

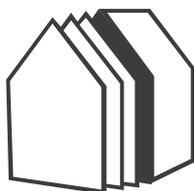


ADVANCED GEOMATICS FOR MODULAR BUILDING RECONSTRUCTION

D4.1

final

Development and advanced prefabrication of innovative,
multifunctional building envelope elements for
MOdular RETrofitting and CONNECTions (MORE-CONNECT)



H2020-EE-2014-1-PPP (EE-01-2014)



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1 INTRODUCTION

Geomatics, according to the Oxford Dictionary, is defined as the mathematics of the Earth, thus the science of collecting (with some instruments), processing (with some techniques), analysing and interpreting data related to the Earth's surface.

The aim of this report is to bring an overview of geomatics techniques that can be used for building reconstruction and to show advantages of their integration into different project phases. The report will provide information to civil engineering companies in order to be knowledgeable in the field of geomatics. Better understanding of geomatics techniques and methodology will lead to more exact specifications of project requirements for surveyors and also to cost optimization of the geomatics work (surveying, processing of data and information transfer into desired software in appropriate format).

2 SURVEYING TECHNIQUES FOR BUILDING DOCUMENTATION

When using prefabricated modular elements for the façade reconstruction the quality of building documentation is crucial.

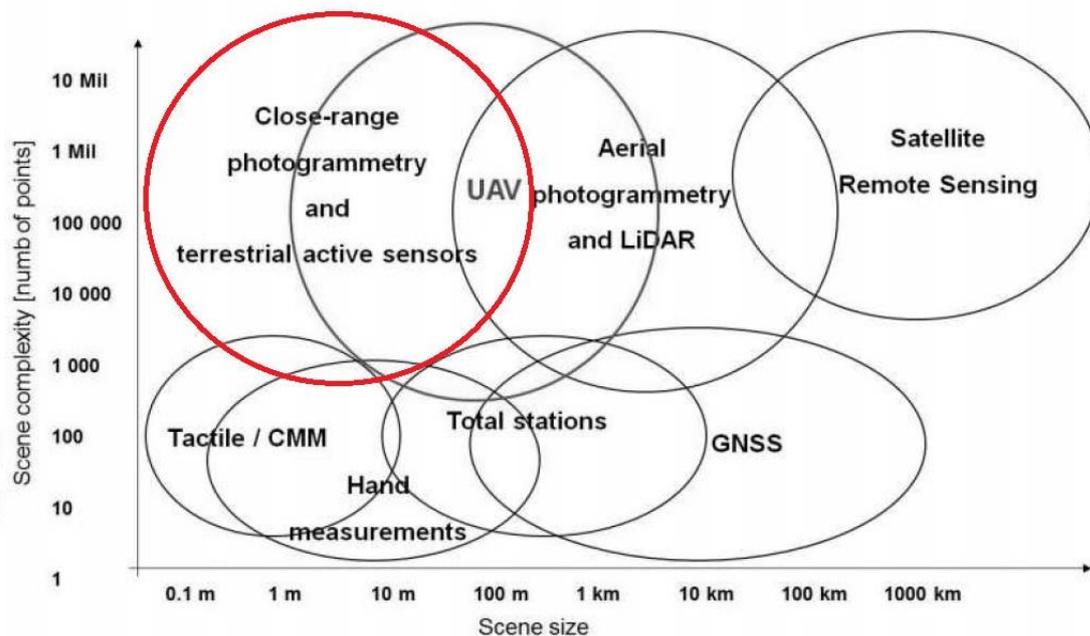


Fig. 1: Geomatics techniques for 3D data acquisition, shown according to the object/scene dimensions and complexity of the reconstructed digital model (Remondino; Campana, 2014)

Surveying techniques performed in the MORE-CONNECT project consist mainly of laser scanning and photogrammetry. These methods have replaced traditional surveying techniques in many applications. Traditional recording methods based on hand recording, e.g. by means of tape measurement, are too subjective, time consuming and applicable only to small areas. In contrast to the terrestrial surveying and analytical photogrammetry, which requires a manual interpretation in

order to derive a representation of the sensed objects, these new automatic recording methods allow an automated dense sampling of the object surface within a short time (Pfeifer; Briese, 2007). It is enabled due to the speed of acquiring high density data and highly automated processing. These methods are used to obtain a 3D model of the building of interest. Basic principles and characteristics of the methods are described further.

2.1 Laser scanning

Laser scanners (active sensors) operate by emitting laser beam to a known direction and then waiting for the reflection to measure distances from the sensor to the object. By measuring the direction the laser was emitted and the distance to the object was determined, the scanner can determine the 3D location of the surface that the laser has reflected off. By emitting the light in a regular pattern (more than 200,000 points/s) the method allows a dense sampling of the object surface. Detail level of the resulting 3D model depends on the setting of the scan resolution and the distance to the object.

Different principles can be used to measure the distance between the sensor system and the target. They differ in precision but all have their justification for a certain range envelope. For the building documentation two of the mentioned principles can be applied: the pulse systems and the phase-shift systems. The largest ranges (>100m) can be probed using the pulse round trip time measurement principle and obtaining a centimetre accuracy. Shorter distances, e.g. up to 100m, can be measured faster and more accurate with the phased based measurement technique.

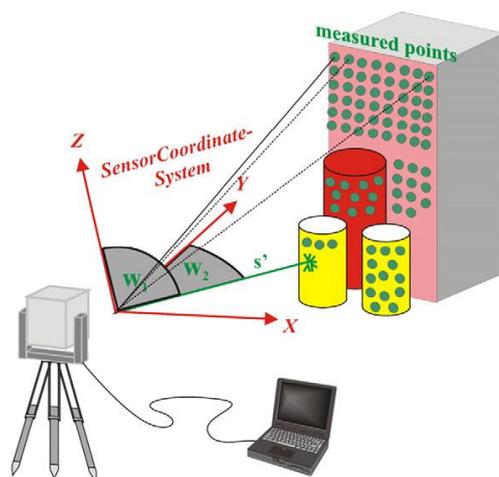


Fig. 2: Laser scanning principle (Tang et. al, 2010)

Primary product of the laser scanning is a point cloud – set of data points in a user defined coordinate system that represents an external surface of the measured object. Software for pre-processing and point cloud export is usually supplied together with the scanning system. The processing of point clouds is described in chapter 3.

More details about laser scanning and its application can be found in Pfeifer; Briese (2007), Vosselman; Maas (2010).

2.1.1 Current Systems

There are two examples of laser scanners suitable for building documentation:

FARO Focus 3D X130

Range: 0.6 –130m
Measurement speed up to 976,000 points/second
Ranging error: 2 ± 2 mm
Integrated colour camera
Laser class: Laser class 1
Weight: 5,2kg
Multi-Sensor GPS, Compass, Height Sensor, Dual Axis Compensator
Size: 240 x 200 x 100mm
Scanner control via touchscreen display and WLAN
Web: <http://www.faro.com/products/3d-surveying/laser-scanner-faro-focus-3d>



Fig.3: FARO Focus 3D X130

3D Scanner Surphaser® 100HSX

Work Range: 1 –50m (Recommended)
Measurement speed up to 1,200,000 points/second
Range Uncertainty: 0.7mm@15m
Laser class: Laser class 3R
Weight: 11kg
Size: 381 x 219 x 120mm
Optional Accessories: Built-in Scan Controller, Camera 60 megapixel
Web: <http://www.surphaser.com/pdf/Surphaser%20100HSX.pdf>



Fig.4: Surphaser 100HSX

Laser scanning equipment overview and parameter comparison of it can be found on: <http://www.geo-matching.com/category/id46-terrestrial-laser-scanners.html>

2.2 Digital photogrammetry

Passive sensors, like digital cameras, deliver 2D image data, which can be afterwards transformed into 3D information. The photogrammetric method generally employs minimum of two images covering the same static scene or object acquired from different points of view. Similar to human vision - if the object can be seen in at least two images the different relative position of the object in the images allows a stereoscopic view and the derivation of 3D information of the scene seen in the overlapping area of the images. Using automatic location of common points in both images (also typically several thousand per second, depending on the PC speed) the digital photogrammetric system is also able to build up a digital model of the scene.

One of the most important parameters which influences the detail of the resulting 3D model is Ground Sample Distance (GSD). The GSD is the smallest element in the object space that can be distinguished by the camera sensor. The bigger the value of the GSD in an image, the lower the spatial resolution of the image/model and therefore less visible details. The GSD can be expressed as:

$$GSD = \frac{\text{Pixel size (on image sensor)}}{\text{Focal length}} \text{Distance object to camera}$$

The equation clarifies that the GSD depends on camera parameters as well as on the distance between the object and the camera.

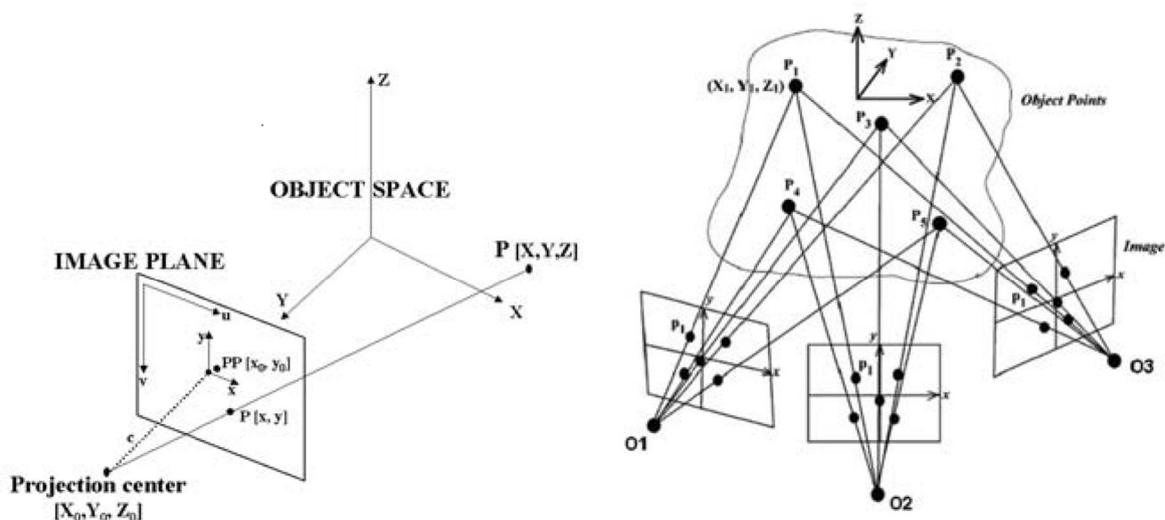


Fig. 5: The collinearity principle established between the camera projection centre, a point in the image and the corresponding point in the object space (left). The multi-image concept, where the 3D object can be reconstructed using multiple collinearity rays (Remondino; Campana, 2014)

The main advantage of the photogrammetry stays in the fact that the images contain all the information required for 3D reconstruction of the scene as well as the photo-realistic documentation. An important point is also the equipment cost - cameras are generally cheap and easily portable.

More details about photogrammetric principles, techniques and application can be found in *Luhman et al. (2011)*, *Remondino; Campana (2014)*.

2.2.1 Image sensors

Images can be acquired using terrestrial, aerial or satellite sensors according to the application and desired scale (level of detail). For the building documentation purposes the terrestrial sensors are useful. In some cases, sensors held by UAV (Unmanned Aerial Vehicle) are convenient. Terrestrial cameras are available in many different types and formats: single CCD/CMOS sensor, frame, linear, multiple heads, SLR-type, industrial, consumer, high-speed, panoramic head, etc. Non-professional terrestrial cameras have at least 10-15 Megapixels for a very low cost, while high-end digital cameras feature even more than 40 Megapixels sensors. The camera choice depends on individual and project

needs. In some cases even low cost ordinary terrestrial camera can be sufficient for 3D purposes. Various camera types' output differences are shown in a case study (chapter 6).

2.2.2 Unmanned Aerial Vehicles

Images can be taken just from hand, from tripod or using UAV (Unmanned Aerial Vehicle). The third option can be very useful, especially when documenting tall buildings and roofs, where the use of UAV can be the only possibility of photogrammetric documentation except the use of a crane.

Unmanned Aerial Vehicle (UAV) is defined as a generic aircraft design to operate with no human pilot on board, which can be remotely piloted, fully autonomous or combinations thereof. UAS refers to the Unmanned Aerial System, which comprehends the whole system composed by the aerial vehicle/platform, held sensors and the Ground Control Station (GCS). Except UAV, there are other terms which are commonly used – Drone, RPAS (Remotely Piloted Aircraft System), (ICAO, 2015; Remondino; Campana, 2014).

There are two main types of UAV construction – fixed wing and rotary. Unlike the fixed wing models, the rotary systems (e.g. multi-copters) are able to fly in every direction, horizontally and vertically, as well as hover in a fixed position. This makes them the perfect instrument for detailed inspection work or surveying hard-to-reach areas including building documentation.

UAV's have currently different safety levels according to their dimension, weight and on board technology. For this reason, the rules applicable to each UAV could not be the same for all the platforms and categories. In the EU, the current regulatory system for drones is based on the fragmented rules. Many EU member states have already regulated or are planning to regulate some aspects of civil drones with an operating mass of 150 kg or less. However, the extent, content and detail level of national regulations differ conditions for mutual recognition of operational authorisations, between the EU member states have not been reached. (*Civil drones in the European Union*, 2015 - [http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/571305/EPRS_BRI\(2015\)571305_EN.pdf](http://www.europarl.europa.eu/RegData/etudes/BRIE/2015/571305/EPRS_BRI(2015)571305_EN.pdf)).



Fig. 6: UAV - rotary (left) and fixed wing (right) system

2.2.3 From images to point clouds

The entire photogrammetric workflow is used to derive metric and accurate 3D information of the scene from a set of images. The procedure consists of a camera calibration, an image orientation and



a point cloud generation, which can be followed by 3D measurements, structuring and modelling, texture mapping and visualization. Compared to the active range sensors workflow, the main difference stays in the 3D point cloud derivation. Unlike photogrammetry range sensors (e.g. laser scanners) deliver directly the 3D data (*Remondino; Campana, 2014*).

A camera calibration and an image orientation are procedures of fundamental importance for extracting accurate 3D geometric information from images. The camera calibration procedure determines the interior parameters (camera focal length, image principal point, lens distortion) while the exterior parameters (positions and angular orientations associated with an images) are determined within the image orientation procedure. These two procedures can be done separately or fused using the same set of images and procedure.

To provide the transformation between images and object space frame the additional measurements are needed to add the scale, position and orientation of the model in the required coordinate system. The transformation is usually ensured by using some Ground Control Points (GCP), whose coordinates are known in image as well as in object frame. Another way is to leave the model in a free-network mode and to retrieve the correct scale using known distance on the object. The position of GCP can be surveyed by GNSS receiver or total station and distance measurement can be performed using electronic distance meter or a tapeline.

Once the camera parameters are known the dense cloud can be derived automatically using image matching techniques.

Software solutions that offer entire photogrammetric workflow one can mention Photomodeler Scanner or Agisoft Photoscan.

3 POINT CLOUD PROCESSING

Point cloud, hereinbefore described, is a set of points in a three-dimensional coordinate system and represents the external surface of an object. Point cloud itself has a great predictive value and can carry highly detailed spatial information about surveyed object. This unorganized structure is not very suitable for further analysis since spatial inquiries have high computational demands in this framework. For designing and further work a model composed of simple structures is needed. These models are called “polygonal” or “prismatic” models and one has to take into account their high generalization level (the level of detail can decrease rapidly).

Model (polygonal or prismatic) creation can be performed by a geomatics specialist in software determined for point cloud processing (e.g. Leica Cyclon, Bentley Pointools, etc.). Particular agreement between the ordering party and the contractor has to be made in order to maintain desired level of detail.

When dealing with BIM there is one more option - the point cloud can be directly loaded into BIM software. In AutoDesk – Revit software the majority of basic point cloud data formats can be inserted right in the import menu. A 3D model in the desired format can then be created straightforwardly using BIM software instruments. This step solves the data transfer problem and level of detail can be



chosen directly according to the BIM designer's needs. If the project is realized in different countries and the survey is done by various companies, this seems like a fine solution.

4 GEOMATICS INTEGRATION

4.1 Specification of object documentation

When using advanced geomatics for the object documentation, the contract owner needs to specify his demands clearly. This information is crucial for the supplier as, without these definitions, a misunderstanding can occur. Requirements depend on the building type, its location, and lead to cost and time optimization.

Basic information for surveyor:

- Object specifications
 - Demanded documentation level – interior (hall, corridors, apartments, basement, attics), exterior (facade, roof), surroundings (trees, pathways, neighbourhood buildings, etc. - e.g. for crane accessibility)
 - Building size (width, length, height - e.g. building height can limit using of terrestrial photogrammetry)
 - Object address – for travel expenses
- Demanded level of detail – resolution and model generalization (size of the smallest detail that should be visible in the 3D model – e.g. window ledges and frames)
- Model accuracy – Final model should be delivered with accuracy assessment (Photogrammetry and laser scanning methods provide models with less than centimetre accuracy)
- Coordinate system - Global or local (e.g. for easy implementation into BIM)
- Demanded outputs – point cloud, polygonal or prismatic model, data formats

Within the MORE-CONNECT project, a façade documentation is the most common.

4.2 Integration into project phases

Geomatics can be useful in all project phases – from basic project data acquisition to final building handover to the ordering party, see Tab. 1. Used methods can be very precise and thus provide valuable information for the building renovation procedure.

MORE-CONNECT partners are especially interested in geomatics implementation into the first phase. 3D data mining will be a part of the project case study, see *chapter 6*.



Project phase	Activity	Method
Before realization	design fundamentals acquisition	Laser scanning/Photogrammetry
During realization	elements emplacement	Total station survey
After realization	quality assessment	Laser scanning/Photogrammetry

Tab.1: Geomatics integration into various project phases

Description of ideal project workflow:

1. Consultation with the ordering party – requirement setup
2. Terrain reconnaissance
3. Method and equipment selection
4. In-situ measurements – preparation, actual survey, additional survey (e.g. tape measurements)
5. Data transfer (from used device into desired software)
6. Software works – image orientation, point cloud generation (in case of photogrammetry), point cloud adjustment, modelling (if required)
7. Accuracy verification
8. Outcome submission to the ordering party

4.3 Technique selection

Method	Photogrammetry	Laser Scanning
Equipment	reflex camera from 2,000eur	laser scanner from 40,000eur
Site limitations	textured object and fine illumination (daylight) needed	problems with extremely wet and mirror surfaces
Time costs	faster acquisition, slower point cloud production process	slower acquisition, faster point cloud production
Common characteristics	<ul style="list-style-type: none"> • Non-selective, non-contact methods, point cloud creation • Data processing more time consuming than data acquisition • Specialized software needed (from 10,000EUR each) 	



Tab.2: General comparison of photogrammetry and laser scanning methods

Recent testing of the photogrammetric and the laser scanning methods shows that these methods are equal in many considerations (accuracy, time demands, demanded outputs) and can be applied for a building documentation. Advantages and disadvantages are summarized in Tab. 2. Tab. 3 shows data acquisition and processing workflow. Tab. 4 provides information and recommendations about method selection, but one must take into account the uniqueness of each project - its requirements and specifications. Both methods have been applied and tested on the project case study in the Czech Republic in order to determine advantages and disadvantages of each of them. Detailed comparison can be found in chapter 6.

Method	Photogrammetry	Laser Scanning
Data acquisition	Image acquisition, additional measurement for scaling or georeferencing (distance, GCPs)	Scanning on scan stations, optionally additional measurements
Data export	Image download	Export point clouds
Processing workflow for point cloud generation	<ul style="list-style-type: none"> • (Camera calibration) • Internal and external orientation, scaling/georeferencing • Point cloud generation 	<ul style="list-style-type: none"> • PC registration • PC orientation and georeferencing
Processing workflow	<ul style="list-style-type: none"> • Point cloud cleaning (deleting outliers, noise reduction...) • Point cloud export (*.asc, *.vtx, *.obj ...)/ • Meshing (creating polygonal model)/ • Modelling (creating prismatic model) • Model export (*.dxf, *.coe, ...)/ 	

Tab.3: General workflow for photogrammetric and laser scanning processing

Object of mapping	Technique
Building – interior	Laser scanning; Geodetic surveying – total station
Building – exterior –	<ul style="list-style-type: none"> • up to 4 floors – Laser



façade	scanning; terrestrial photogrammetry <ul style="list-style-type: none"> • over 4 floors – Laser scanning; photogrammetry using UAV/crane
Building – exterior – roof	photogrammetry using UAV/crane
Surroundings	Laser scanning; Geodetic surveying – total station
Additional measurements	Tape; Electronic distance meter, GNSS receiver, Geodetic surveying – total station

Tab.4: Technique selection

5 FINANCIAL COSTS

5.1 Subcontracting

When subcontracting a geomatic work the building and 3D model / point cloud specifications are crucial. For the quote request a set of parameters like the outcome type (point cloud, polygonal or prismatic model, data formats), scanning area (interior, exterior, surroundings), demanded level of detail, accuracy, object size and address, coordinate system and other are needed, more information can be found in chapter 4.1. These parameters have to be defined in cooperation with the BIM creator as well as the user.

The cost of this work varies distinctively along European countries. *Tab. 5* shows costs based on market research (up to five companies in each country of interest have been contacted) of the geomatics work for a three floor residential house (size 44m x 13m x 15m) in seven European countries. It is a case study building for the Czech Republic. The desired outcome is a point cloud method that has not been specified. A 100km travel expenses are included.

Country	Point cloud generation cost range in EUR (Excluding VAT)	Comment
The Czech Republic	800 – 1300	
Denmark	1500 - 2500	For an engineering surface creation add (2500 –



		3500EUR)
Estonia	800 - 1100	
Latvia	1000 - 2600	Full 3D model of façade LS 5800 – 6700, FTGM 5300 - 6500
The Netherlands	1000 - 4500	For engineering surface add (1500 -2500 EUR)
Portugal	1500 - 2500	
Switzerland	2500 - 3500	For creating a full 3D model (indoor and outdoor) 11000 - 16500

Tab. 5: Approximate cost of geomatics work - previously defined building

Authors would like to mention that not all companies providing point cloud creation have their web sites in English. It is assumed that mentioned costs are only of an informative character and they vary within a country (from company to company). For cost determination a quote for specific object of interest needs to be requested.

5.2 In house

Other option prior to subcontracting geomatics surveys is to create a geomatics department in the company. This step needs high-quality preparations together with precise financial calculations. Laser scanning equipment as well as the processing software can be very expensive. A medium range laser scanner suitable for building documentation can cost 50.000€ in average and one must also take into account costs of processing software (from 10.000€), powerful hardware (PC) and last but not least salary of a geomatics specialist. These professionals usually gain their knowledge at university and their precise work can be a big financial issue. When using photogrammetry, costs can be significantly reduced. A quality reflex camera suitable for photogrammetric purposes costs from 2.000€ upwards. Data processing costs (software, hardware, labor) are a bit higher when compared to laser scanning since point cloud generation is more time-consuming and specialized photogrammetric software is needed in addition to point cloud processing software. For documentation of roofs and higher areas of tall buildings RPAS employment is essential in order to gain high quality data. Professional rotary based RPAS units price starts at 10.000€ and rises depending on a manufacturer, type of camera included, battery type, etc. The final company decision for a geomatics department creation should be based on the number of contracts demanding 3D data survey.



5.3 Comparison

Final decision how to deal with geomatics work stays always on the company management. Both solutions have their advantages and disadvantages and they have to be taken into consideration. When creating a geomatics department, the number, size and regularity of contracts are crucial. Geomatics specialists are always available, but the question is if they would have enough work all the time. Different projects have different demands and the department has to be prepared for dealing with various methods (photogrammetry and laser scanning). Equipment for both methods can become very expensive and specialist's salary as well. When using a RPAS device for commercial use in diverse countries local policies are unequal and must be adhered. As an example a pilot licence can be non-transferable and does not need to be valid at different location than the country of purchase. In case of working in sundry countries travel expenses can significantly increase supposed expenses and thus subcontracting can be advantageous.

6 CASE STUDY

A previously defined building type has been chosen for the case study. It is an edifice that has been suggested by the Czech project partner. This selection has been made in order to provide easy accessibility. East façade has been documented by photogrammetric and laser scanning methods. Procedure of data acquisition, data processing and outcome comparison is explained hereinafter.

A personal computer (PC) with following setup has been used for calculations:

- Processor: Intel® Core™ i7-3770 CPU @ 3,40GHz
- RAM 16GB
- 64bit system Windows 7 Enterprise

6.1 Building identification

Residential House "dvouletka" type in Kladno. The city of Kladno is located northwest of Prague, the capital of the Czech Republic. Distance from the capital city center is approximately 30km.

6.1.1 Present state

The building has simple, rectangular floor plan. It has three floors with similarly designed flats. The house has a hip roof with a number of chimneys.

6.1.2 Typical problems

Old-fashioned appearance, devastated common areas, unsatisfied overall energy performance, insufficient ventilation, mould growth in the basement floor, water-proofing failures, ruptures in plaster, badly insulating original wooden windows with loose closing mechanism, condensation and mould growth in the flats with replaced wooden windows for the new "euro" standards. Failures and water leakage in the area of chimney-roof run through.

6.1.3 Appearance

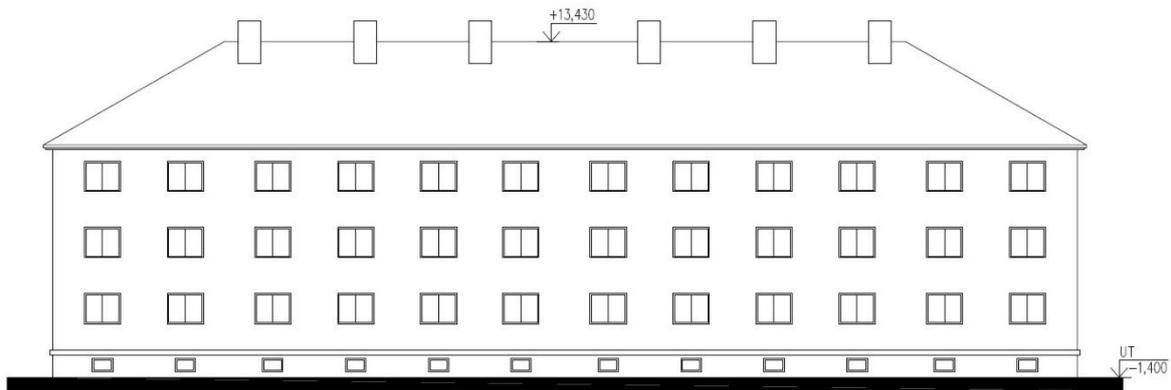


Fig. 7: East view

6.2 Laser scanning

6.2.1 Survey

The data has been acquired by a phase shift laser scanner Surphaser 25HSX. Scanner parameters are shown in *Tab. 6*.

Parameter	Value
Distance to object	12-13m
Number of scan stations	4
Scanning resolution	5mm at 10m distance
Scanning time	2h

Tab. 6: Surphaser 25HSX scanning parameters



Fig. 8: Surphaser 25HSX

6.2.2 Data Processing

Point clouds were exported into *.xyz data format and processed using Geomagic Studio software. The point clouds were cleaned manually. Next step was a manual registration – approximate transformation of point clouds into one common coordinate system using manually selected identical points. This was followed by a global registration – automatic precise transformation applying ICP (iterative closest point) algorithm. After joining point clouds into one, the resulting point cloud was oriented – the documented façade follow the main axis of the local coordinate system.

6.2.3 Results

The resulting point cloud has over 6.1 million points and the distance among the points on the surface (GSD – ground sample distance) does not exceed 1.5 cm. The expected GSD according scanner settings was 6mm. The difference between expected and achieved GSD can be caused by lower surface reflectance since not all reflected arrays returned to the scanner. Higher point density (lower GSD) can be achieved by using higher scanning resolution or by lowering the distance between the scanner and the object. However it is recommended to keep the object – scanner distance not shorter than half of the building height. It is because the closer the scanner to the object, the lower the incidence angle at higher parts of the building. That leads to an accuracy decrease and also to a GSD increase in higher building sections.

A side measure has been used for model accuracy verification. The variance between length measured in-situ by tape and length derived from the created model did not exceed 6mm.

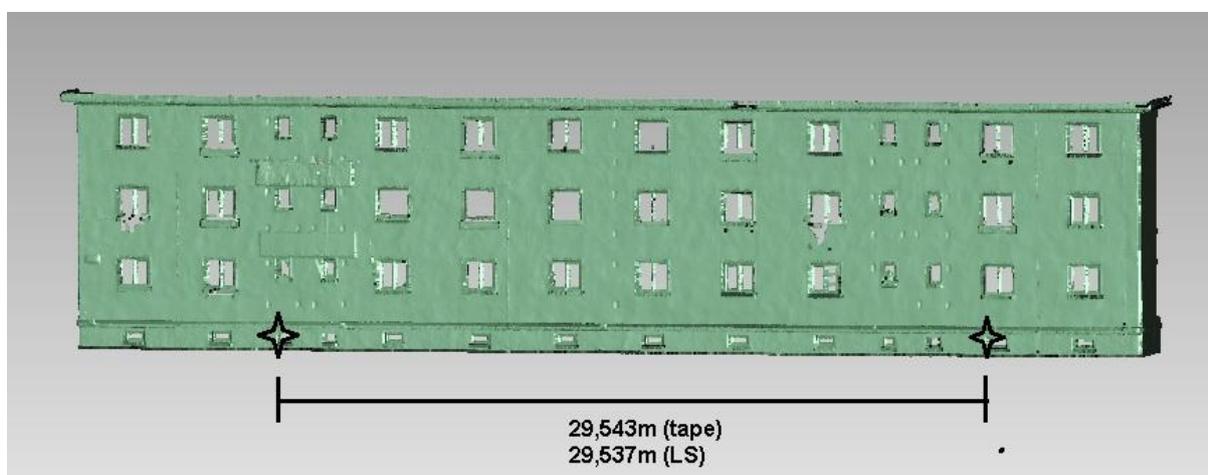


Fig. 9: Side measure

6.3 Photogrammetry

6.3.1 Survey

In the photogrammetric part of the project four cameras were tested: two reflex cameras – Pentax 645D and Cannon EOS 450D, one low-cost compact camera – Sony CyberShot DSC-HX50 and camera build-in iPhone 5s. The range selection of camera was tested to show the potential of various camera types.

The main parameter which can determine the level of detail in generated model is the GSD (Ground Sample Distance, see *chapter 2.2*). An aim of the testing was to set the same GSD for all cameras. Due to this assumption and different cameras parameters the scanning distance had to vary from 15 to 40m, see *Tab. 7*. Given the situation on site this was not possible, the distance has been set to 12m and imaging has been performed by various camera types (see *Fig. 10*). Facing the camera differences (focal length and sensor type in particular) images cover various object areas. That led to a different number of images needed to cover the entire object, see *Tab. 8*.

Image acquisition took from 10 to 20 min dependent on the camera used.



Fig. 10: Tested cameras: a) Pentax 645D; b) Canon EOS 450D; c) Sony CyberShot DSC-HX50; d) iPhone 5s

Camera	Pentax 645D	Canon EOS 450D	Sony CyberShot DSC-HX50	iPhone s5
Distance to object for GSD=2mm	18m	15m	42m	40m
Element size	0.0060mm	0.0052mm	0.0017mm	0.0015mm
Focal length	55mm	40mm	35mm	30mm
GSD for dist.=12m	1.3mm	1.6mm	0.6mm	0.6mm
Image size - MB	18	5	4	2

Tab. 7: Camera parameters

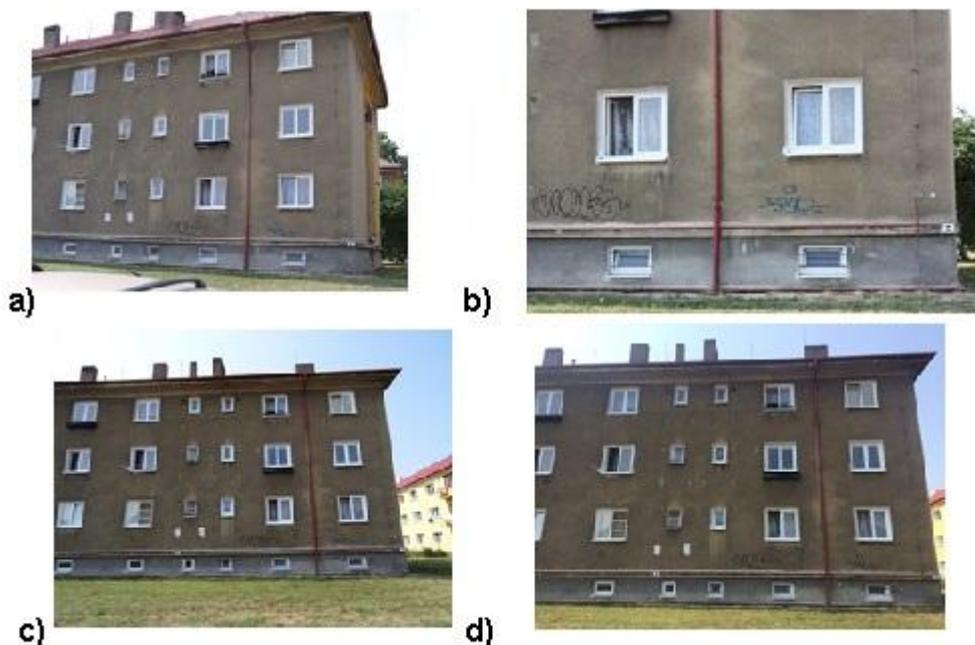


Fig. 11: Image from camera: a) Pentax 645D; b) Canon EOS 450D; c) Sony CyberShot; d) iPhone 5s

Camera	Pentax 645D	Canon EOS 450D	Sony CyberShot DSC-HX50	iPhone s5
Image size - MB	17	3,5	4	2
Number of processed images	56	83	34	32
Number of points (in millions)	43.0	24.9	4.3	4.5
GSD for dist.=12m	1.3mm	1.6mm	0.6mm	0.6mm
Average distance between nearest points in point cloud	0.2-0.5cm	0.2-0.5cm	1.0-1.5cm	1.0-1.5cm

Tab.8: Image processing – parameters

6.3.2 Data Processing

Imaging data processing has been conducted using Agisoft Photoscan software according basic workflow. After image import an image alignment has been performed. It is the automatic identification of connecting tie points followed by calculation of interior and exterior orientation parameters. Orientation and scale setting was ensured by using ground control points (GCP) – see *Fig. 12*. The GCP coordinates have been gained by reading the model derived from laser scanning and use of similar coordinate system for an outcome has been ensured. This principle of method comparison has been recently performed by *Bayram et al. (2015)*. After image orientation a point cloud has been generated and exported into *.txt format. Following workflow has been similar to laser scanning data and has been accomplished by Geomagic Studio software.

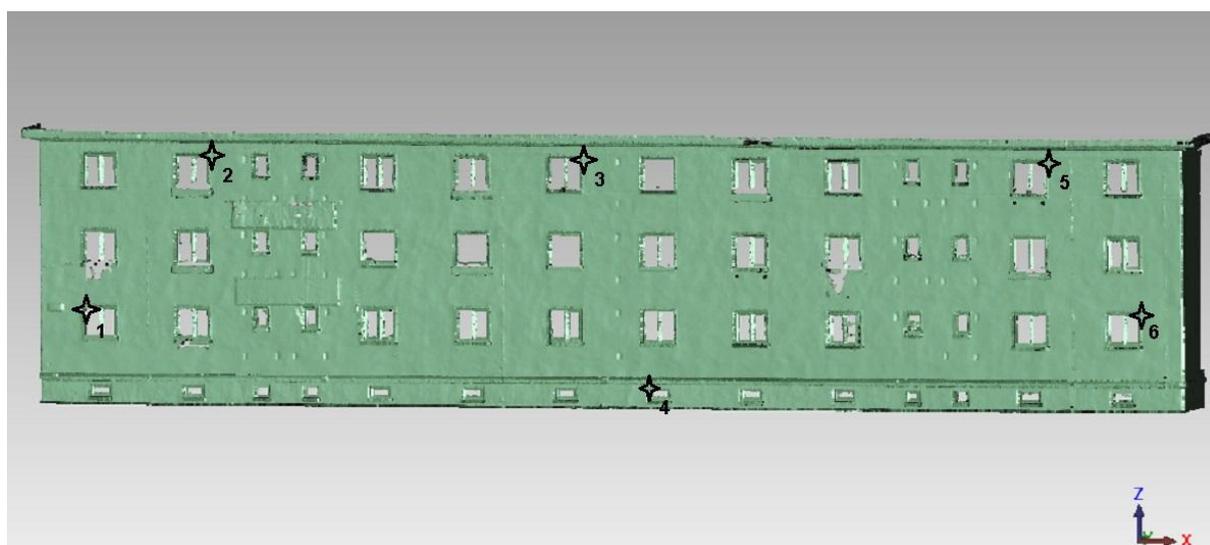


Fig. 12 Position of GCP

6.3.3 Results

Several parameters vary according to the camera type. It is the number of images required for computations (32-83), the processing time (from 1.5 hour for iPhone to approximately 20 hours for Pentax) and the density of final point cloud. Processing time differs according to the image size and number. Density of the final point cloud is mainly based on camera quality and especially on the camera sensor size. The larger the sensor the larger the elements that correspond to the pixel size. The larger the sensor the more light is coming towards it resulting to an image of higher quality (higher signal to noise ratio). The amount of noise in the derived point cloud shows the image quality – the less noise the higher quality image (*Fig. 13*).

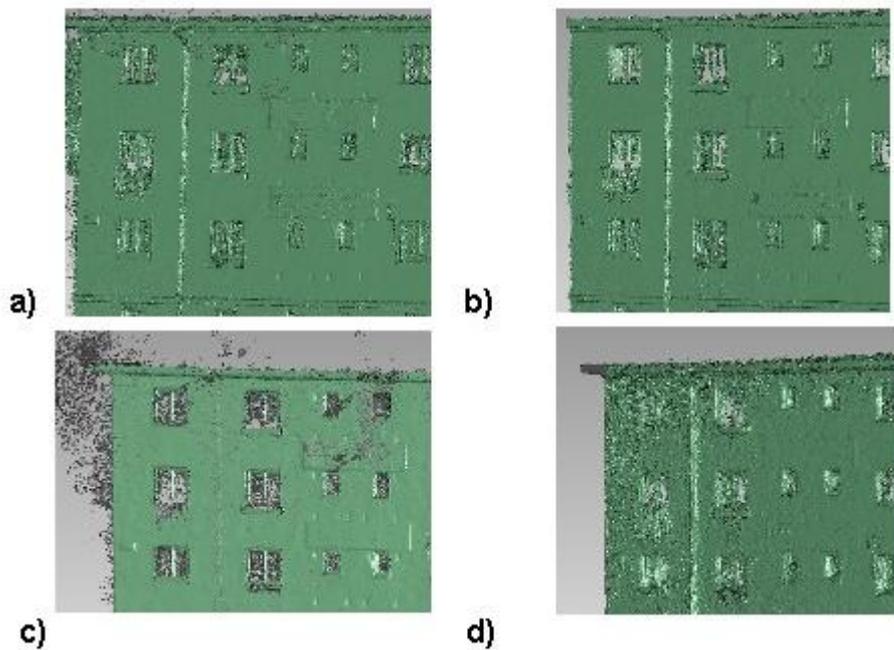


Fig. 13: Point Cloud from: a) Pentax 645D; b) Canon EOS 450D; c) Sony CyberShot; d) iPhone 5s

6.4 Comparison

The resulting point clouds derived from various camera types have been compared with polygon model created from laser scanning data using Geomagic Studio software. For this comparison the laser scanning method has been used as a reference. Figures 14 to 17 demonstrate distances between points acquired from photogrammetric and laser scanning point clouds. Mentioned values are given in meters.

Comparison indicates that the largest variances between the laser scanning and the photogrammetric outcomes can be seen in a case of a low-cost Sony and for iPhone camera. Both cameras show significant noise level in the data – noise level reaches values as high as several centimetres. A part of this noise level can be eliminated using software tools, but generally these data cannot be used for the MORE-CONNECT project purposes.

Variations between laser scanning and photogrammetry outcomes when using reflex cameras are distinctly lower (see Fig. 14 and 15). These differences are lower than 5mm on the majority of the model. Noise level has been considerably reduced when compared to non-reflex cameras mentioned earlier. A systematic error has probably occurred in the Cannon camera output – building margins have negative difference values whereas in the centre of the edifice positive difference values can be found. A deformation has arrived in the model creation. This model has been made using the highest number of images (83). When a larger number of images is employed, the risk of the model deformation rises. This risk can be reduced by using larger number of GCP

It has been found that the point cloud derived from the Pentax camera provides the best results. These data carry accuracy comparable to the laser scanning point cloud and have higher density.

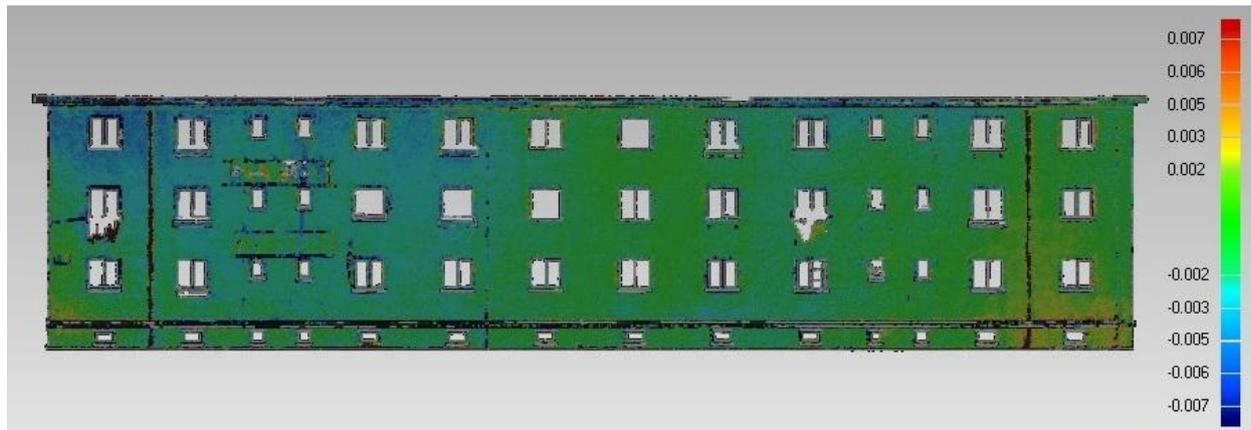


Fig. 14: Pentax 645D (values in meters)



Fig. 15: Canon EOS 450D

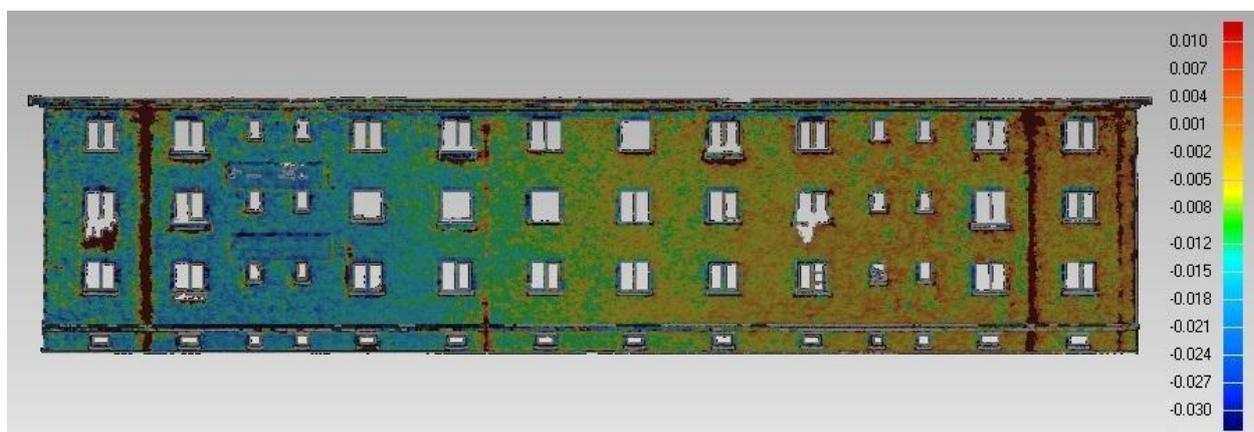


Fig. 16: Sony CyberShot

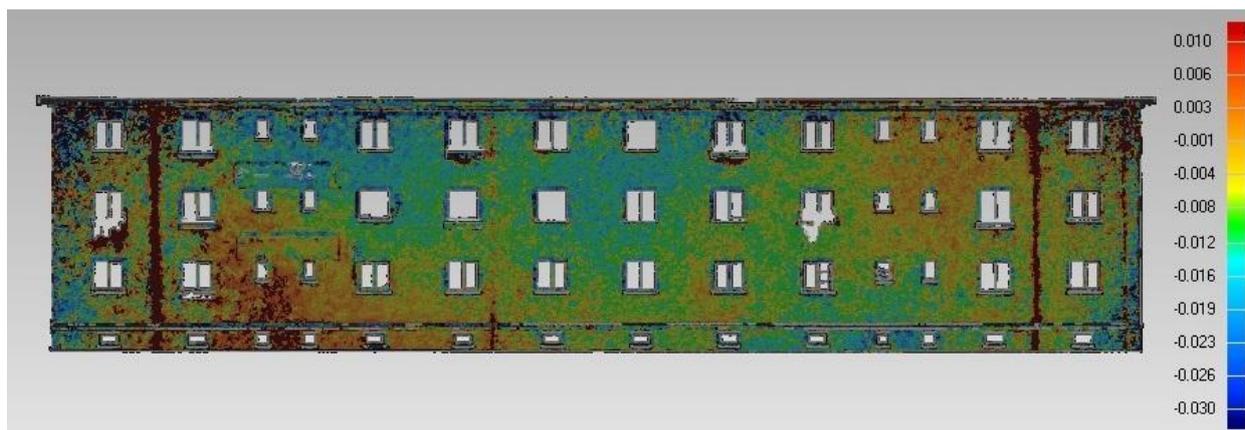


Fig. 17: iPhone 5s

7 DISCUSSION

Photogrammetric and laser scanning methods have been used and tested for the building documentation in the MORE-CONNECT project. Testing shows that both methods are convenient. Use of a particular method is based on project specifications and requirements as well as on ordering party preferences. Use of Ground control points (GCP) is recommended for higher accuracy demands (<5mm) and when larger objects (residential houses) are of interest. Geodetic total station provides fine and quick GCP measurements.

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