Techniques, protocols, application 3D scanning/ geomatics

Deliverable Report D1.5

Deliverable D1.5, issue date on 31.08.2017

P2ENDURE

Plug-and-Play product and process innovation for Energy-efficient building deep renovation

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

Techniques, protocols, application 3D scanning/ geomatics

Deliverable Report D1.5

Issue Date	31 August 2017
Produced by	Invela
Main authors	Furqan Rathore (INV), Finn Christensen (INV).
Co-authors	Anders Martiny (INV), Piotr Dymarski (MOW), Anna Gralka (DMO), Emanuele Piaia (SGR), Agnieszka
Version:	Final
Reviewed by	P2ENDURE Steering Committee
Approved by	Rizal Sebastian (Project Coordinator)
Dissemination	Public

Colophon

This research project has received funding from the European Union's Programme H2020-EE-2016-PPP under Grant Agreement no 7723391.

P2ENDURE
PLUG & PLAY BUILDING RENOVATION

Publishable executive summary

This report gives an overview of the pilot activities of the demonstration tools to be used within P2ENDURE. The main focus is on the part of 3D building scanning technology, describing: the 3D scanning procedure, the types of 3D laser scanning in the building industry, and the scanning process in relation to its connection with Building Information Modelling (BIM). In this context, a short brief of the BIM is given, next to the application descriptions of 3D laser scanning and its overall benefits portrait.

Three real demo cases on 3D laser scanning are being performed by P2ENDURE partners in Warsaw (Poland), Gdynia (Poland), and Palmanova (Italy). Focus3D FARO 3D laser scanner is the main scanning technology used within these activities, while its general characteristics and set-up requirements are presented in this report. Next to the 3D laser scanning method, the description of the Photogrammetry method is included in this report. A case study was carried out through a synergy with H2020 project MORE-CONNECT; this presents a comparison between Photogrammetry method and 3D laser scanning method.

Finally, a brief on-site demo case study of Robot-At-Work is documented. The case study is about 3D printing and wall rendering in the building industry, performed by the robot on-site. Robot-At-Work is a company that provides on-site robotic solutions for the construction industry. The company is one of the P2ENDURE stakeholders.

List of acronyms and abbreviations

BIM: Building Information Model

EeB: Energy-efficient Building

EPBD: Energy Performance Buildings Directive

GIS: Geospatial Information System

R&D: Research and Development

VR/AR: Virtual / Augmented Reality

RAW: Robot At Work

INV: Invela

CAD: Computer Aided Design

LiDAR: Light Detection and ranging

Contents

1. Introduction

The P2ENDURE project promotes evidence based innovative solutions for deep renovation, based on prefabricated Plug-and-Play systems in combination with on-site robots, 3D printing, and BIM. Invela, a partner in P2ENDURE, is a company that provides building renovation solutions and is the lead author of this report. The main aim of this report is to provide an overview of the State-of-the-Art 3D building scanning procedure in relation to Building Information Model (BIM), as an overall introduction to the technology within P2ENDURE project and the context of real pilot cases. In addition, some of the future foreseen developments of 3D scanning and 3D printing technology are addressed in this report. . An insight of Robot-At-Work´s (RAW) innovative project regarding 3D design on facade and wall rendering (on-site 3D printing) is given.

The report gives an overview of technical developments in the construction industry, mainly focusing on geomatics techniques that can be used for building reconstructing, and showing the advantages of their integration with laser scanning of buildings. This report can be used as a reference, summarizing current and innovative on-site application techniques with regards to geomatics, for P2ENDURE partners and civil engineering companies that work within this field.

Paradigm

A constructive, empirical approach was followed to prepare this report. The data is collected through primary and secondary sources, using qualitative and quantitative methods. The author gathered the required information by performing a literature review and compiling interviews surveys material. In addition, reflections from real on-site demonstration activities demands with respect to the 3D facade pilot project innovative approach implementation, tailored to the needs of each use case, allowed realistic conclusions for this review.

2. State-of-the-art review of 3D scanning / geomatics

2.1 General context

Relating to the P2ENDURE pilot case projects, 3D scanning is the most advanced form of measurement of spatial objects with large dimensions and surfaces. There are mainly two types of scanning, site scanning and building scanning. In the P2ENDURE pilot case a building scanning model is described in detail. Description of laser equipment, which is used for building scanning, requirement and constraints of the 3D scanning process, description of the scanner devices, and practical application of 3D scanning. The 3D scanning process is described in an understandable language, for a user who does not have a technical background. This part of the report is intended to provide other non-technical partners in P2ENDURE with a better understanding of what a 3D scanning on-site looks like and why it is needed.

- The 3D scanning is the most advanced form of measurement of spatial objects, with large dimensions and surfaces reflecting details. The 3D scanning technology is used in many fields like digital mapping of 3D models and development of technical documentation and designs for a building. This method is very efficient and timesaving in comparison with traditional on-site surveying.
- Laser scanning is an innovative measurement method, which uses laser light to obtain a geometric 3D model of the scanned object. The effect of laser scanning is a point cloud. The most common types of 3D laser scanners are:
  - Pulse – laser scanners, which are based on the method of measuring average accuracy, with extended time scan, giving the distance measuring capabilities (up to approx. 1800 m).
  - Phase – laser scanners with very high precision at high speed (up to 1 million points/s), with a maximum range of up to 180 m.
  - Triangulation, which are close-range laser scanners from a few centimetres to several meters.

The basic work principle of the laser scanner is based on the deviation of the laser beam, which is the scanning mechanism with an integrated measuring system. It is a system of rotating mirrors, where the result of the scan is a point cloud.

2.2 Description of 3D laser scanning in building construction

3D scanning is used in many fields, such as digital mapping of 3D models. The laser scanning process is fast, accurate and useful. The technology is not necessarily a new technology, but recently has become a practical economic choice. The technology which is used for on-site scanning and building scanning is called (LiDAR) Light Detection and Ranging. This refers to a technique of shooting a laser over a surface area and record the depth of the surface in the computer server. [i]

The traditional Manuel surveying method is replaced by the laser scanning. The traditional recording method based on hand recoding, taking measurement using tape is time consuming and applicable only to small area. [ii]

3D laser scanner types

There are 2 types of scanners **short range 3D scanners** and **laser based 3D scanners**. The short-Range 3D scanners mostly utilize a laser triangulation or structured light technology. The other laser based 3D scanners use trigonometric triangulation process to accurately capture a 3D shape as millions of points. The way it works is that the laser scanner projects a laser line or multiple lines onto an object and then captures the reflection with a single sensor or multiple sensors. The sensors are located at a known distance from the laser's source. By calculating the reflection angle of the laser light, accurate point measurements can be made. [iii]

Benefits of 3D laser scanners:

- Easier/ faster to use and therefore low cost, more simple design
- Less sensitive to changing light conditions and ambient light
- Portable and easy to carry
- It can scan surfaces such as shiny or dark finishes.

Projected or structure light 3D scanners

3D scanners known as "White light" 3D, in comparison to other structured light 3D scanners, use mostly a blue or white LED projected light. These 3D scanners project a light pattern consisting of bars, blocks and other shapes onto an object.[iv] The structured light scanners can be mounted on tripod or hand held. The structured light 3D scanner has one or more sensors that look at the edge of those patterns or structure shapes to determine the objects 3D shape.

Benefits of structured light 3D scanners:

- Safe for the eyes while 3D scanning of humans and animals
- Very fast scanning time (2 seconds per scan)
- Easy to carry and move,
- Enabling very high accuracy: 10 microns (.00039")
- Large scanning area: up to 48 inches in a single scan
- Available in various prices, from low cost to expensive depending on the resolution accuracy. The resolution is as high as 16 million points per scan and 16 microns. [v]

Medium and long-range 3D Scanners

Pulse based and **phase shift** are two major formats in long range 3D scanners. Both are well suited for large objects such as building, structures, aircraft, and military vehicles. For medium range scan needs such as automobiles, large pumps and industrial equipment Phase shift 3D works well.

Laser Pulse- based 3D scanners

This scanner is based on a very simple concept, also known as time-of- flight scanners. The speed of light is known very precisely. The way it works is that it calculates the length of time a laser takes to reach an object and reflect to the sensor. The millions of pulses are projected by the laser to the object. The pulses of the laser then return data to the sensor and it calculates a distance. The scanner has capacity to scan up to a full 360 degrees around itself by rotating the laser and sensor (usually via a mirror).

Laser phase-shift 3D scanners

Conceptually it works similarly to pulse-based systems, but it is another type of time of flight 3D scanner technology. The phase shift measurement is typically more accurate and quite comparable to Pulse scanner. The disadvantage is that it is not flexible for long range scanning as the pulse based 3D scanners are. The advantage of phase 3D scanner systems is that it also modulates the power of the laser beam, and the scanner compares the phase of the laser sent out and returned to the sensor. “Laser pulse based 3D scanner can scan objects up to 1000 m away while phase shift scanners are better suited for scanning objects up to 300 m or less”. [vi]

Benefits of long range 3D scanners:

- Portable
- Safe to scan all types of objects
- Ability to scan large scanning area up to 1000 meters
- Good accuracy and resolution based on object size
- 3D scan millions of points in a single scan – up to 1 million points per scan

2.3 Available laser scanner on the Market

The laser scanning can be done today with known laser equipment. A device which looks like a digital camera comes in different models and shapes. There are mainly two devices used for two different purposes. Some examples are shown below:

One device mounted on the tripod **Faro focus 3D x130** is used for building laser scanning and the **3D scanner surphaser 100 HSK** is used for surface scanning.

Figure 1: FARO Focus 3D X130

Figure 2: 3D Scanner surphaser 100HSX

The Faro Focus 3D X130 is an ultra-portable scanning device which captures fast, straightforward and accurate measurement of complex objects and buildings. The device has touch screen which shows images and provides user friendly experience. A build in 8 mega pixels, HDR camera provides real time image while scanning under extreme lighting conditions. This device has 4-5 hours battery runtime per charge. Different models of this device are built according to their scanning range. Examples are The Focus 350 model that offers extra range up to 350m, and the Focus 150 model this mid-range device scans up to 150m.

The way 3D scanner works is that it shoots a pulse of light with a laser to the surface of the object/building. The active sensor is placed on the object which is being scanned. The laser pulse hits the scanner and receives the reflection, which helps the laser beam to measure the distance from the sensor on the object. The scanner then creates a representational point from where the pulse hits the surface that is being scanned. All the points the scanner records in the computer are called a point cloud.

Figure 3: FARO Focus 3D X130

The new models of laser scanners capture the colour of the surface area and map that colour to the points. The detail levels of the resulting 3D models depend on the setting of the scan resolution and the distance to the object. In the building scanning **two methods** can be applied, **pulse system** and the **phase shift** system. Both methods are explained in the section above. The difference can be justified for their certain range to the envelope. The largest ranges more than 100 m is probed using the pulse round trip time measurement method to obtain centimetre accuracy.

Digital photogrammetry

Digital photogrammetry is a well-established technique for acquiring dense 3D geometric information for real objects from stereoscopic image.[vii] This application is widely used in different fields. A passive sensor, like digital cameras, project 2D image data, which is to be later transformed into 3D information. The method generally requires two images covering the same static scene or object acquired from different points of view. Using the automatic location of common points in both images (using computer) the digital photogrammetry system can build a digital model of the scene (see example below).

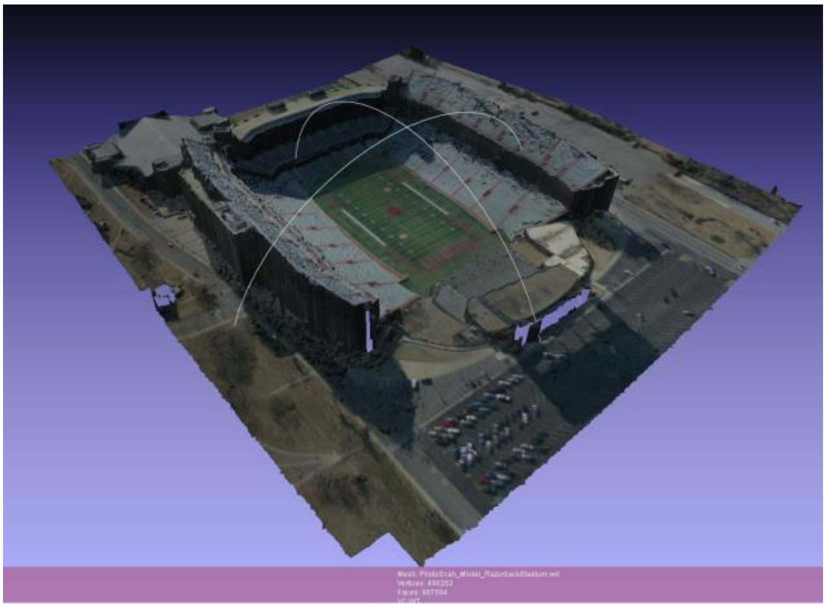

Figure 4: 3D model of Razorback stadium created from four digital aerial images using Photo Scan Pro

In 3D modelling, most important parameters which influence the detail of the result are the Ground Sample Distance (GSD). There is likely to be less visible details if the distance is larger between the camera/ scanner and object. The reason to use photogrammetry is that, image contains all information required for 3D reconstruction of the scene, as well as the photo-realistic documentation. It is also economic, cameras are cheap and portable.

Image Sensors

In building scanning the image can be obtained using, **Aerial laser scanning (ALS)** and **terrestrial laser scanning (TLS)**. One of the applications can be used according to desired information.

Aerial laser Scanning (ALS) is the most modern method used in building scanning. ALS system can acquire over 50 points per square meter and to register multiple echoes. Mostly used for reconstruction of the terrain.[viii] On the other hand ALS is less accurate in collecting data on ground level. It is often incomplete with no information especially around the face or structure which has been covered by other structure.

Terrestrial laser scanning (TLS) however provides higher accurate data. It is also capable of registering those elements which are incomplete or not visible using ALS methods, such as façades, complicated structures, and interiors. Therefore, to obtain a complete 3D model of a building in high level of details, combination of ALS and TLS data is essential.[ix]

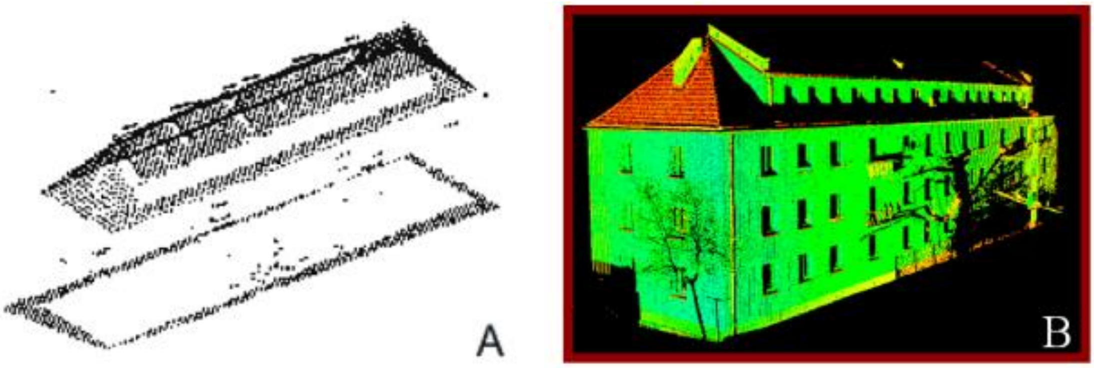

Figure 5: Block of flats, perspective view. (A) Aerial laser scanning data (B) Terrestrial laser scanning data (intensity colours).

The image A is completed though Aerial laser scanning, it is not rich in details. Image B is done using terrestrial laser scanning. It has better view presentation. One of the main applications of TLS/ ALS, which is sometimes also called LiDAR, is 3D city modelling.

2.4 BIM process and its relations to laser scanning

The common understanding of many people is that BIM as a specific model or software; on the contrary Building Information Modelling (BIM) is a process. BIM is "an improved planning, design, construction, operation and maintenance process using a standardized machine-readable information model for each facility, new or old which contains all appropriate parametric information created or gathered abut facility useable by a throughout its lifecycle". [x] There are different software's which can be used for BIM process, which can create confusion. Such as the Revit drawing tool is used to establish parametric model, or Navis work to conduct clash detection. See the illustration below from Autodesk.

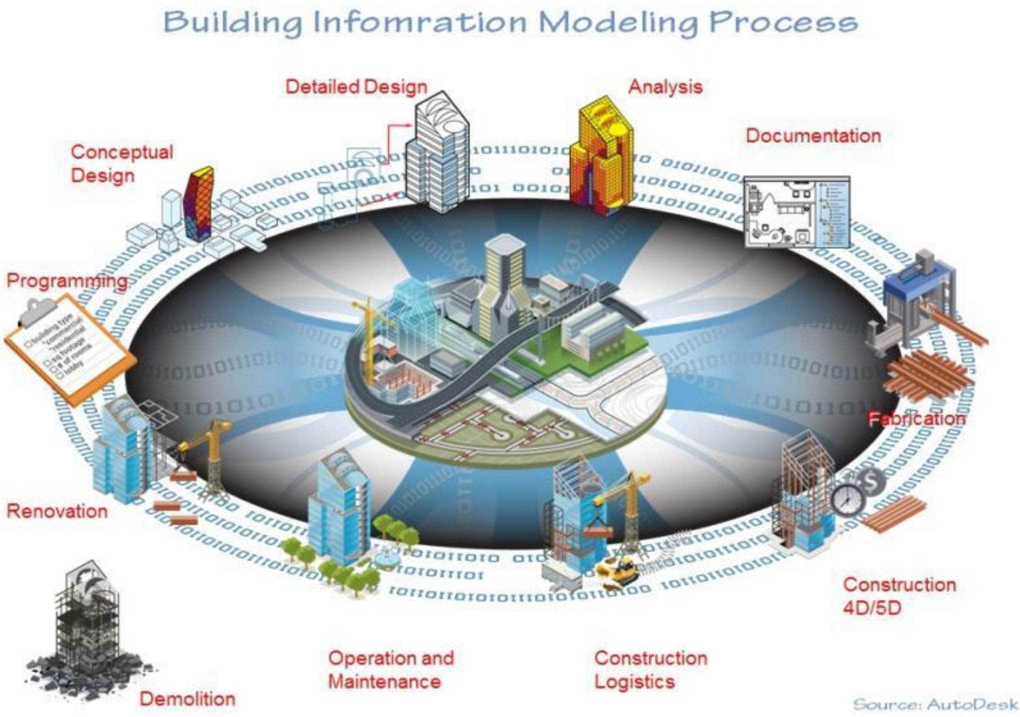

Figure 6: Illustration of Building Information Modeling (BIM) by Auto Desk

BIM process connection with Laser scanning

The laser scanning technology has become popular in survey industry in the recent years. The scanning for building construction was applied mostly in existing structures, but though its significant advantages; it is now also used in new construction work. The advances in hardware technology and BIM are helping the engineers on a new level of scanning utilization for the building construction industry.

This section of the report will help the reader to understanding how the scanning technology can be applied to BIM workflow in building construction. After reading this section reader will be able to see and understand the benefits of scanning technology and how it is used to optimize the building construction process. [xi]

To understand how the scanning technology is used in the integrated BIM workflow, it is important to understand what laser scanning is and how it works. This is further explained in chapter 3.

Converting scan data into BIM models is traditionally a three-step process:

- 1st. multiple scans are captured from different scanning stations ;
- 2nd. data from multiple scanning stations is stitched together in what is commonly known as the post processing or registration state;
- 3rd. CAD or Autodesk Revit is used to author object models while referencing the point cloud. [xii]

Point-cloud processing

The FARO Focus series is supported by many industry-standard laser scanner software packages. These packages provide extensive facilities for point-cloud processing, photo-realistic modelling, reverse engineering of CAD models and geometric calculations. 'SCENE 3D' laser scanner software is specifically designed to process 3D point clouds collected by FARO Focus laser scanners. SCENE processes and manages scanned data easily and efficiently by using automatic object recognition, as well as scan registration and positioning. SCENE can also generate high-quality colorized scans very quickly, while providing the tools for automated target less or target-based scan positioning. This registration software is extremely user-friendly, from simple measuring to 3D visualization to 3D meshing and exporting into various point cloud and CAD formats. Added verification steps now allow users to confirm if a scan registration result is contextually correct, adding an additional level of confidence to their data quality.

Figure 7: Point cloud generated from laser scanning in the pilot case of Gdynia

CAD - Computer Aided Design

CAD is a replacement of manual drafting with an automated process. CAD is a computer technology used for design documentation. This program helps architecture and structural engineers explore design ideas, visualize concepts through photorealistic renderings, and simulate how a design performs in real world.

2.5 General requirements and constrains with 3D scanning

The conditions needed for the proper execution of a scan are:

- No vibrations
- Not dusty environment
- No rainfall
- Temperature 0-40 ˚C
- No moving objects and a clean/ ordered scan area
- Free access to the scanned areas: no barrier guards, floor boards or scaffolding

See illustration below for some conditions that may have negative impact on the laser scanning process on-site.

Area glass

Area highly reflective

Area highly absorbing

Too much distance

Sharp edges

Sunlight

Lighting

Figure 8: Example of unfavourable conditions during laser scanning.

Materials reflection

Because the different materials have various reflection coefficients this aspect should be carefully analysed before the scanning process. Table below shows coefficients of reflection for the selected materials that have an impact during the laser scanning:

Material	Reflection coefficient [%]
• **White paper**	• 100
• **Wood, Wooden material**	• 94
• **Snow**	• 80-90
• **White stone**	• 85
• **Limestone, clay**	• >75
• **Printed newspaper**	• 69
• **Deciduous trees**	• 60
• **Conifer**	• 30

• **Flat beach shore**	• 50
• **Smooth concrete**	• 24
• **Asphalt with pebbles**	• 17
• **Lava**	• 8
• **lack tar**	• 5

Before and during the actual 3D laser scanning, following criteria and limitations should be assed:

- Detail, accuracy and density of spatial information
- Identification of the presence of narrow places and hard to reach areas
- Identification of possible limitations:
  - the size and height of the object
  - vegetation
  - the type and form of the output needed as a final product/ result
  - the experience and competence on behalf of the performing part of the scan

2.6 3D scanning process

The general guidelines for the positioning of the laser scanner and the location of the binding points are:

- Positioning the scanner needs to be deployed in a way to ensure the accuracy of scans
- Optimal number of binding points is between 5-6 and the minimum number is 3
- Placement of binding points at different levels on the cross
- It is recommended that the binding points are at a distance from the scanner between 1-30 m
- Maximum deviation of the laser beam is 45 °
- Most accurate angle of the laser beam to a point 90 °
- When raising the colours of objects, there is a need for providing the correct stable lighting
- Use of a sphere with a diameter of 145 mm-resolution scan 1/4 – for a distance from the scanner not more than 18 m
- Use Board A4-scan resolution 1/4- for the distance from the scanner not more than 15 m,
- Use of the sphere with a diameter of 200 mm scanning resolution 1/4- for the distance from the scanner not more than 45 m.

There are three main types of the binding points (Figure 9).

Figure 9: Types of binding points.

2.7 Description of the FARO Focus 3D scanner device

The FARO Focus^{3D} scanner was used for the 3D scanning process for Warsaw and Gdynia demo cases (in Poland). The weight of the scanner is around five kilograms; the Focus^{3D} laser scanner is suitable for mobile use on the building site (Figure 10). It scan/ records foundation, excavations, building shells and buildings in 3D – in a complete, fast and cost-efficient manner.

Figure 10: Scanner FARO Focus3D X130

Main characteristic features of the scanner (based on the Focus^{3D} FARO tool) are:

- Reach Focus 3D X130: 0,6 – 130m
- Measurement speed up to 976,000 points / sec
- A measuring error: ± 2 mm
- Built-in camera: up to 70 megapixels
- Laser class I
- Weight: 5,2 kg
- Multi-Sensor: GPS, compass, altimeter, biaxial compensator
- Dimensions: 240x200x100 mm
- Control by using the touch screen or WLAN

Measurement method of the scanner FARO Focus 3D are:

- Distance: Scanner uses a laser beam which is reflected to the scanner by an object/ surface. The distance is measured in millimetre accuracy by the phase shift between the sending and receiving beam.
- Vertical angle: Mirror deflects the laser beam in vertical direction onto the same object. The angle is encoded simultaneously with the distance measurement.
- Horizontal angle: Laser scanner revolves 360° horizontally. The horizontal angle is encoded simultaneously with the distance measurement.
- Computation of the 3D coordinates: Distance, vertical angle and horizontal angle make up a polar coordinate, which is then transformed to a Cartesian coordinate (x, y, z).

Possible applications of the scanner FARO Focus3D are:

- Faca inspection: 3D dimensional inspection of building shells and facade components before final assembly.
- Structural analysis and maintenance: Rapid and cost-effective control of the specified load-bearing capacity of supporting structures as well as wear and tear.
- Construction progress monitoring: Seamless capture and monitoring of construction progress for legal and technical documentation.
- Built environment: Precise geometrical recording of existing properties as the basis for conversions or extensions.
- Free form components inspection: Precise dimensional check of complex components such as free form shape elements.
- Space optimization: This is done by prior creation of 3D models.

Additional features of the FARO Focus3D scanner are:

- Photorealistic imagining and 3D visualization of different concepts of building use
- Immediate processing of the data in all commonly used CAD programs
- Simple variance comparison in the construction process and in the case of final building inspections
- SCENE Web Share Cloud for simple and secure online sharing of scan data via the internet
- Million point/second scanning rates, ease-of-use, portability, scanning range up to 130m and integrated GPS
- As WLAN, remote control makes it a universal
- Control over WLAN

3. Practical application of 3D scanning

3.1 Demonstration of practical 3D building scanning within P2ENDURE

To demonstrate 3D building scanning, renovation projects has been scanned within P2ENDURE pilot cases. These projects are described in this section of the report and provide the reader the status and knowledge within P2ENDURE on the already done 3D scanning's.

3.2 Demo site in Warsaw (Poland)

On 17.03.2017, a laser scanning of the Nursery school no. 3 was performed at Warchalowskiego Street no. 8. in Warsaw, Poland. The volume of the Nursery school is 5525 m3 and it has 1484 m2 area. Inventory of the Nursery school was done by a company called 3D Scanning Szymon Bloch. The scan was carried out for 2 days (Figure 11). The purpose of the scan was to make a precise inventory of the 3D points. The building is from the 70's and does not have complete paper documentation. Thanks to the 3D inventory we will be able to develop technical documentation and BIM model to further clarify the objectives of modernization. For the 3D laser scanning a Faro Focus 3D was used, which is a good device for both internal and external measurements. This is a non-contact scanner designed for modelling and 3D documentation. The model will be developed by a team of BIM engineers from Mostostal Warszawa. The effect of the scanning is shown in Figure 12.

Figure 11: Laser scanning of nursery school in Warsaw (Poland).

Figure 12: Point cloud model obtained from laser scanning process for Gdynia demo case.

3.3 Demo site in Gdynia (Poland)

Demo site in Gdynia is a building of a kindergarten no 16 located in a city centre at Jana z Kolna Street no. 29. It is a two-story building, constructed in year 1965 and attended by around 130 children. Building volume is 2712 m^3 and the built-up area is 464 m^2. The building has no electrical documentation. For correct planning of the demonstration activities there was a need for creation of BIM model of the building. Therefore, first step was to perform the 3D laser scanning, with the use of Faro Focus 3D scanner. The scanning process started on 24/11/2016 with the scanning of the building envelops. The scanning process is shown in Figure 13. The next step was the inside scanning; this activity needed to be perform on Saturday (26/11/2016) when the kindergarten was empty (without children and teachers). The result of the 3D scanning was a cloud point model that is shown in Figure 14.

Figure 13: The 3D laser scanning of Gdynia demo site.

Figure 14: Point cloud model obtained from laser scanning process for Gdynia demo case.

3.4 Demo site Palmanova (Italy)

The Palmanova demonstration case is unique for the P2ENDURE project. In comparison to the other demo cases that work on the building scale, Palmanova will propose an energy refurbishment project at district scale (Total energy system). The focus is on “deep renovation of the (small-scale) neighbourhood energy system”. The project will propose solutions for RES and (small-scale) neighbourhood energy system.

The refurbishment project at district case will include several typologies of interventions: demolitions, new constructions and restoration of historical buildings. The building renovation and new construction (after demolition) is complementary to the renovation of energy system.

To reduce the geometric survey timing of the existing buildings (objects of restoration) will be propose a 3D laser scanner survey selecting between two different possible approaches:

1. Survey of all existing buildings in low definition (including the buildings that will be demolished)
2. Survey of existing buildings that will be restored:
   a. Water tower
   b. Historic building with porch
   c. Napoleonic military barracks

The survey campaign, using laser scanner Faro Focus designed for outdoor applications, will take 4-5 days to work on-site. At the moment, the 3D survey of the "water tower" is completed.

The next 3D survey campaign will be planned to have defined the correct approach in consideration of the final aims.

Figure 15: Photo of the water tower

Figure 16: 3D image of the water tower

Listed 3D laser scanning benefit and applications:

- detailed and highly accurate 3D data rapidly and efficiently
- detail computer model of exiting building and site
- improving the BIM process using ReCap software - rapid, simple and complete recording of the current condition of buildings and building sites - time savings and high fidelity for 3D documentation of complex factory and plant installations
- precise 3D documentation of the current state of the property as the planning basis for conversions and extensions
- possibility of precise-fit off-site assembly, thanks to exact 3D CAD data and dimensional control
- simplification of facility management, maintenance, training, etc. through comprehensive 3D master data, simulations and training in virtual reality
- improved coordination between different trades and comprehensive documentation and supervision of all work

Laser scanner Faro Focus characteristics

A built-in 8 mega-pixel HDR-camera captures detailed imagery easily while providing a natural colour overlay to the scan data in extreme lighting conditions. Familiar traits, such as light weight, small size and a 4.5-hour battery runtime per charge, make the Faro Focus Laser Scanner truly mobile for fast, secure and reliable scanning. The device is built to safeguard against intrusions such as dirt, dust, fog and rain as well as other outdoor elements which typically occur in challenging scanning conditions. It is specially designed for outdoor applications due to its small size, extra light weight and extended scanning range. Faro Focus provides scanning results even in challenging environments, narrow job-sites, dusty or humid areas, in rain or direct sunlight applications. An on-site compensation tool allows data quality optimization on-site. Integrated GPS & GLONASS receiver enables easy positioning. HDR imaging and HD photo resolution ensure true-to-detail scan results with high data quality.

3.5 Processing with 3D cloud points model

Important step during development of a BIM model is creation of a point cloud model that is a result of a 3D scanning process. The example of the program for processing point cloud is a *Recap of Autodesk*, which helps to capture images of the photos and laser scans. Point clouds are taken from the raw data collected using a 3D scanner for objects such as buildings or items. Before using the data, they need to be converted into readable files of point cloud. The *Recap* program combines all images obtained from the 3D scanner in one cloud of points that can be used later in *Autodesk Revit*. Another software that can be used for visualizing a XYZ RGB format (result of the scanning) is *Undet 2.0 for SketchUp*. This plug-in generates the 3D cloud point map, based on which BIM model in *SketchUp* can be performed. Different possibilities for processing a map of point cloud are shown in Figure 17.

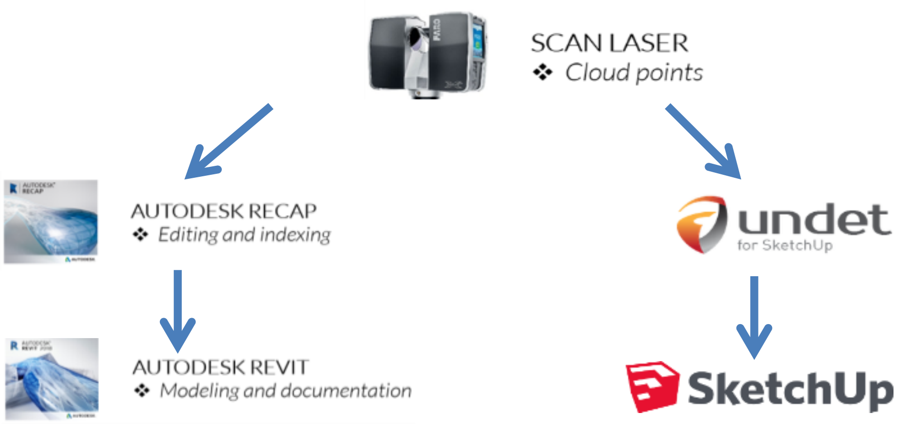

Figure 17: Different software possibilities for processing point clouds.

The process of creating three-dimensional model based on the data obtained by scanning can be performed in two stages. The first step is the processing of points cloud to eliminate information that have been scanned and are not needed (e.g. trees, grass, pavement, etc.). The goal of the processing, editing and cleaning is to increase the accuracy/quality of the model and to decree the time needed for further model development. Example of the cleaning process is shown in Figure 18.

It should be highlighted that each of the engineer (architect, structural engineer, HVAC engineer, etc.) should prepare/clean the points cloud according to individual needs. Example of the processing/cleaning process is shown in Figure 18.

Figure 18. On the left: point cloud before cleaning, on the right: example of the model after cleaning.

During the processing of point cloud, different styling colours facilitating the analysis of the elements can be used. It is also possible to trim/isolate rectangular polygonal areas to view the most important part of the point cloud, see Figure 19.

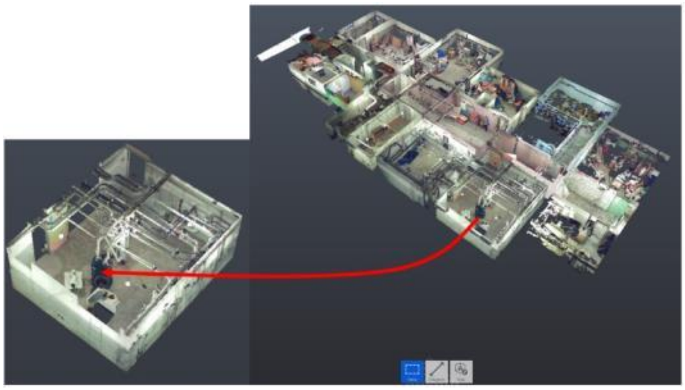

Figure 19. Isolation of area of interest from point cloud.

The second step is the modelling, in which point cloud is already "cleaned" and is used for creation of dimensions and outlines of shapes. Firstly, the points are snapped and then the line between them is drawn, in this way the building and the element shape is created. To perform modelling works in an efficient way, it is important to have high quality and complete point cloud. Examples of the models created in P2ENDURE project based on the 3D scanning are shown in Figure 20.

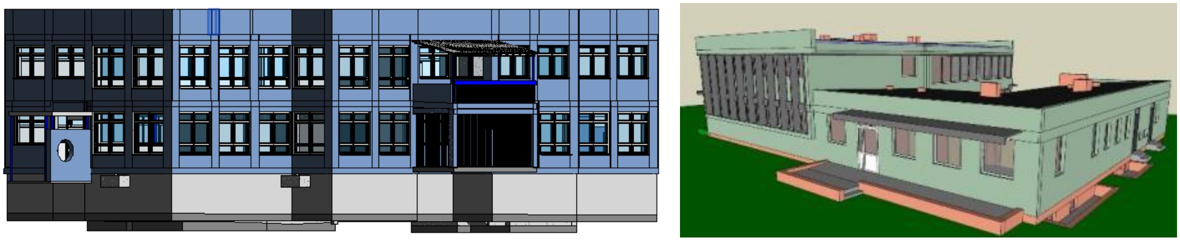

Figure 20: On the left model created with AutoCAD software for Warsaw demo case, on the right model created with Sketch up Pro software for Gdynia demo case.

When modelling the installations (sanitary, HVAC, rain water systems) there might be some difficulties since those installation often is hidden in the building elements. Therefore, to trace them it is recommended to perform on site survey (Figure 21).

Figure 21: Imagine showing hidden radiators that are part of the heating system.

3.6 MORE-Connect H2020 project practical case study

To explain furthermore about 3D scanning and alternative method such as Photogrammetry Survey, MORE-Connect project from horizon 2020 was partly imbedded and analysed in this section of the report. This section from the MORE-Connect D4.1 report will elaborate the costs of 3D scanning, outcome results and Photogrammetry survey method as follows.

Basic Information for Surveyor

The cost of the survey depends on building type, location and country. Before documentation of the object, the contract owner needs to specify his demands clearly. The information should be precise and detailed for the supplier to avoid misunderstanding.

Object Specifications that needs to be documented

- Building size: For terrestrial photogrammetry (width, length, height) should be provided
- For travel expenses- Object/Building address should be provided
- Specifications for interior should specify information such as (hall, corridors, apartments, basement) and exterior (facade, roof) surrounding (trees, pathways, neighbourhood buildings) crane accessibility
- The contact owner should specify further its demand level: size of the smallest details which should be visible in 3D model. Example window ledges and flames.
- Model accuracy: Final model accuracy assessment (Laser scanning methods and photogrammetry method provides models with less than centimetre accuracy). The coordinate system for BIM (global or local)
- Demanded outputs- point cloud, polygonal or prismatic model

Cost Details of Subcontracting

The cost detail information is gathered from MORE-Connect project. The information is collected through secondary research method. This information is provided for the reader to grasp knowledge about cost occur during the 3D building scanning process. The process can be performing by hiring subcontractors or using in house method. The cost structure varies from one country to another due to different VAT and Tax regulation." The prices are collected from the company's website. Information is provided in English". [xiii]

The cost of point cloud generation in 7 countries in Europe is collected based on 3 floor residential house (size 44m * 13m * 15m). It's important to provide crucial information to surveyor before conducting of geomatics work for 3D modelling. For the quote request a set of parameters, like the outcome type (Point cloud, polygonal or prismatic model, data formats), Scanning area (Interior exterior, surrounding) parameters shall be defined in cooperation with the BIM creator as well as the user. The price rate gathers through market research (source: MORE-Connect D4.1).

Country	Point cloud generation cost generation cost range in Euro	Extra information
Denmark	1500-2500	For creating engineering surface extra (2500-3500 Euro)
Latvia	1000-2600	Full 3D model of facade LS 5800-6700, FTGM 5300-6500
Estonia	800-1100	
Portugal	1500-2500	
Switzerland	2500-3500	For creating a full 3D model (indoor and outdoor) 1100-16500
The Netherlands	1000-2500	
The Czech Republic	800-1300	

Cost Details of In-house

Geomatics survey is costly if performed in-house. For short term operation, this is the most expansive method. But this method is cost effective for company which provides geomatics survey at commercial level. The in-house method requires Laser scanner equipment and software. The medium range laser scanner suitable for building documentation can cost 50,000€ in average and the cost of processing software can start from 10,000€, furthermore require powerful hardware (pc) also the salary of a geomatics specialist.[xiv]

Using Photogrammetry method, the cost can be reduced. The quality camera suitable for photogrammetric purposes cost from 2.000€ upwards. The data processing cost, such as software, hardware is a bit higher compare to laser scanning. For documentation of roof top and tall building remotely piloted aircraft is important to gain high quality data. It is very important to calculate the cost before setting up geomatics department in an organization.

Demo site Kladno, Prague

A residential house has been the subject of the project, located in the city of Kladno (northwest of Prague 30 km away from capital city). The scanning has been performed using photogrammetric and laser scanning method. A personal computer is used for calculations.

Specification of the (PC)

- Processor: Intel® core™ i7™-3770 CPU@ 3,40GHz
- RAM 16GB
- 64-BIT system windows 7 Enterprise

PC with following specification is adequate for the job.

Scanned Building Details

There are three floors with similar design flats, simple rectangular floor plan, and a hip roof with number of chimneys on top. The building was selected for this project due to its insufficient energy consumptions. The building infrastructure documented to be old-fashioned in appearance, devastated common areas, insufficient ventilation, waterproofing failures, ruptures in plaster, bad insulating wooden windows with loose closing mechanism.

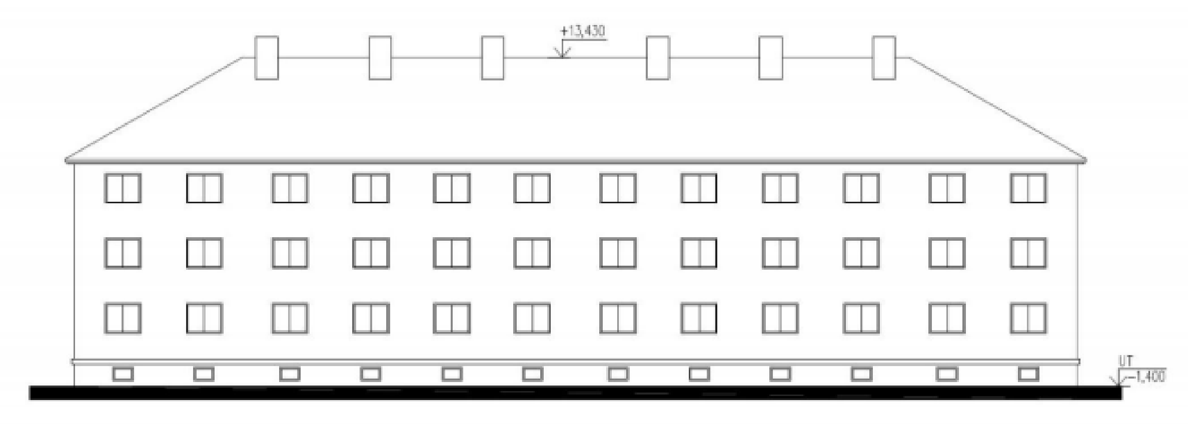

Figure 22: East view (source: More-connect D4.1)

Laser Scanning Survey

The model Surphase 25HSX laser scanner is used to collect adequate data for the project by MORE-Connect.

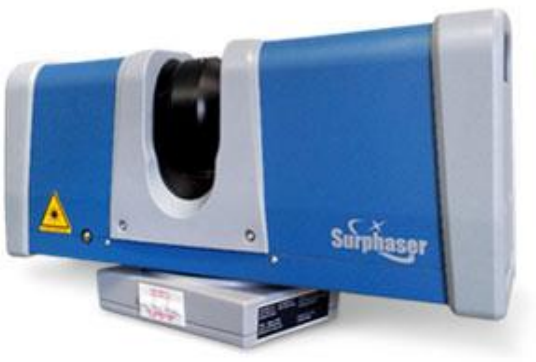

Figure 23: Picture of the Surphaser 25HS

As follows the parameters and values of Surphaser 25HS

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

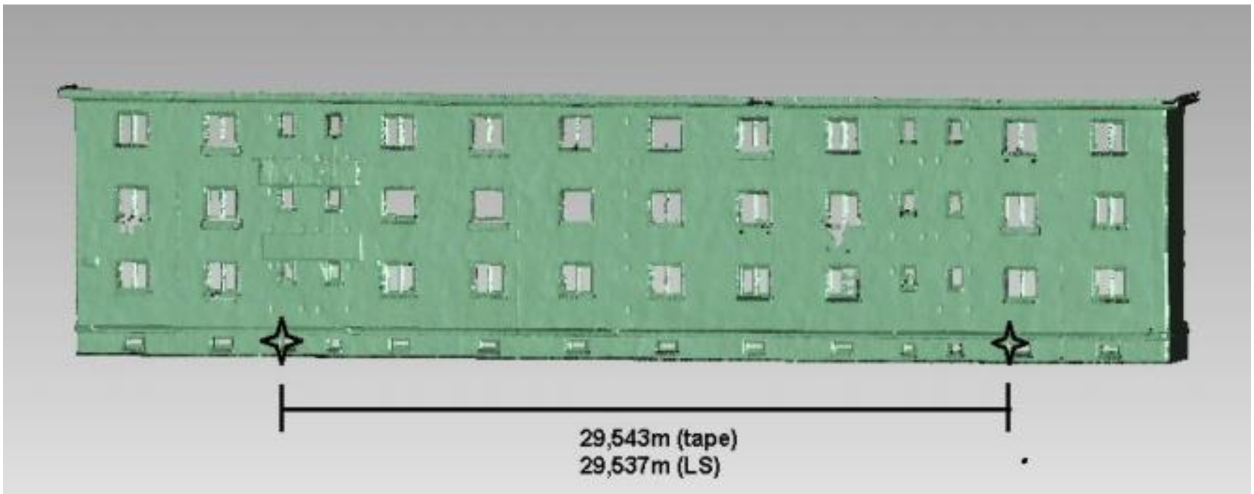

Figure 24: Side measure (source: More-Connect D4.1)

Data Process

The image is a result of laser scanning. The laser scanner provided the points cloud and using geomatics studio software clouds points were exported into XYZ data format. The step was taken transforming of point clouds into one common coordinate system manually selected identical points. Applying the ICP (iterative closest point) algorithm, point clouds transformed into one, resulting point clouds orientation. 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 higher point density is possible to achieve by using higher scanning resolution or by lowering the distance between the scanner and the object. It is recommended to keep the object-scanner distance not shorter than half of the building height. [xv]

Photogrammetry Survey

4 photogrammetric images are produced using 4 different cameras. 2 reflex cameras - Pentax 645D and cannon EOS 45OD,one low cost compact camera- sonny Cyber shot DSC- HX50 and camera build in iPhone 5s.

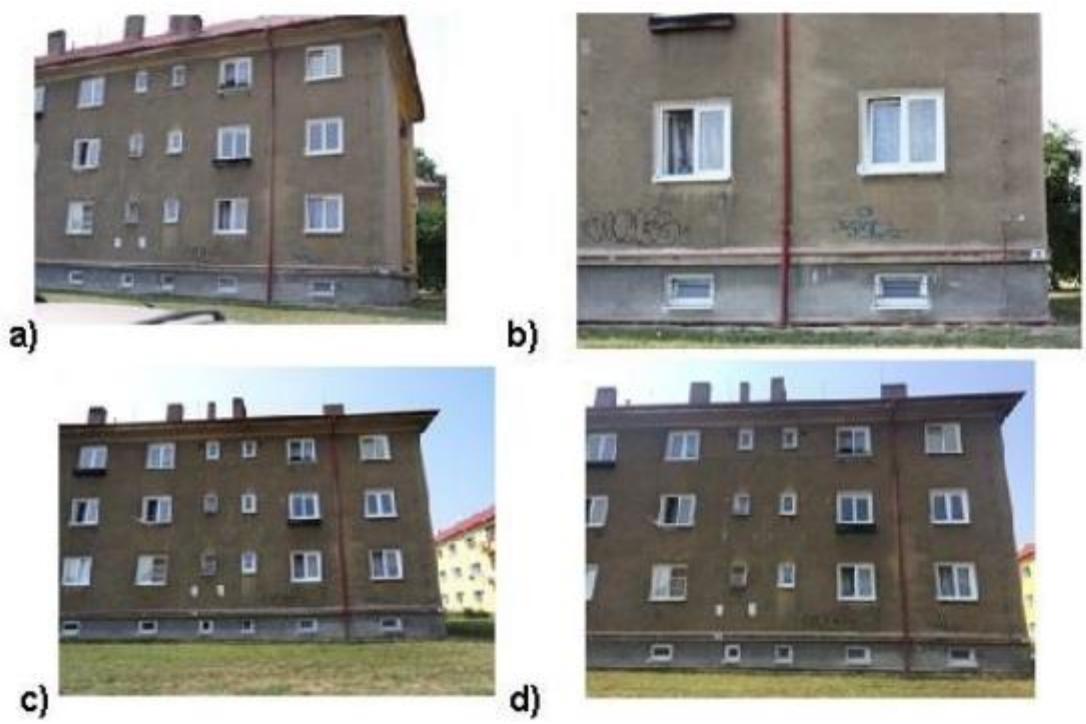

Figure 25: Four different camera images: a) Pentax 645D, b) Canon EOS 45OD, c) Sony Cyber Shot, d) iPhone 5s (More-connect D4.1)

In the photogrammetric survey, the level of detail is determined by (GSD) Ground sample Distance. If the distance is short between object and sensor (camera), the outcome is expected to be less noisy. In the More- connect project aim was to set same GSD for all cameras, between 15 to 40 m. But due on site restrain the distance was set 12 m and images were taken from 4 different camera types. Each camera has different focal length and sensor type. Different images were taken to cover the object area.

Camera	**Pentax 645D**	**Canon EOS 45OD**	**Sony cyber Shot DSC-HX50**	**iPhone s5**
Number of images processed	56	83	34	32

Number of points (in millions)	43.0	24.9	4.3	4.5
GSD for dist=12 m	1.3 mm	1.6 mm	0.6 mm	0.6 mm
Average distance between nearest points in point cloud	0.2-0.5 cm	1.0-0.5 cm	1.0-1.5 cm	1.0-1.5 cm

Image processing -parameters (Source: More- Connect D4.1)

Figure 26: a) Pentax 645 D, b) Canon EOS 45OD, c) Sony Cyber Shot, d) iPhone 5s

Camera	Pentax 645D	Canon EOS 45OD	Sony cyber Shot DSC-HX50	iPhone s5
Focal length	55 mm	40 mm	35 mm	30 mm

Using the Agisoft photo scan software image data is process according to basic workflow. The image alignment is performed after images were imported. The software connected tie point using the calculation of interior and exterior orientated parameters. Orientation and scale setting were insured by using ground control points (GCP)[xvi].

8.

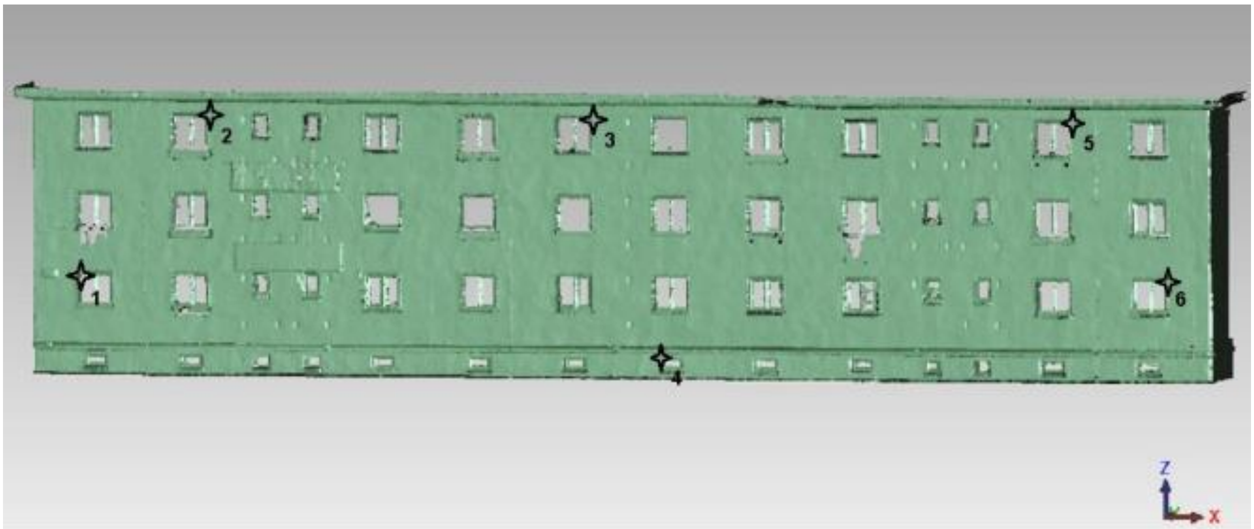

Figure 27: Position of GCP (Source: More-connect D4.1)

The GCP coordinate system are gained by reading the model derived from laser scanning and use of similar coordinate system for an outcome to be ensure. The *.txt format is generated using the image orientation of point cloud. The geomatical Studio software is used to finish the following workflow like laser scanning data.

The process time varies by camera type, also the number of images which require for computations (32-83), the processing time (for iPhone is about 1.5 hour and approximately 20 hours for Pentax) and the density of the final point cloud. Camera sensor plays the big role, the larger the sensor the better-quality pixel of the image. More light gets into larger sensor, which 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.[xvii]

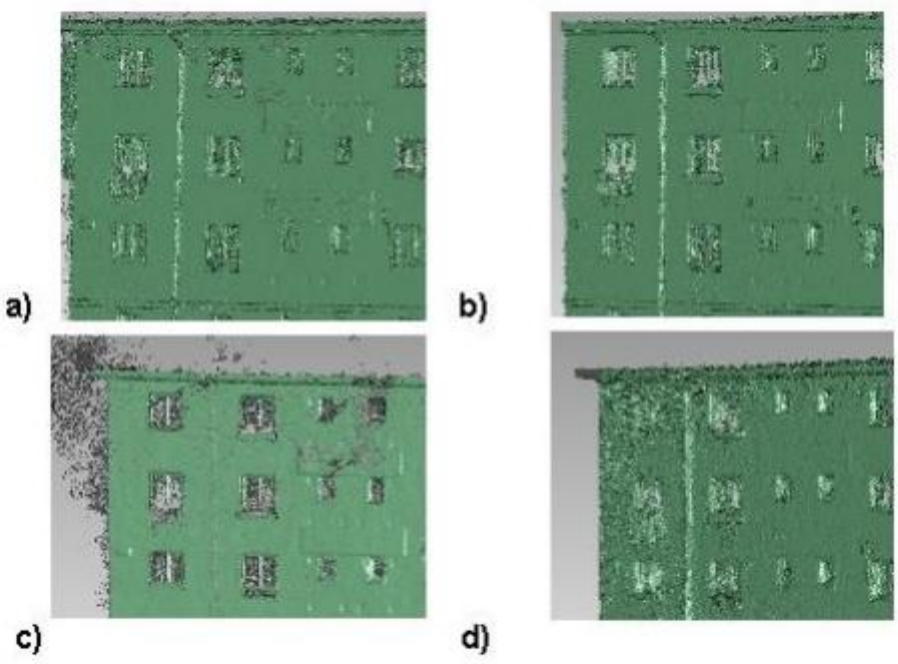

Figure 28: a) Pentax 645D b) Canon EOS 45OD c) Sony CyberShot d) iPhone 5s (source: MORE-Connect D4.1)

Comparison

Various camera types are used to derive resulting point cloud; the results are compared with polygon model created from laser scanning data using Geomatics studio software. Laser scanning method is used as reference to compare the results. Figure 28-A to 28-D demonstrate distances between points acquired from Photogrammetric and laser scanning point clouds. The nominated values are given in meters

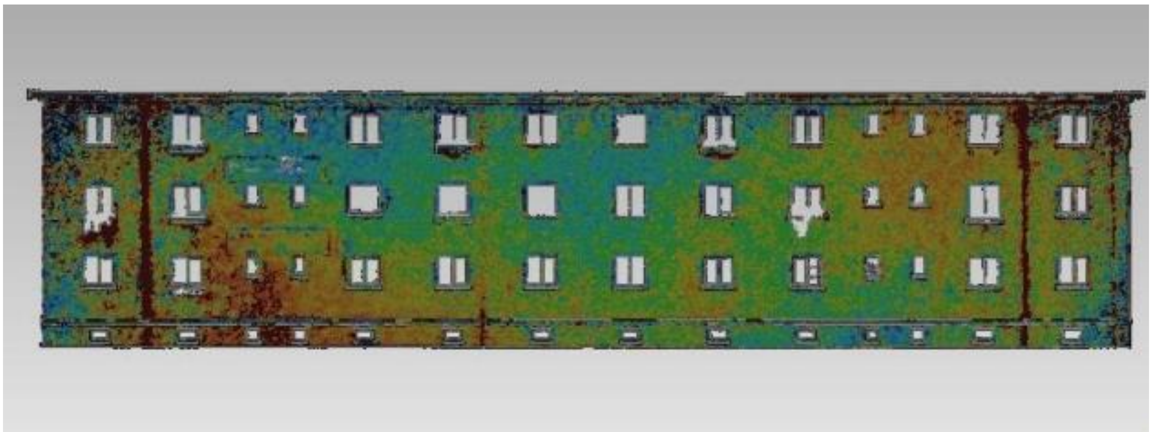

Figure 29: iPhone 5s (Source: More-connect D4.1)

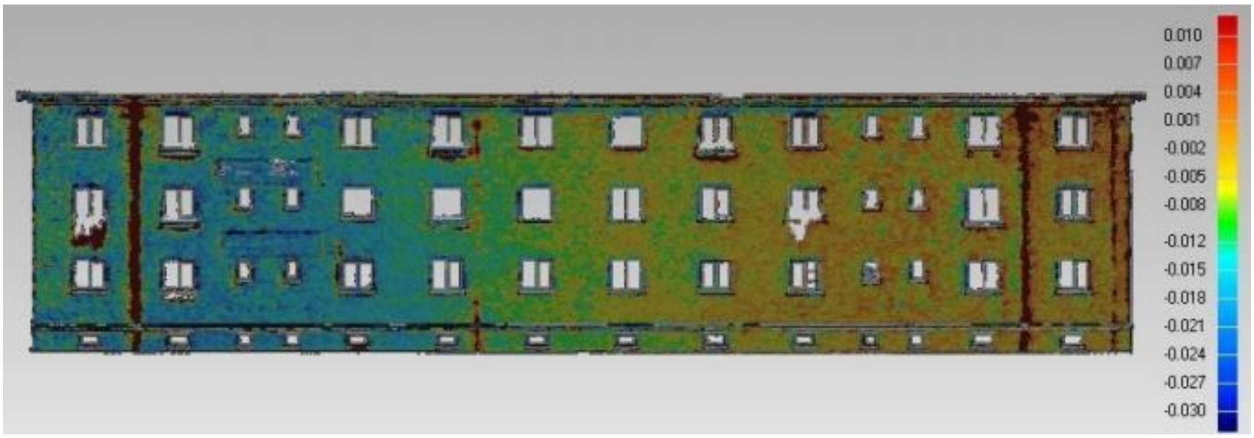

Figure 30: Sony cyber shoot (Source: MORE-Connect D4.1)

The low-cost Sony and iPhone (Figure 29 and 30) cameras showed largest variations when compared photogrammetric outcomes to laser scanning. Both cameras showed notable noise level in the data-noise level reaching high as several centimetres. There is software which can be used to reduce the noise level, but are not used for in More-connect project.[xviii]

The noise level is considerable reduced when it is compared to non-reflex cameras. The result can be seen in image (see figures 31 and 32). Variations between laser scanning and photogrammetry outcome when using reflex camera are distinctly lower. In majority of the model distance are lower than 5 mm.

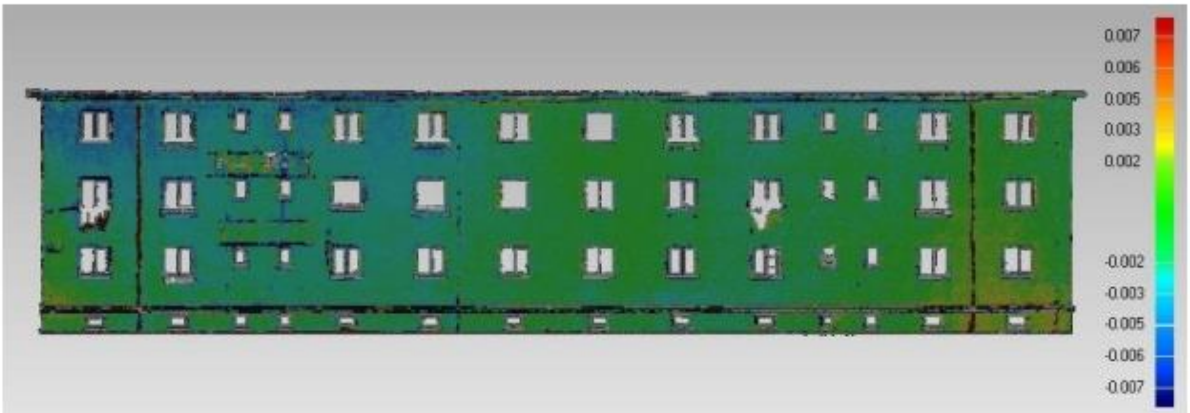

Figure 31: Pentax 645D (values in meters)

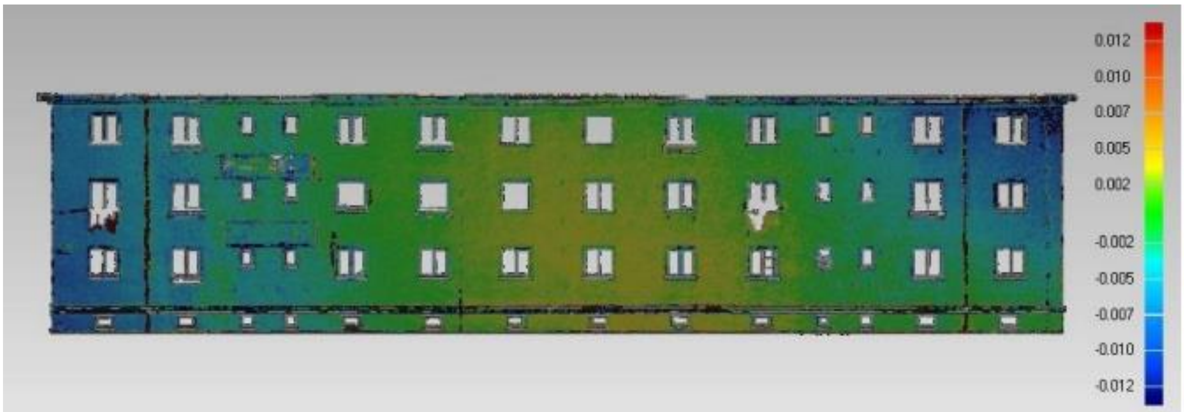

Figure 32: Canon EOS 45OD (Source: MORE-Connect)

Summary of Photogrammetry Survey

The point cloud derived from the Pentax 645D camera provide the best result. The one reason for that is that Pentax camera's focal length is 55 mm which is high in comparison to another camera used in the test. The data accuracy comparable to the laser scanning point cloud has higher density. The outcome of the result also depends on the Distance to object.

Pentax 645D camera Distance to object was 18 m compare to iPhone s5 40 m. Cameras with less focal length require greater distance to object. The iPhone s5 focal length is 30 mm compare Pentax 654D. The bigger image size greater result but higher process time.

Laser scanning method and photogrammetric are both convenient. Both method is applicable when require 3D can of the building. The Photogrammetric scan can be more economical over laser scanning. Both methods are applicable. Use of method based on project specification and requirements. The process can be only performed by professional.

4. Foreseen Development and Exploitation

4.1 Drone tech scanning

Drone Tech Scanning on-site is an upcoming technology for generating point clouds of very large area's and buildings. This is just mentioning two of the most advanced on the market.

Unmanned Aerial Vehicles

UAV refers to unmanned aerial vehicles. It's an aircraft design that operates with no human pilot on board. It can be controlled remotely. It is used especially when documenting tall buildings and rooftops. UAV is mostly used for photogrammetric documentation.

UAS refers to unmanned aerial system, which comprehends the whole system composed by the aerial vehicle/platform, held sensor and the Ground control station.[xix] Two Types of UAV are available for aerial scanning, fixed wing and rotary. The rotary system (multi-copters) can fly in every direction, horizontally and vertically. Unlike fixed wing models, the rotary drones can hover in a fixed position as well.

Figure 33: This is two typical UAV, on the left a fixed wing model and on the right a rotary drone.

4.2 3D printing robot technology with BIM tech and scanning solution offsite/ prefab

One of the foreseen developments of BIM process is 3D printing in the construction industry. The advanced developments of the BIM Process credit go to 3D laser scanning technology. Autodesk Revit is building an information modelling software for architects, structural engineers, MEP engineers, designers and contractors with algorithmic intelligence. It allows users to design a building and structure and its components in 3D, annotate the model with 2D drafting elements and access building information from the building model's database, but with the algorithmic help for optimisation or even general international laws of construction. In short, we will have the possibility of modelling buildings, with the help of different algorithmic guidelines for design and functions and not only the 3D vision and building information data and overview from a static model.

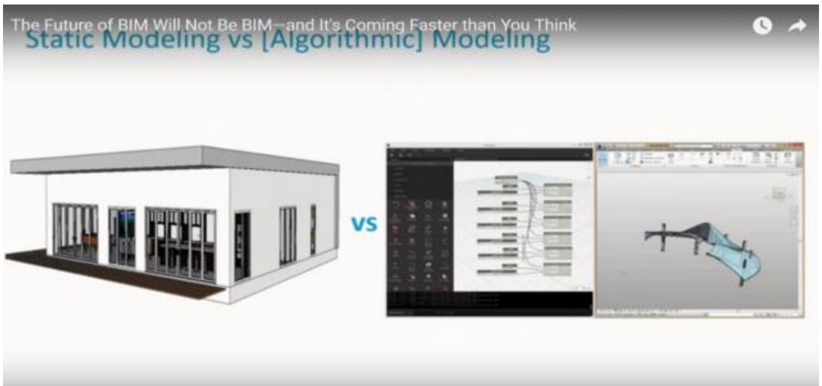

Figure 34: Static Modelling vs Algorithmic Modelling (source: Autodesk university)

The 3D laser scanner not only creates a 3D scan image of the building, but it also creates a point cloud data for future prefab elements construction. In an easy way 3D laser scanning is documenting all needed dimensions of the object/ element, x,y,z coordinates, which is put through a post process. The output is precise construction data for actual input into the factory production line of the element. The technology is now developed so far, that robots can use this data and make an actual 3D house or precise bricklaying for a new wall.

Figure 35: Robot laying bricks (source: Autodesk university) *Figure 36: 3D printed castle (source: Autodesk university)*

Prefab off site 3D printed micro home in Amsterdam

Dutch studio DUS Architects has brought innovation to the next level in 3D printing technology. The firm has built Micro home in the hard of Amsterdam city. The house is built with small 3D printed plastic panels which are bio degradable. The idea is to provide quick residential solution in disaster areas.
When micro home is no longer need, it can be destroyed and almost all the materials can be reused. [xx]

Figure 37: 3D printed cabin Source (DUS Architects)

Prefab off site 3D printed villa in China

As European companies are moving forward building an off-site 3D printed house, China has also joined the race. A company from Xian, China installed a complete villa in less than 3 hours. The villa was assembled like Lego bricks. 90 percent of the construction is performed off-site in the factory. The house construction and material can withstand 9.0 magnitude earthquakes. The modern 3D printed house materials are created from industrial and agricultural waste, it's fireproof and waterproof, and it's free from harmful substances.[xxi]

Figure 38: Source: inhabitat.com

4.3 On-site 3D printing/ surfacing robot technology from 3D design – Robot-At-Work

General description of Robot At Work

Robot-At-Work is a robotic company from Odense, Denmark founded by Finn Christensen and Anders Martiny. Robot-At-Work provides on-site construction solutions. The company provides 3D milling on façades and 3D wall rendering. Robot-At-Work is also developing a new solution, such as milling between brick joints using robotic technology and acoustic solutions for inside wall decorations.

Robot-At-Work - Demo case in Odense, Denmark - Korsløkken

On-site 3D façades using robot technology is predicted to become a new design solution in the construction industry. Today only prefab solutions for 3D surfacing can be performed, and this typically creates long production time and logistics problems when mounting the elements on-site. Robot-At-Work has performed a 3D façade on a live demo case in the Odense city in Denmark. In this report only an overview of the solution is presented. More detailed description of the solution and the development process will be provided in the deliverable report D1.6 “Demonstrator of 3D printing with on-site robotics” of the P2ENDURE project.

3D facade creation on-site

To perform on-site 3D printing on a facade following things are required:

- Collaborative robot - Universal Robot, UR 10
- Milling tool for milling in insulation
- Industrial scale vacuum for the specific suction cup around the milling tool
- Mortar pump for pumping the high precision mortar on the facade

Figure 39: Picture of 3D milled design on facade (Source: Robot At Work)

Process

The design to be printed on the façade of the demonstration case in Denmark was created by a local artist from the Odense city. The design is a handwriting name of the housing location – “Korsløkken”. This word will be scaled up in design software from a few centimetres up to 3x10 meters format according to the dimensions of the wall. When the design of the surface was done it was put through the postprocessor of Robot-At-Work. The output format is adjusted to the toolpath of the robot which allows the Universal Robot to perform its precise movements. A platform was installed on the construction site, close to the wall for stability of the working process.

Figure 40: Robot doing design milling

Figure 41: Robot doing milling in the insulation

Figure 42: Robot is rendering with mortar

Figure 43: Mortar pump and spray gun

A rail is installed on the platform which allows the robot to move horizontally, from point A to B. After installation of the robot on the rails, a special developed milling tool is mounted on the robot. A suction cup is added on to the milling tool, the suction cup sucks the excavated material during the milling process. An industrial vacuum is then connected to the suction cup. The specific robot toolpath file is uploaded to the robot operating system. The robot starts milling 1 square meter at a time, in total 32m2. For the wall rendering a spray gun is mounted on the robot. The mortar pump is added which pumps the mortar to the spray gun. An air compressor is linked to the spray gun, which allows the spray gun to project the mortar on the wall in the specific developed pattern for the wanted mortar.

There was no 3D scan of the building available, and this design didn't need a specific 3D measurement for excavation on-site. Measurement of the wall where taken by hand and the platform was manually calibrated in the robot software on-site.

All the work pages for each m2 with toolpaths for the robot are to be controlled in a Linux WIFI solution. This will guide the craftsman through the workflow of the whole design and working process and control all the machinery in the solution, without the need of special robot or computer knowledge. This user interface will be tested and further developed and described in more detail in D1.6.

5. Conclusions

Laser scanning method and photogrammetric are both handy. Both methods are applicable when a 3D scan of the building is required. The Photogrammetric scan might be cheaper than laser scanning. Both methods should be used tailored to project specifications and requirements. The scanning process can only be performed by a professional. After evaluating the scan results of Warsaw and Gdynia Demo case studies, it is recommended to use 3D laser scanner method over photogrammetric method. The 3D laser scanning method is easier to be applied, more advanced, faster, and cheaper considering the availability of the latest laser scanners in the market. The Focus^{3D} laser scanner is suitable for mobile use on the building site. It can be used for recording foundation, excavations, building shells, and buildings in 3D in total.

To perform photogrammetry method, multiple images are required before creating a point cloud. This method might be more sufficient when scanning when roof top of the building using drones. The final scanning result can be obtained using both methods at the same time. For example, it is possible to perform 3D laser scanning for the ground level part of the building and drone-based scanning for the top view of the building using drone images (Photogrammetry method).

The Focus3D FARO is most probably the best choice compared to other laser scanners due to its multiple functionalities. It is also recommended to provide all the sufficient details of the building project and surroundings to the surveyor in advance, before requesting a service.

The foreseen developments of BIM and 3D printing in the building industry depends on the 3D laser scanning technology and the new possibilities with the involvement of the algorithmic data and software that will advance the construction industry drastically in the coming years. The 3D facade on-site technology is new and it is hard to say, if it is cost efficient or not yet. Although, the current use cases show that having robots working on site can save time as less manpower is needed. In addition, the work can be done with higher precision and quality.. With further advancement of the existing solutions the working process can be optimised and it is expected to be more cost-effective as well compared to traditional work in the coming future. When compared to traditional 3D facade elements transported from prefab factories, such on-site technology will soon become more cost-effective.

The experience from P2ENDURE partners, help us to make the conclusion that foreseen development of BIM is going to lead future automated building design and automated urban planning. The partners work reflects the importance of 3D laser scanners in BIM process and its connection to 3D construction/printing. Information collected though primary source and secondary source reveals that it is now the golden age of robotics leading the building industry towards a more automated construction future.

References

[i] http://lanmarservices.com/2014/04/02/the-basics-of-3d-laser-scanning/

[ii] More-Connect project D4.1 - page 1 - D4.1 Advanced Geomatics for Modular Building reconstructions

[iii] https://www.ems-usa.com/3d-knowledge-center/3d-scanning-knowledge-center/types-of-3d-scanners-and-3d-scanning-technologies/

[iv] https://www.ems-usa.com/3d-knowledge-center/3d-scanning-knowledge-center/types-of-3d-scanners-and-3d-scanning-technologies/

[v] https://www.ems-usa.com/3d-knowledge-center/3d-scanning-knowledge-center/types-of-3d-scanners-and-3d-scanning-technologies/

[vi] https://www.ems-usa.com/3d-knowledge-center/3d-scanning-knowledge-center/types-of-3d-scanners-and-3d-scanning-technologies/

[vii] http://gmv.cast.uark.edu/photogrammetry/

[viii] www.mdpi.com/journal/sensors

[ix] www.mdpi.com/journal/sensors

[x] http://ontargetcloud.com/blog/Bim-is-a-process

[xi] https://www.tekla.com/de/trimble-5d/laser-scanning-for-bim.pdf

[xii] https://www.tekla.com/de/trimble-5d/laser-scanning-for-bim.pdf

[xiii] P2ENDURE partner D.15 P2ENDURE_SGR_Memo 2

[xiv] P2ENDURE partner project (More-connect page 12 section in house)

[xv] More -connect project D4.1 page 15

[xvi] More-Connect project D4.1 page 18

[xvii] More -Connect D4.1

[xviii] More connect project D4.1 page 19

[xix] More-Connect project D4.1 - page 6 - D4.1 Advanced Geomatics for Modular Building reconstructions

[xx] https://www.dezeen.com/2016/08/30/dus-architects-3d-printed-micro-home-amsterdam-cabin-bathtub/

[xxi] http://inhabitat.com/chinese-company-builds-3d-printed-villa-in-less-than-3-hours/