INTELLECTUAL OUTPUT 1

TASK O1-A2

Sustainable construction methods and procedures used with new technologies

INTRODUCTION

This report is included in the task "*O1-A2. Sustainable construction methods and procedures used with new technologies*" corresponding to Intellectual Output 1 "*Establishment of common learning outcomes on industrial areas restoration with new technologies, Life Cycle Assessment (LCA) and relative regulations*" of the RecoverIND project.

All methods, skills and competences related to new technologies (use of drones, thermography, sensor-devices, 3D scanners, collaborative process robotization, application of cyber physical systems) were analysed, to complete a report that can be transposed to improve the training system and pedagogical methodologies in this sector. The environmental methods and procedures of the use of new technologies in the construction and rehabilitation sector has also been considered.

This task was fundamental to establish the theoretical base that supports the curriculum produced in this IO1.

This report and all the information about the project are available in the following url:

- RecoverIND project website: https://recoverind.eu/en/project/

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New ecological and innovative technologies and methodologies apply recovering industrial areas from LCA and Energy Efficiency point of view

For future generations to enjoy the beauty and richness of the Earth, scientists have developed and implemented since 1972, the concept of sustainable development. The concept focuses on environmental issues and natural resources, especially those related to energy. The construction sector has a great impact on energy saving, and for this reason, Romania, as all EU Member States, adopted the laws, regulations and administrative provisions necessary to comply with Directive 2012/27 / EU on energy efficiency [1].

The concept of sustainability in the built environment

The concept of sustainable development was born in 1972 in Stockholm at United Nations Conference where 113 nations present have expressed concern about how human activity affects the environment. The problems highlighted in this meeting were related to pollution, destruction of resources, environmental deterioration, extinction of species and the need to raise the living standards of people and environmental quality for present and future generations.

Major changes must occur at both the conceptual and technological level if it is implemented in constructions field the concept of sustainable development. It can build sustainable, based on conceptual models of performance, with little impact to the environment, using recycled materials and/or materials with low embodied consumption of primary resources and energy. Energy use throughout the life of the building, called operational energy is one of the most important keys in the construction sector. In buildings, thermal performance or energy efficiency have significant economic, social and environmental impacts [2].

The environmental methods and procedures of the use of new technologies in the construction and rehabilitation sector can be a vital approach that is fast, time efficient and eco-friendly. These technologies are based on the use of drones, thermography, sensor-devices, 3D scanners, collaborative process robotization, and application of cyber physical systems.

To have a holistic image regarding the concept of sustainability, besides the modern technologies we need to focus on the building and its related area. This area must meet the following parameters: the effective selection of the site, the design in terms of construction sustainability, the material selection, the implementation of the waste management, the energy and water efficiency, the indoor air quality, and the dismantling and the reuse of recycled components. All these parameters have a great influence on the life cycle assessment of building.

Considering the huge amount of energy and materials used in construction, the environmental impact is becoming a necessary condition of the design process. Moreover, this impact should be considered in all phases of construction, starting with the erection, the operational duration and life end. Since the construction industry is responsible for more than half of the planet harmful emissions, estimating the impact that they have on the environment will become a necessity soon, to be integrated into the design process.

Energy efficiency – a new target for the building stock

The future solutions will be those that can ensure the safety and functionality of a building, leading to a minimum cost, and to a minimum impact on the environment. Romania still must improve this segment, the mandatory legislation for determining the impact that newly designed buildings have on the environment is not relevant enough.

The current state of energy efficiency in Romania has evolved compared to 2012-2014 when no coherent mechanism for the quantification existed. In addition, the legislative context has adapted to the new context and necessities. Some of the main targets focus on the reduction of greenhouse gases and the increase of renewable energy. Moreover, the document entitled "Energy Roadmap 2050", presented by the European Commission in December 2011, shows that, to achieve the target of reducing by 80% the emissions of greenhouse gases by 2050, regardless of the sources of energy used, a higher level of energy efficiency is necessary [2]. This is possible only with the help of modernization not only regarding the construction methods and materials, but also regarding the procedures that rely on new technologies. With the help of these new technologies, we can enhance energy efficiency and life cycle assessment.

National energy efficiency policy defines the specific targets and the improvement measures of energy saving related to all sectors of the national economy, especially referring to (Law no. 121/2014 on energy efficiency) [3]:

a) Introduction of energy efficient technologies in industry, modern systems of measurement and control and energy management systems, for monitoring, ongoing evaluation of energy efficiency and energy consumption forecasting.
b) Promotion of equipment and energy efficient appliances for the end-users, and promotion of renewable energy use.

c) Reducing the environmental impact of the production, the transportation, the distribution and the consumption of all forms of energy.
d) The application of modern principles of energy management.
e) Providing financial and fiscal incentives for renewable energy use, in the law.
f) Developing the market for energy services.

Energy efficiency has become one of the most important research topics in the current era in terms of its multiple approaches: ecological, technological, economic or social [4]. It is regarded as a key economic and social development resource [5] and as one of the most effective ways to achieve climate change mitigation [6].

In the European Union, buildings are the most important element of energy efficiency policies. They account for almost 40% of final energy use at the EU level. The national demand for energy was 21,644 toes from which 7375 toe was the energy used in households, 6472 toe energy used in industry, 1762 toe energy used in services, 5577 toe energy used in transports and 458 toe energy used in agriculture [4]. In Romania, residential and non-residential energy use accounts for almost 45% of total energy use. As it makes a significant contribution to energy use, the residential sector is subject to several policies aimed at reducing energy use in this sector. At national level, it is necessary to implement the requirements of Directive 2010/31/EU on the energy performance of buildings [7] and of Directive 2012/27/EU on energy efficiency [8]. Directive 2009/28/EC (RED) requires the use of minimum levels of energy from renewable sources for new buildings and existing buildings undergoing major renovations [9].

At a European level, in addition to the three targets for 2020 (20% reduction of greenhouse gas emissions in the EU, 20% increase in the share of energy from renewable sources), several long-term objectives for 2050 with an obvious impact on the residential sector were established. These objectives focus on moving to a low-carbon economy (which will involve a significant reduction in residential carbon emissions) and the energy perspective that involves increasing the energy efficiency of new and existing buildings. At a sectoral level, a strategy was adopted in 2014 to mobilize investment in renovating the existing residential and commercial buildings at a national level. According to the strategy adopted at the sectoral level, the annual target for thermal rehabilitation is at least 1% of the existing national building stock [4].

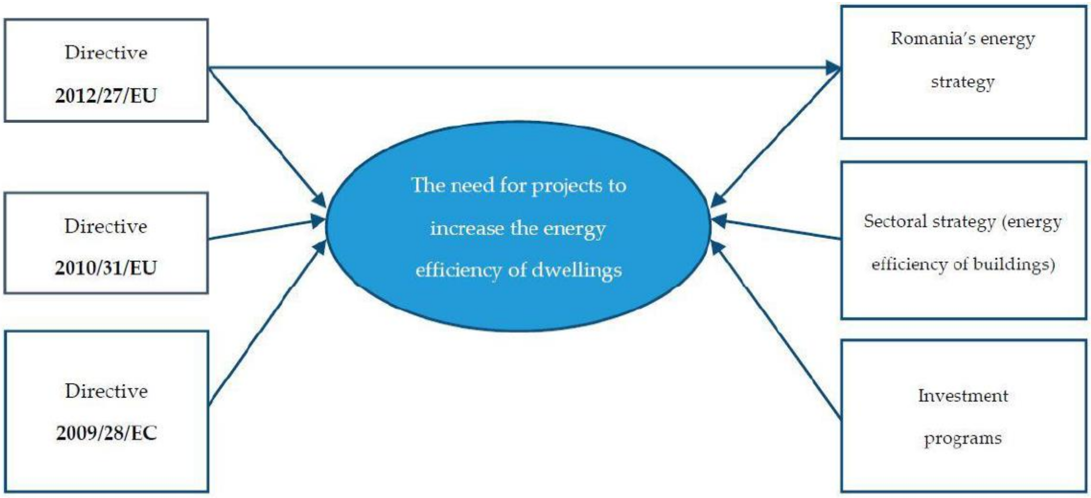

Figure 1. The main determinants of energy efficiency projects for dwellings stock.

At present, the care for global energy depletion makes from the increasing of building energy efficiency a necessary economical standard; so besides the aesthetic factors underlying the construction of a building, it needs to be designed also from the point of view of energy efficiency [10].

A major objective of low energy buildings is to minimize the amount of external energy purchased – providing indoor thermal comfort of occupants – regardless of the season and outdoor climatic conditions [11]. Low energy buildings usually use a high level of insulation and energy efficient windows to reduce heating and cooling demand and obtaining of high-energy efficiency.

The energy efficiency increase of buildings consists of a set of methods and techniques that consider both the buildings, as well as that centre of energy exchange with the environment.

Increasing the energy performance of a building can be achieved by different methods such as:

- At the building level by creating the indoor comfort conditions, respectively a good insulation of walls and the use of windows with a high degree of thermal protection.
- Increasing the performance of heating systems.
- Increasing the performance of air conditioning systems and those concerning the electrical installations.

Possibilities to increase the energy efficiency of building

The best solution and the one with the best efficiency of heat gain and of heat carrier saving is the insulation of whole building, both roof as well as of the basement, by which large amounts of heat are lost. The highest losses of a building are found in the field of thermal energy. For this reason, there are required several additional measures that consider the following aspects:

• The building thermal envelope must ensure the comfortable indoor climate with low energy consumption, regardless of the season (both in warm seasons as well in the cold ones) [12-16].

• The windows must have a coefficient of thermal loss as low as possible and the highest solar gain, for saving more energy.

• The proper insulation of the roof especially for buildings with a few floors.

For a detailed study of the energetic behaviour of buildings, the constructive properties and the materials for walls, ceilings, floors, windows and roof must be known.

Besides the above-mentioned aspects that focus on the thermal envelope, windows, and proper insulation, we can invest also in the valorisation of the existing building stock by approaching the following steps:

- Functional reconversion of industrial buildings into office space, creative-hubs or apartments.
- Improving the construction site management by using modern methods and technologies for supervision and control on site: 3D scanners, drones.
- Using thermography, sensor-devices and cyber physical systems for improving energy efficiency.
- Increasing the performance of HVAC systems.
- Utilizing materials from sustainable source, local resources.

The energy performance simulation of building proposed to study was performed using transient analysis software, TRNSYS (TRansient System Simulation) [17]. This software is dynamic simulation program that benefits by a modular structure that makes possible its supplement with mathematical models.

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The energy simulation was performed using the weather data recorded by a local weather station (Braşov urban area) by implementing them in TRNSYS subroutines; it was considered the fact that to achieve an energy calculation as accurately is important to have accurate weather data (solar radiation data, ambient temperature, relative humidity, wind speed and direction) [10].

Implementing the building model consisted of the following steps:

• The defining of thermal zones and their characteristics.

• The detailed specification of envelope elements for building, the optical properties of windows, the working programme of the equipment.

• Defining of the orientation for building and for glazed surfaces.

• The specification of infiltration due to leaks and the type of air conditioning.

• The specification of heating and cooling regimes (temperatures during the day and the night, supplied heating power).

• specifying the internal gains distributed in the three components (persons, artificial lighting, electrical devices).

• The detailed description of shading type.

This case study focusing on the energy calculation with the help of computational methods was realized for an office building of *Transilvania University of Braşov*; the building has two floors with a built area of 260m2. The North and South oriented exterior walls of the second floor are formed mostly from windows, which significantly changes the buildings energy behaviour [10].

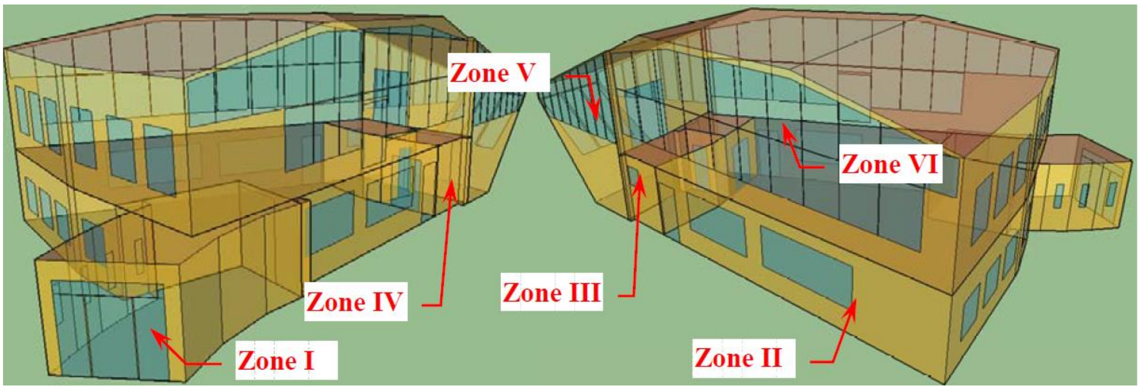

Figure 2. Energy calculation for a building in Brasov (Romania) utilizing computational methods.

The role of computer simulation in the design based on energy performance of buildings is very important, to obtain some results based on which the final solution will decided. Using libraries of building materials, windows, weather data and standards for

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determining the buildings performance, through computer simulations there can be evaluated the parameters that ensure the energy efficiency of a building (calculation of building loads and of energy consumption; evaluation of thermal comfort conditions, thermal behaviour, etc.).

Energy efficiency is the centre of all strategies for smart and sustainable growth, and the transition to a resource efficient economy. Energy efficiency is one of the most profitable ways to enhance security of energy supply and reducing greenhouse gas emissions and other pollutants. In many ways, energy efficiency can be seen as the largest energy resource in the world [18].

Therefore, investments in energy efficiency will help achieve 3 objectives:

- Sustainable economic growth.
- Ensuring energy security.
- Reduction of greenhouse gas emissions.

An important part of monitoring the effect of energy policy strategies are the databases, necessary for strategic analysis and assessment, especially for preparing and interpreting reports an energy consumption and energy efficiency progress.

Internationally there are large databases managed by international organizations with long tradition in making energy statistics:

- International Energy Agency (IEA), conducting detailed statistics on energy balances, rates and fees for various forms of energy, CO2 emissions and developing energy forecasts.
- ODYSSEE MURE project, funded by the European Commission under the "Intelligent Energy Europe Programme", includes energy efficiency indicators at macroeconomic level, sectorial and subsectorial for 29 countries (EU27, Norway and Croatia). This project focuses on two major databases:

  • ODYSSEE database with energy efficiency indicators, CO2 indicators and all the data needed to calculate these indicators.

  • MURE database for assessing the impact of energy efficiency measures.

- Economic indicators, used as input in the calculation of energy efficiency indicators and necessary to develop energy forecasts and strategies. They allow assessment of the economy as a whole and disaggregated at economic sectors and subsectors levels.

- Energy indicators are indicators of energy consumption and its structure and underlying the rationale energy efficiency strategies [18].

Passive house standard

This concept is gaining more awareness in the segment of end-users but also in the case of specialist such as: architects, engineers, constructors, etc. The first certified passive house was built in 2008, in Denmark under the supervision of architect Olav Langerkamp. Before this Project also other experimental projects were erected in Switzerland or Germany, mainly focusing on collective housing or targeting the educational sector (kindergardens, schools).

Passive house (German: Passivhaus) is a voluntary standard for energy efficiency in a building, which reduces the building's ecological footprint. It results in ultra-low energy buildings that require little energy for space heating or cooling.

In Romania, the passive house concept is relatively new, and most people are sceptical of approaching it, generally because of the higher initial investment. Nevertheless, in recent years, several passive house projects were successfully implemented in different parts of the country [19].

Figure 3. Passive House Che situated in Suceava County.

Located in northern Romania in the town of Suceava surrounded by a mature forest, Passive House Che enjoys its surrounding environment by engaging with it through large windows. Although most passive houses don't have huge glazed walls, this one do and enjoys a high level of natural light. In fact, a central core is completely glazed and serves as an atrium for the house to pull light into the inner reaches. This is also where the home has a ground floor of grass and a net lounge accessed from the second story. The inhabitants can play or relax on the canopy and feel like they are outside even though they are indoors.

Besides lots of light and a fun play zone, the home designed by Tecto Architecture is going through its passive house evaluation process and is estimated to use only 14 kWH/sqm/year. The home features natural insulation materials, high performance windows, an energy management system, and a ground water heat pump. A green roof replaces the living space lost to the footprint of the home and natural cedar slats on the exterior help it blends in with the surrounding environment. Eventually a photovoltaics system will be installed on the roof to provide energy for the home [20].

Regarding new technologies in construction all methods, skills and competences related to these new technologies (use of drones, thermography, sensor-devices, 3D scanners, collaborative process robotization, and application of cyber physical systems) will be analysed and presented in the context of Romanian built environment and construction methods.

Drones

Romania is a part of the European Union and therefore must abide by the drone regulations put in place by the European Union Aviation Safety Agency (EASA). In addition to these regulations, Romania also has regulations that are country specific.

Until last year the legislation was not clear regarding the utilisation of drones and this can be one of the reasons why drones still haven't been used in the construction sector. Even though drones have been present in Romania in the last 10 years, their main purpose was for monitoring or aerial view source for different companies that develop infrastructure such as highways or national roads.

There is big potential and interest coming from the construction sector, especially for large scale project implementation where a drone can make the process more efficient and cost-effective [21]. Monitoring large construction sites is one of the most difficult aspects of construction project management. Each stage of a construction project has its own key monitoring areas. Project managers must monitor the work of field workers as they dig in the ground to lay the foundation. Project managers must monitor field workers who are working on scaffolding during the stage of ground construction.

Compared to other sectors, the industry has been slow in embracing new digital technologies, even though the long-term benefits are significant. For this, the commercial drones—or unmanned aerial vehicles (UAVs) are the best option.

Figure 4. Drones utilized in construction.

Builders use drones to collect real-time data about projects and understand what's happening on site. Aerial insights can improve progress tracking and catch problems early before they become costly or delay a project's schedule. Using a specially developed software (DroneDeploy) makes it simple to plan, communicate and keep projects on track with this information. Drones can help in aerial survey, mapping topography, the drone imagery outputs being very diversified:

- Orthophotos and orthomosaics.
- Point clouds.
- Digital terrain models (DTMs), and digital surface models (DSMs).
- 3D models.
- Raw images.

These imagery outputs have different advantages and functions all of them being described in the table below.

1	**Orthophotos and orthomosaic**	Post-processing corrects image distortion and stitches them together to create an orthomosaic map. Each pixel can be used to obtain precise measurements such as distances and surfaces. These can be used to overlay plans and projected designs to track site progress.
2	**Point clouds**	Drone images can create a dense point cloud. Each point has colour and geospatial information (X, Y, Z). It is a highly accurate model of distance, area, and volume
3	**Digital terrain models (DTMs) and digital surface models (DSMs)**	Each pixel in DSM and DTM models contains 2D information (X and Y) as well as the altitude (Z) at the highest point. These models can be used, for example, to determine which area of the site is susceptible to flooding from water or to hire a contractor who will flatten the earth.
4	**3D models**	The 3D textured mesh reproduces the edges, faces, and texture of the area that was shot by the drone. This model is best used for visual inspection, or when public input or external stakeholder involvement is essential.
5	**Raw images**	Raw images are not processed and offer a greater level of detail, which can prove very helpful for asset inspection and analysis.

Table 1. Imagery outputs of drones.

Drones also have a very quick effect on the construction industry, especially in the operations sector. Companies are aware of the advantages that come along with the utilisation of drones, even though in Romania we are still in an incipient stage. These companies are open to adapt and change their way of work, drones being able to ease thair work: help them coordinate their teams better, track progress more frequently, and complete projects more quickly with less waste.

Drones are used globally (and start to present potential also in Romania) in the following ways:

- Pre-Planning.
- Keeping the Client in the Loop.
- Safety.
- Progress Monitoring to Improve Efficiency and Avoid Wasting.
- Monitoring Productivity and Accountability On-Site.

1	**Pre-Planning**	Construction companies can use drone data to get visual data of the entire site before they start construction. These pre-planning data may show drainage areas, elevation changes, and other factors that could help you decide the best locations to build, dig stockpile, or store materials. If a map made with data shows that an area is in floodplains, it's likely not the best location to build. Pre-planning can also use drone data to help architects and designers see how a new building will look next to an existing building. This allows them to understand the impact of the new project on the surrounding area, both from a practical and aesthetic viewpoint.
2	**Keeping the Client in the Loop**	Clients can get detailed reports in real-time on the progress of things on-site using photos, videos, 3D models, and orthomosaic maps made with drone data. Clients would need to visit a site to get visual data. Or they could hire a helicopter for prohibitively expensive aerial photos or video. They can receive regular reports, which are easy to send because of the low cost of collecting visual data from a drone at a construction site.
3	**Safety**	Drones are affordable for collecting visual data, and construction companies can use drones to perform aerial surveys more often. This data can help them keep track of changes that could affect safety. The visual data from regular drone surveys assist in on-demand (could be daily, weekly) operational planning. Drones can also safely survey dangerous

		locations, reducing workplace accidents and increasing job site safety.
4	**Progress Monitoring to Improve Efficiency and Avoid Wasting**	You can create maps using drone data and send them to your project manager. They can then plan and monitor progress and help you avoid delays that could lead to the project over budget. Drone imaging can show crane locations, erection sequences, and perimeter security. These sequences can also be viewed frequently to identify areas where projects are getting delayed or congested.
5	**Monitoring Productivity and Accountability On-Site**	Project managers can use maps of construction sit created using aerial data to help them monitor their crew's productivity. These maps can be used for identifying equipment and machinery that is missing or left in an unsuitable area. They can also help managers identify areas they may need to investigate to determine why work isn't progressing as fast as expected.

Table 2. Advantages of drones in construction.

Drones can do much more than improve communication and keep projects on schedule. Drones can also be used to increase safety, speed up surveying and provide exact measurements. To find out how drones are used on job sites, we surveyed construction customers.

There has been an increased demand for greater accurate data as construction companies use drones to collect aerial data. Today, companies use ground control points (GCPs) — ground markers measured with GPS to calculate absolute global positioning — more than ever with DroneDeploy. GCPs processed 5X more maps in 2017 and are currently growing at 20% per month.

The trials and increasing use of drones are becoming more common and, as the studies show, drones could have a significant impact on many areas of practice in the future. Digital data is increasingly being used this technology being expected to revolutionize not only the way the industry works but also the business and reporting processes. In addition, the development of integrated systems offers exciting opportunities for the construction site. Regulating use and register process are still developing.

Drones are changing the construction industry in ways that will transform how buildings are built and this is a potential that Romania is becoming more aware of

Thermography

Infrared thermography (IRT), thermal video and/or thermal imaging, is a process where a thermal camera captures and creates an image of an object by using infrared radiation emitted from the object in a process, which are examples of infrared imaging science. Thermographic cameras usually detect radiation in the long-infrared range of the electromagnetic spectrum (roughly 9,000–14,000 nanometres or 9–14 µm) and produce images of that radiation, called thermograms.

It has multiple applications in different fields but in the construction industry it is mainly used for:

- Low slope and flat roofing inspections.
- Building diagnostics including building envelope inspections, moisture inspections, and energy losses in buildings.
- Thermal mapping.

Infrared thermography has applications in assessment of properties of building materials and structures in civil engineering and construction. In this generation, equal importance is given for both building construction study as well as building evaluation studies. This has led to much sophisticated, but accurate methods to evaluate the present structural condition of the building, to save it for the future. Infrared Thermography is such a great innovation which help in the investigation of what condition the building is in and guide in damage fixing.

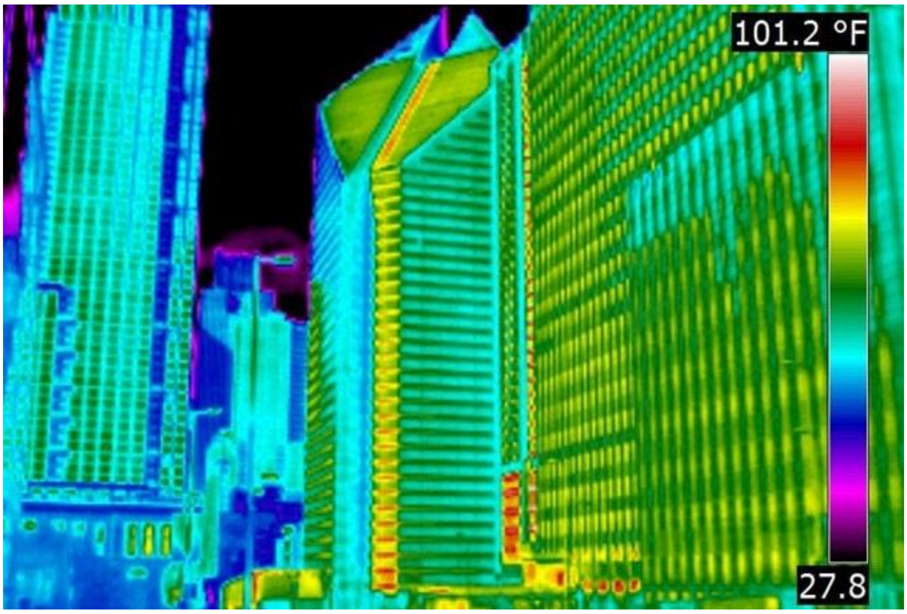


Figure 5. Thermography – a non-destructive method for building assessment.

In Romania due to legislative changes and EU Directives that aim energy efficiency of the built environment, starting with 2010, thermography has been mainly used as a tool for evaluating the level of thermal efficiency of the new building stock.

Thermography in constructions or infrared thermal imaging of buildings is useful for determining the following deficiencies encountered in buildings:

- Determination of areas with high heat loss, due to improper insulation of the tire (identification of thermal bridges).
- Visualization of large infiltrations of external air (old carpentry).
- Clogged pipes can be seen.
- Electrical problems of various equipment [23].

Thus, the thermal imaging for different office buildings in Bucharest, as shown by a rehabilitated and unhabilitated block and for the People's House situated in the capital of Romania, Bucharest.

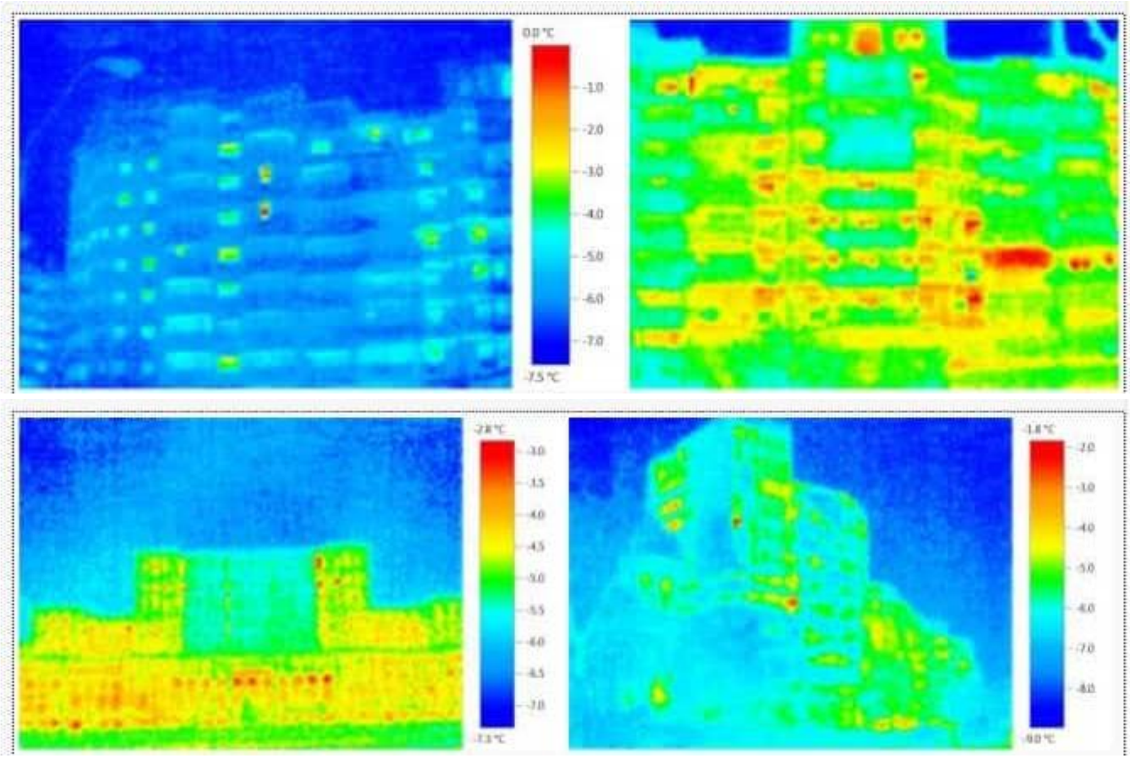


Figure 6. Thermography – examples from Bucharest.

3D laser scanner

When it comes to engineering and building construction, the key to success is accuracy. Architects, engineers, and construction teams need accurate plans to start from and detailed reviews as they go along to make sure everything works the way that it should. 3D laser scanning in construction provides that level of detail and control.

3D laser scanning works by using a laser to shoot a beam of light out into an area and measuring the beam as it is reflected off objects. Scanners do this thousands of times per minute with small changes in the angle of the laser. The result is a map of laser point measurements called a point cloud.

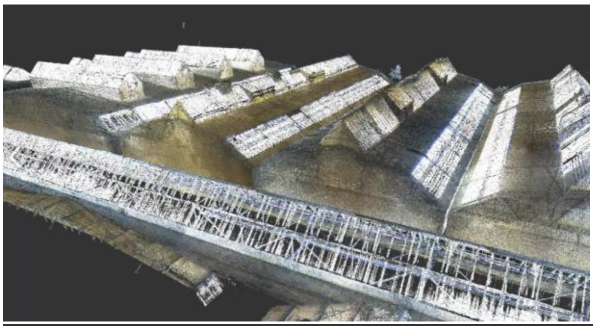
Programs like Autodesk let engineers share 3D scans using cloud systems. That way, whole teams can work on the same document at the same time. From marking important items in a scan to leaving notes for the team, the ways to edit a document are seemingly endless. With high-quality scans and easily managed collaboration, construction companies have everything they need to improve project outcomes.

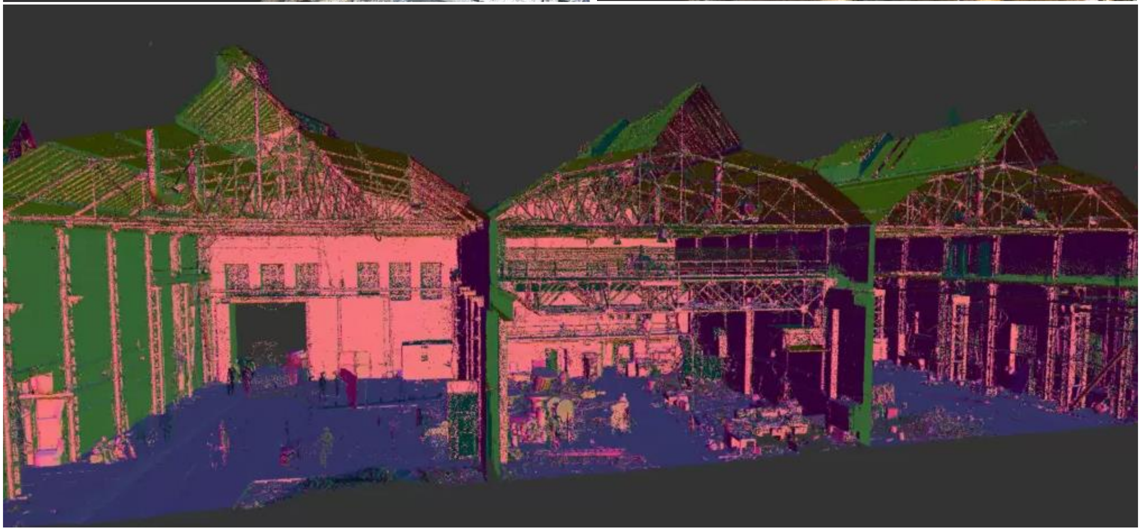
Most small to medium-sized 3D scanners can be mounted on drones. This offers users the possibility to fly the drone to the survey location and complete a scan. If we need to scan a bridge or a site with a lot of difficult terrains, sending a drone is much safer than sending human resource. There are also drones that have a 3D scanner-built in. 3D scanning can directly be linked with the modelling, the scanning process generating as a result a series of point measurements that form a point cloud. Based on this point cloud, architects and engineers can generate an accurate 2D and 3D plan of the construction/project.

In the last 10 years, 3D scanning in the construction sector has developed rapidly in Romania. In this moment there are several companies that offer this service, 3D scanning being directly linked also to topography, BIM (Building Information Model), on-site survey of old/new building [23].

The case study below shows an industrial building, GRIRO situated in Bucharest. The scope of the 3D scanning was to obtain all elevations, horizontal and vertical sections of the industrial hall. This employed a necessity of a clear workflow containing the following steps:

- Taking over the site located in Bucharest.
- Establishing the positioning of the scanning stations as well as the resolution used according to the degree of detail required by the design theme.
- The binding of the previously positioned stations was carried out on the basis of the scanned common plans (the common plans are represented by: floor, ceiling, partition walls). A total of 255 3D laser scanning stations were realized.
- Point cloud registry was performed with Trimble RealWorks with a general deviation of 1.88 mm (overall cloud-to-cloud error).
- Extraction of facades, vertical and horizontal sections of the point cloud with the help of AutoCAD software.





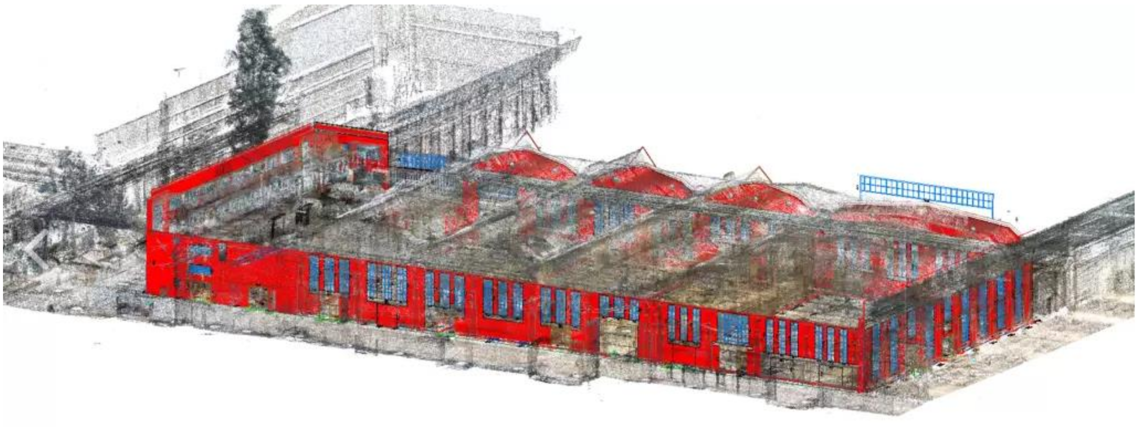
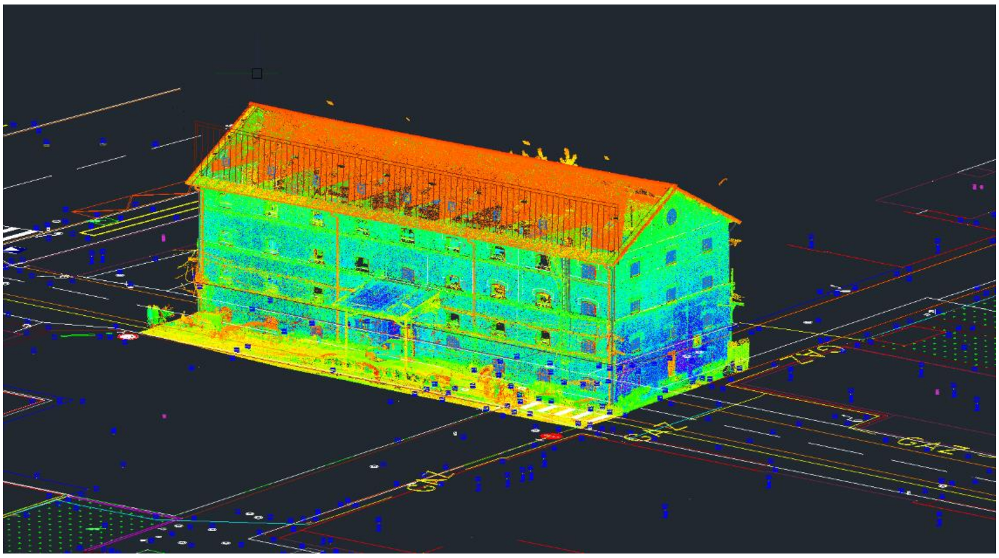


Figure 7. 3D scanning of an industrial building from Bucharest.

Another example can be found also in the industrial building stock, situated in Plevnei area in Bucharest. In this case, to the 3D scanning also thermal scanning was added.



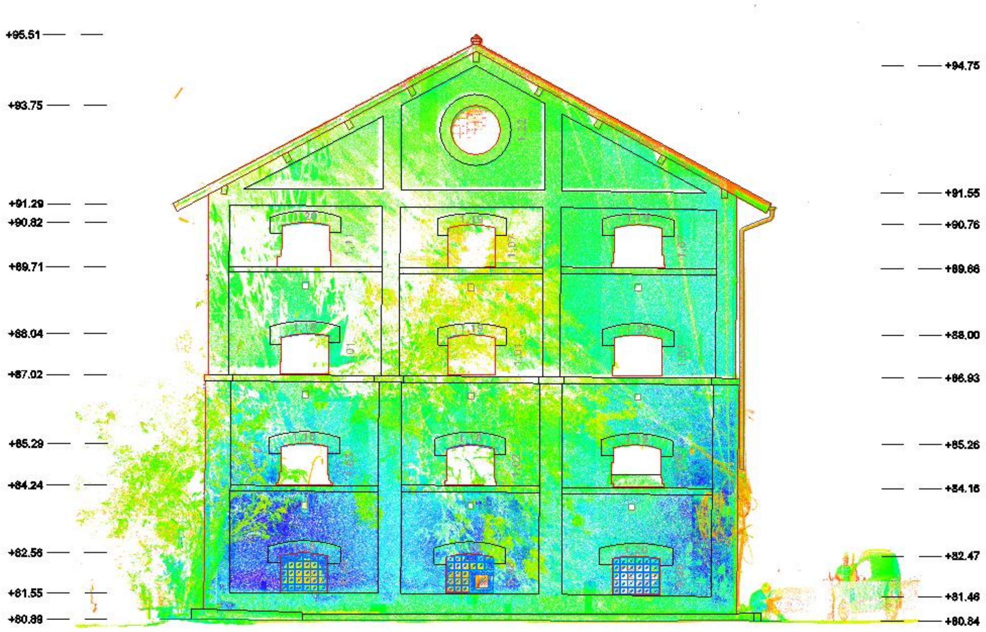


Figure 8. 3D and thermal scanning of an industrial building from Bucharest.

The workflow for this project was conducted in the field and then continued in the office and had the following phases:

- Taking over the site located in Bucharest.
- Establishing the positioning of the scanning stations as well as the resolution used according to the degree of detail required by the design theme.
- The binding of the previously positioned stations was carried out based on the scanned common plans (the common plans are represented by floor, ceiling, partition walls). A total of 18 3D laser scanning stations were made.
- The point cloud registry was made with the Trimble RealWorks program having a general deviation of 2.45 mm (overall cloud-to-cloud error).
- Extraction of facades from the point cloud with the help of AutoCAD.

Photogrammetry

Photogrammetry is the science and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring and interpreting photographic images and patterns of electromagnetic radiant imagery and other phenomena.

Photogrammetry is used in fields such as topographic mapping, architecture, engineering, manufacturing, quality control, police investigation, cultural heritage, and geology. Archaeologists use it to quickly produce plans of large or complex sites, and

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meteorologists use it to determine the wind speed of tornados when objective weather data cannot be obtained.

Most common applications are in the field of archaeology, mapping and 3D modelling. A somewhat similar application is the scanning of objects to automatically make 3D models of them. Since photogrammetry relies on images, there are physical limitations when those images are of an object that has dark, shiny or clear surfaces. In those cases, the produced model often still contains gaps, so additional clean-up with software like MeshLab, netfabb or MeshMixer is often still necessary. For example, Google Earth uses photogrammetry to create 3D imagery.

Photogrammetry can be efficiently used in the workflow of architects, designers and engineers.

Site planning relies on thorough measurements to create an accurate design. By stitching maps together in 3D renderings, photogrammetry can help architects understand the area before building. Having a clear, accurate rendering will help decide important design elements before the design phase.

In the **design decision** process making some common decisions include building orientation, size, and general layout. These decisions are made much simpler when designed in an accurate visual rendering. Architects have room to try new things and experiment with different ideas in a safe virtual space.

In the **construction process** a visual rendering of the building design is useful not only during the design process but also after construction. Monitoring the construction process is easier when there is a clear reference that is easy to follow visually. The construction progress can be seen in real-time with the help of architectural photogrammetry software.

In the same time, visual renderings are a valuable asset in **marketing** and promotional tools. When selling large projects or attracting investors, a visual rendering is a great asset. By telling the story of the project through a visual rendering, it’s much easier to sell the idea of a place! Photogrammetry software can even add realistic environments to surround a building or project, which can help create a clear vision of a space that isn’t yet completed.

Regarding construction in Romania, this process has been utilised in the last 5 years and has potential to develop very rapidly. By photogrammetry and aerial photogrammetry, one can measure, determine metrically and represent graphically and photographically, portions of the earth's surface or other objectives of interest. The method of aerial photogrammetry with the help of drone can be seen as a supplement or as a replacement for terrestrial photogrammetry and annex domains such as topography or cadastre.

The example below shows how photogrammetry with the help of a drone, 3D scanning, identification of cloud points can offer a very precise and good result regarding the built environment.

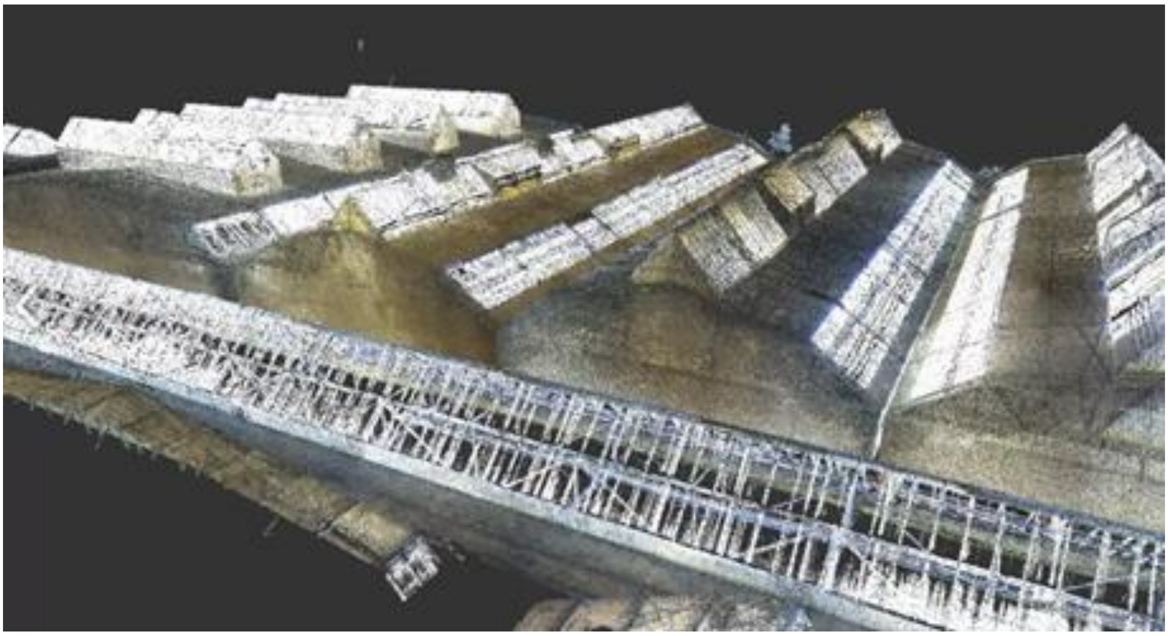

Figure 9. Photogrammetry and 3D scanning of an industrial building from Bucharest.

The drone, having the capability to make an automatic flight according to a well-defined flight plan based on GPS coordinates, makes a succession of aerial photographs. These will subsequently, by processing images with specialized software, maps and topographical plans of some areas, 3D digital models of buildings, 3D digital models of land surfaces, etc. will be made.

Cloud points

A point cloud is a set of data points in space. The points may represent a 3D shape or object. Each point position has its set of Cartesian coordinates (X, Y, Z). Point clouds are generally produced by 3D scanners or by photogrammetry software, which measure many points on the external surfaces of objects around them.

As the output of 3D scanning processes, point clouds are used for many purposes, including to create 3D CAD models for manufactured parts, for metrology and quality inspection, and for a multitude of visualization, animation, rendering and mass customization applications [24].

Point clouds are closely linked to BIM. In Romania this type of activity and approach has gained territory in the last decade. The latest development the Point cloud is one system for making a BIM from a present building. Through laser advancement, it is conceivable to survey the spaces in a present building to make a robotized "cloud" of geometrical center hobbies. Most of this information can then be utilized to convey the geometry of the building. This is then transported in into a BIM-empowered CAD group and the materials are perceived.

The expense of a point cloud review is in barely a second generally the same as a customary 2D study. It is essentially correct and makes a 3D model from which inconceivable 2D "cuts" can be taken. There are specialized firms in Romania that offer this kind of support on-site.

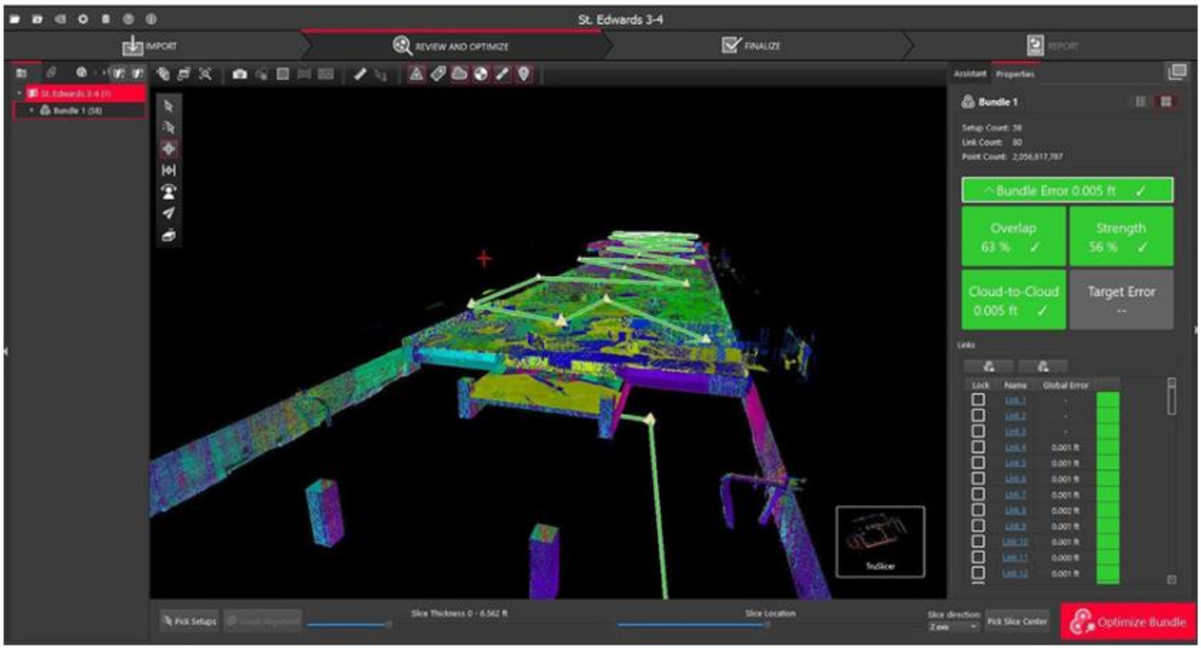

Figure 10. Point clouds provide accurate data for a high-productivity approach to building construction. Image from Leica Cyclone REGISTER 360 software, courtesy of Lydig Construction [25].

Models generated from point cloud data can be used for the following (also in use in Romania):

- Visual documentation.
- Inspection and verification.
- Construction remodeling.
- BIM.
- Engineering and design.

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- Retrofitting, re-engineering and reverse engineering.
- Animation and effects.

Point cloud technology integrates with BIM and other forms of computer models without any trouble. It provides the ability to replicate a 3D physical asset into a digital format and augment the existing digital models.

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