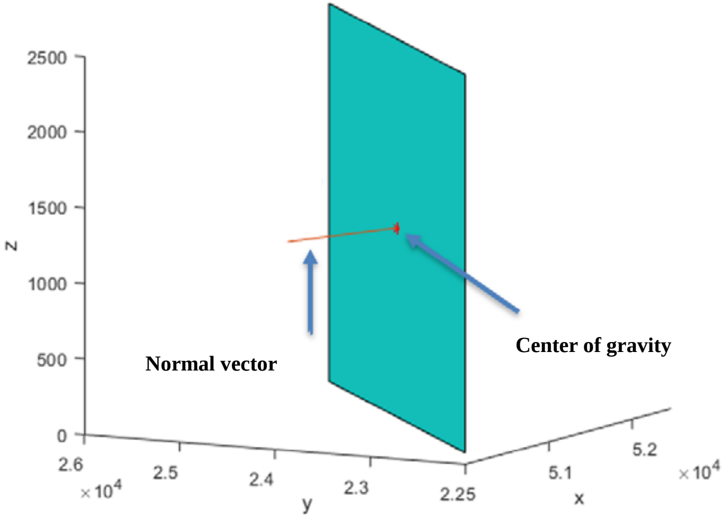
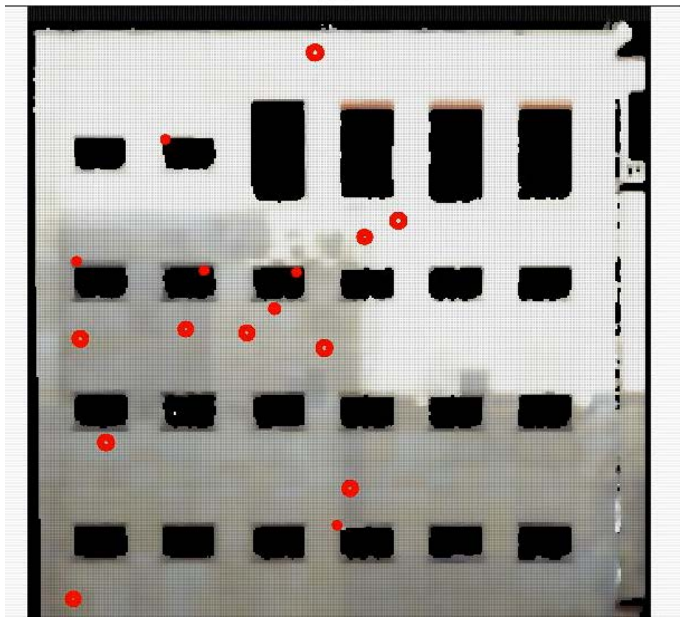


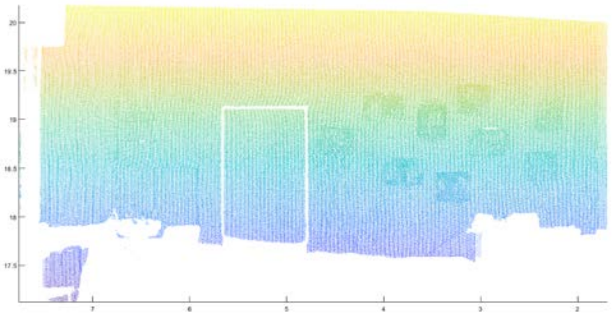


Verification of the as-built geometry of structures

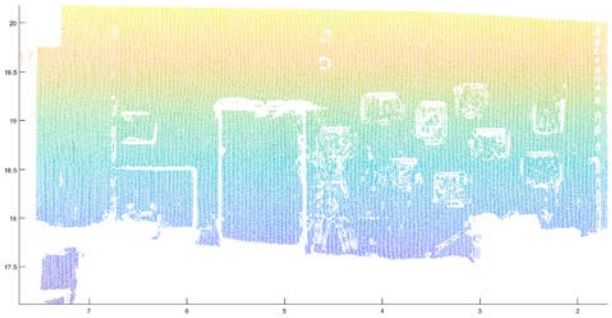
Original point cloud

Curve Segmentation based filtration
RGB, Intensity, local normal

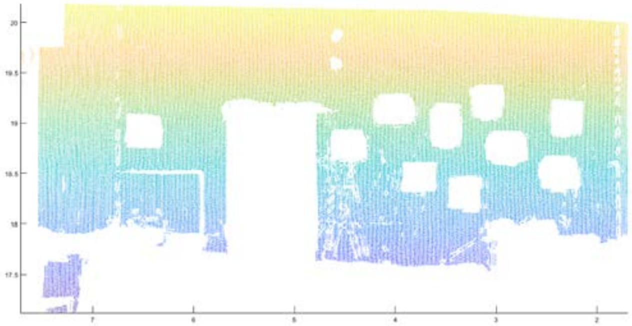




Regression plane
50 mm threshold



Filtering on the base of local normal vectors
4° threshold



Curve Segmentation based filtration
RGB, Intensity, local normal

Verification of the as-built geometry of structures

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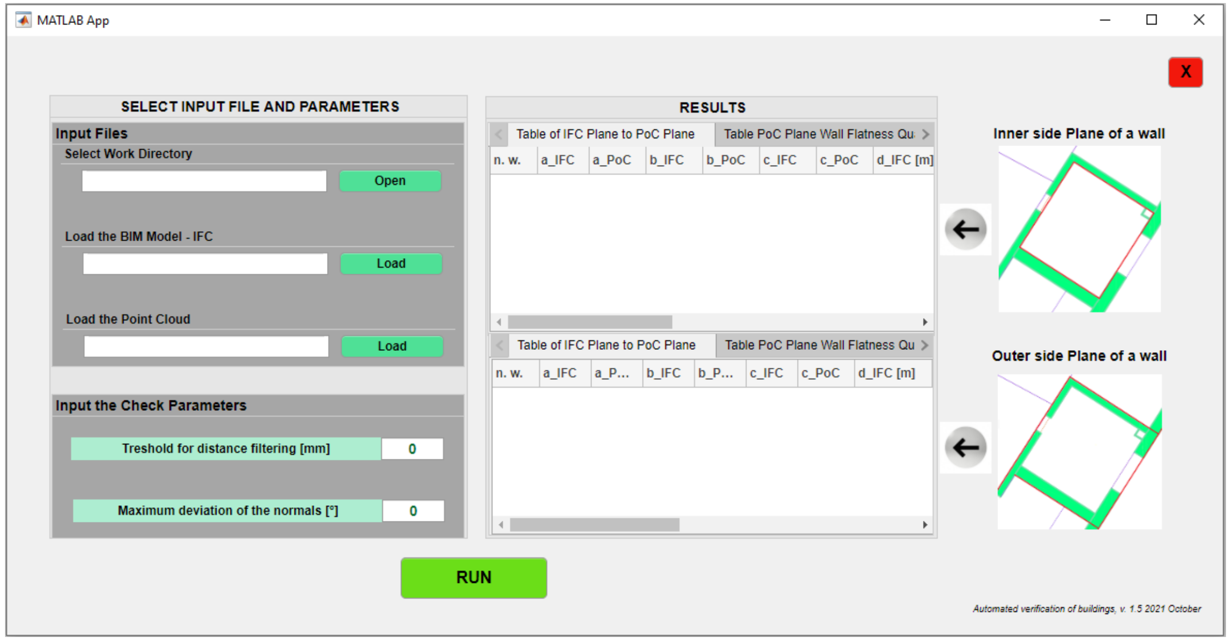
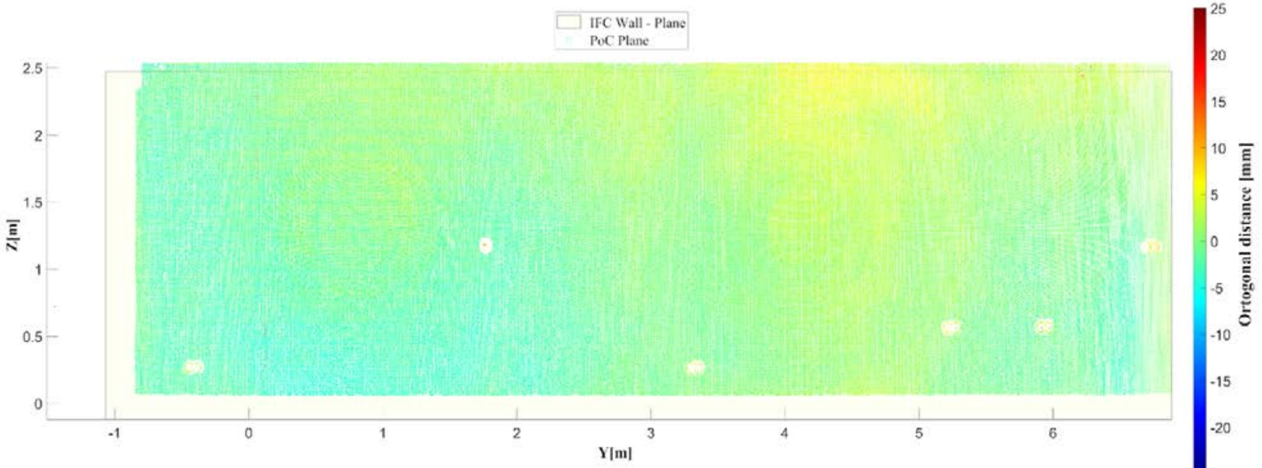
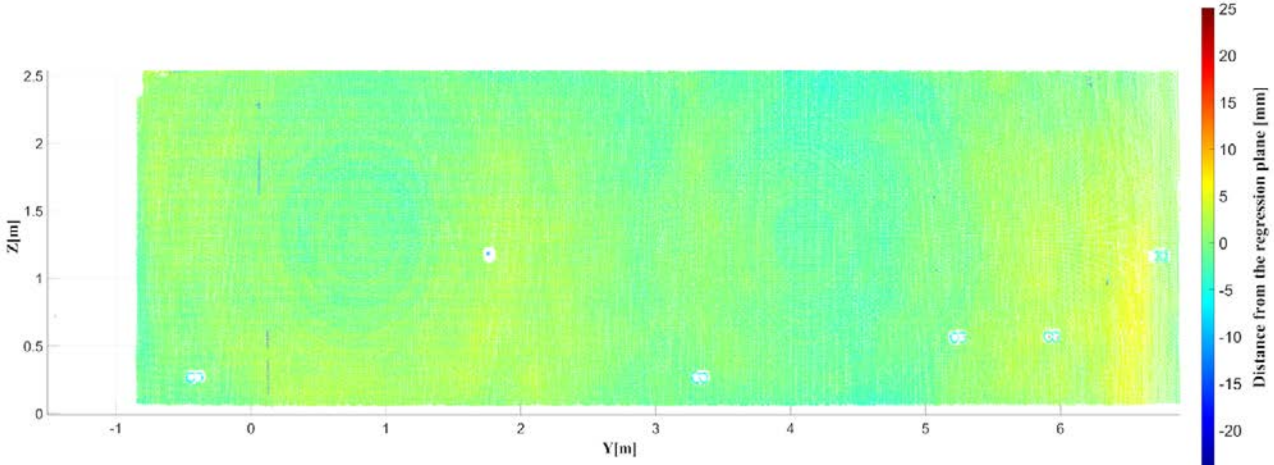




IFC plane vs. point cloud



Wall flatness – regression plane vs point cloud

Thank you for your attention

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