HANDBOOK

# 3D AND MODERN TECHNOLOGIES IN THE PRESERVATION AND MANAGEMENT OF CULTURAL HERITAGE

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# 1 INTRODUCTION

**Hanna Geiran, Director of the Norwegian Directorate for Cultural Heritage**

Documentation is a cornerstone of cultural heritage management and research, and new technology is providing us with increasingly efficient and sophisticated ways of documenting and learning about cultural heritage. This development poses fantastic opportunities, but also several challenges. Choosing the right technology for the right task can be challenging and requires awareness of the purpose of the data gathering.

Documentation is a prerequisite for managing and preserving cultural heritage. Objects, buildings and sites may face threats such as climate change, uncontrolled urbanisation, armed conflict, and general wear over time, and documentation acts as a safeguard, ensuring that knowledge about cultural heritage can be accessed by future scholars and communities. Digital records and photographic archives are vital in creating a comprehensive repository of cultural heritage. In addition to providing a foundation for academic research, it can ease surveillance of cultural heritage, help guide maintenance and restoration efforts, and even be a blueprint for reconstructions.

Good documentation practice is not only a matter of collecting information, but of getting the right level of detail to solve the problem at hand. By using new documentation technologies, we can generate detailed models of objects and places with extreme accuracy and resolution. However, detailed documentation requires large amounts of data, with related safety and security concerns. The data can be difficult and costly to store, and it may be cumbersome to access and use for the owners of the data.

There is a wide variety of tools available, using technology with different levels of sophistication, and most often requiring specialised skills. For owners and managers of cultural heritage, it can be challenging to manoeuvre in an ever-changing landscape of new documentation technologies. This handbook is meant as a guide, with a structured and cohesive description of relevant documentation practices. It presents the various tools accessible to us, how they function on a technical level, and in which situations they ought to be used. Our aim is that the hanbook will help actors in the cultural heritage field to make better decisions on the choice of documentation technologies and improve safeguarding of cultural heritage for future generations.

# 2 | PURPOSE AND TASKS OF THE HANDBOOK

For as long as we know, humanity has always tried to preserve historical evidence and items of historic value, preserving this foundation of its identity for future generations.
The forms and methods used to document cultural historic heritage have evolved over time. From stone tablets and cave art to digital data today.
At this time, we are witnessing rapid advances in technology that make documenting and surveying cultural historic heritage a more accessible and multi-faceted activity. The surveying of heritage objects involves various devices and methods that deliver precise results of many different types.
The target audience of this handbook includes those whose daily life is not closely associated with digitising and surveying heritage objects, and who may be somewhat lost in the extensive range of features that technology offers when it comes to making a decision about surveying a particular object.

The purpose of this handbook is to introduce its readers to the types of cultural historic heritage and the methods that can be used to survey it, and to choosing the best-suited methods and technologies in each particular case.

**TASKS:**
- build the reader's understanding of the variety of objects and appropriate surveying methods;
- educate the reader in modern surveying methods;
- create an understanding of the use of various methods and the associated quality risks;
- provide clear guidelines for quality and deliverables requirements, as well as regarding the choice of methods;
- explain the principles for secure long-term storage of data;
- present the current experience in the field of surveying cultural heritage objects in Latvia and Norway.

# 3 OVERVIEW OF CULTURAL HISTORIC HERITAGE SURVEYING

**Dr. Arch. Juris Dambis**

The documenting of items of cultural value has been evolving throughout the world since the earliest attempts to preserve cultural heritage: from its beginnings with the collection of very little information and precision not being a major concern, to today, with vast amounts of information and a capacity for precision that is still to be fathomed. Although the amount of information included in the oldest materials describing and depicting cultural heritage is small, they are of great importance for the discovery and restoration of items of cultural value.


Panorama of Riga, 1650, J.C. Brotze.

Today, the work for the protection of tangible cultural heritage, as it is done by professionals, cannot be imagined without the comprehensive identification and precise recording of such items. The documenting of cultural heritage has become a continuous process that produces appropriate and timely information to enable the monitoring, maintenance, and understanding of cultural historic assets. Documenting is both a product, in the form of a collection of materials, and an activity that generates information for the monitoring and restoration of heritage. This work produces accessible tangible and intangible resources in

the form of information that records, measures, discusses, and thematically describes cultural historic assets and their state of preservation.
The field of preservation of tangible cultural heritage focuses on the use of traditional materials, technologies, methods, techniques, old tools and craftsmanship. In identifying such assets today, it is not enough to be interested in the history of a particular cultural heritage object, its appearance, structure, and layout. Every detail, surface texture, signs of use of tools by the craftsman, deformations, wear, extent and nature of damage are becoming more and more important.
In order to better understand and successfully use the modern technologies of today in documenting tangible cultural heritage, it is first necessary to remember the traditional methods used in the 20th century. The type, extent, and precision of the documenting of built heritage depended on the goal it was intended to achieve. The most common goals were as follows:

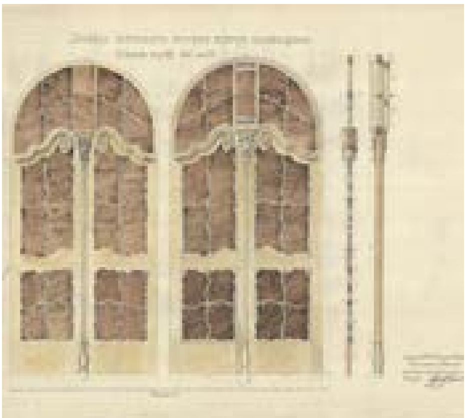
**1. General identification of cultural historic assets.** The objects were usually mapped, described, their overall appearance from the outside sketched and planned, as well as the most valuable details. In the second half of the 20th century, sketches were mostly replaced with photographic records.

**2. Identification and documenting of the cultural heritage site for its inclusion in a list of protected cultural heritage objects.** The scope and type of such documenting was chosen by the specialists of the respective cultural heritage institution; later, it was determined by laws and regulations. The record documentation for cultural heritage objects usually consisted of basic information about the location, origin, date, cultural and historical significance, state of preservation of the object, including graphic and photographic information describing the substance of the object with as much precision as possible.

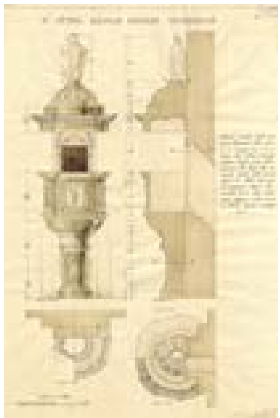
**3. Documenting of the state of preservation of the cultural heritage object through monitoring.** The type, extent, and precision of such documenting was based on the potential threats to the object, as well as modifications or damage to it. The documenting was usually in the form of a detailed description, accompanied by descriptive sketches, measurements, and photographs. Also often used were monitoring measures involving very precise measurements of the deformation of structures.

**4. Documenting and recording the cultural heritage object for the purpose of its restoration or controlled modification**. This has always been the most challenging way of documenting cultural heritage objects, aiming to gain the most complete information and the highest possible level of precision. The information is necessary for an in-depth understanding of the assets, for preparing the documentation for the planned work, and to monitor the progress and quality of the work.

In Latvia, active collection of information about cultural heritage objects began with the establishment of the Monuments Administration in 1923, whereas intensive surveying began in the second half of the last century, still preserving the approaches developed during the first period of independent Latvia. The extensive architectural heritage surveys carried out are remarkable for the scope and quality of the information they contain, as well as a high level of professionalism, and looking at them today reveals the mood and artistic value of the depictions of the respective assets in them. These professional drawings demonstrate the passion and love of the people recording the assets several decades ago for Latvia's manors, castles, and churches, who paid attention to even the smallest details. Conducting an accurate survey requires a careful field survey of the object using relatively simple methods and tools. Geodetic instruments were widely used for topographic surveys, with tape measures, measuring rods, plumb lines, and levels, as well as, later, photographic equipment, used in the surveys of buildings. Once the measurements were taken, the survey documentation was set up based on the notes and sketches, with an object layout plan, relatively precise floor plans, cross-sections, facades, and detail drawings. Surveying an architectural object was a labour-intensive

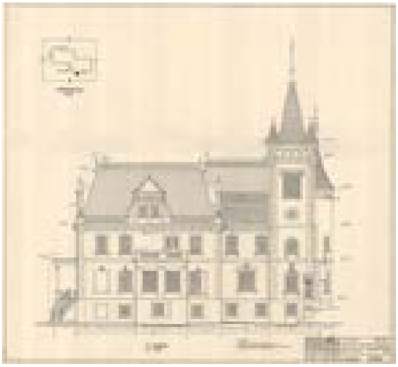


Measurement of internal glazed double doors, M. Smilšu Street 8, 1948. NHB collection.

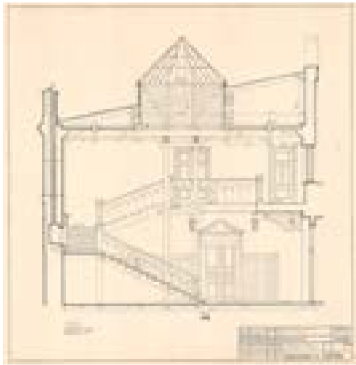


St. Peter's Church pulpit measurement. NHB collection

Survey of the southern facade of the Priedes pub, Open-Air Museum. NHB collection.



Survey of the facade of the Stāmeriena Palace, 1985. NHB collection



Stāmeriena Castle survey, section 1985. NHB collection

process, and areas that could not be accessed in the field were sketched in keeping with the proportions of the structure and its details. Thanks to the historical documentation materials, we can today achieve much higher quality in the restoration of architectural heritage sites.

The restoration of built heritage today cannot be imagined without a careful study of the object itself, without surveying and recording the object layout plan, recording facades, cross-sections, structures, and every detail, gaining more and more precise data on the substance of the object, its volume, form, colour, and material quality.

In our age of modern technology, new opportunities arise for obtaining precise information about the shape, colour, surface texture, layout, and structure, as well as the finest of deformations and lost pieces in a cultural heritage object, without even touching it. This information opens up new opportunities for better identification, understanding, restoration, and monitoring of cultural historic assets.

# 4 CURRENT EXPERIENCE USING LATEST 3D TECHNOLOGY IN MANAGING AND RESEARCHING CULTURAL HERITAGE IN NORWAY AND LATVIA

## EXPERIENCE OF USING THE LATEST 3D TECHNOLOGIES IN CULTURAL HERITAGE MANAGEMENT AND RESEARCH IN NORWAY

**Kristian Løseth**

When I studied archaeology some 20-25 years ago, we learned the trade of documentation using measuring tape, pencil and paper. Even photography was still having its final analogue moments. Total stations and GPS were just starting to become common in excavations and field survey. Some early adopters documented the micro topography of archaeological sites by painstakingly measuring each 10 cm of the site with a total station and using these points to construct a 3D model. My first experience with remote sensing was during a historically dry summer in Central Norway. We rented a helicopter and photographed crop marks while leaning out the side door.

Aerial photo showing traces of ancient structures in a meadow, Trøndelag.
Photo: Lars Forseth

Now that analogue cameras are a faint memory, digital methods are widely used in archaeological field work, and you can buy a drone for aerial photography that costs less than an hour of helicopter time. And you can make a 3D model of an archaeological site quite effortlessly using photogrammetry. Even ground penetrating radar has made a considerable impact on Norwegian archaeology.
The field of cultural heritage research and management is inherently interdisciplinary. There is a long tradition of using methods from other disciplines. In Norway, the heritage sector has been quite eager to adopt new methods of documentation. 3D models are routinely used in archaeological field work, both to support the excavation process, to document the site itself and to create models that can be shared with the public. The Museum of Cultural History has made a portal for their 3D data at https://3d.unimus.no/. Here we can examine 3D models from both archaeological sites and artefacts. A notable use of 3D scanning in Norwegian archaeology is the Saving Oseberg project, which aims to document some of the most important finds from the Norwegian Viking Age that are in a bad state of preservation due to outdated conservation methods.


3D model of a shipwreck,
Norwegian Maritime Museum collection

The Norwegian Maritime Museum has exciting projects that show how 3D documentation can be used to increase the knowledge gained from archaeological excavations. Urban development on Oslo's waterfront has yielded many ships and boats from the old harbour. These finds are 3D-documented, not only to preserve data about the finds, but also to digitally reconstruct the boats to gain more knowledge about their function and capacities. Two of the finds are also reconstructed in full scale, giving both researchers and the public an opportunity to sail 16th century boats in the Oslo fjord.
3D documentation has provided new and exciting possibilities for buildings and ruins in Norway. At Riksantikvaren, we have a project on the conservation of our medieval ruins that started in 2006. Digital documentation has been a central part of this project since the very beginning and has several functions. It serves as a basis for the conservators, masons and craftsmen working to preserve the ruins. In addition to this, it is used for public outreach and to show the effects of conservation. But there are challenges with the data that have not yet been dealt with, especially considering data management. This is a recurring theme in discussions regarding 3D data in Norwegian cultural heritage institutions and will probably be a big issue in the years to come.
Norwegian underwater archaeology has a long history of innovative use of technology. There are several reasons for this. One is that our underwater topography is equally as spectacular as that which can be seen above water. This means that a lot of our underwater archaeological sites are too deep for ordinary diving. Also, having divers underwater is expensive and the amount of time they spend underwater is limited. Furthermore, Norway being a country with extensive offshore industry, there was early use of subsea technology in maritime archaeology. Now, some of the advanced equipment is becoming more available and within reach for institutions responsible for underwater cultural heritage. Today, both side-scan sonars and remotely operated vehicles (ROV) are everyday tools of marine archaeologists. In addition to this there is research being undertaken at NTNU Applied Underwater Robotics Laboratory on the scientific use of subsea equipment. Here they are shaping the future of archaeological applications of underwater technology.
As we reap the benefits of these new technologies, several challenges present themselves. Most of these methods of documentation result in large amounts of data. The data comes in a large variety of formats and these often require specialised software to open, edit and analyse them. Both storage capacity and proprietary software

usually come at a high cost. Usability and reusability are severely limited if data is not managed in a proper way. The FAIR principles for data management and stewardship are gaining popularity in the cultural heritage sector. To make data Findable, Accessible, Interoperable and Reusable is a good and future-proof way to handle our data, but it also places demands on resources. In Norway, there are national systems for certain kinds of data, e.g. information on heritage sites (Askeladden) and artefacts from university museums (Unimus). But data from 3D scanning/photogrammetry, ground penetrating radar, sonar and other types of documentation are handled in very different ways, depending on the resources available. At present, this is one of the big discussions in Norway – how do we store data and make it available in a sensible way within realistic budgets?

Another discussion concerns what the future will bring. All the technologies in this handbook are developing rapidly and new technologies are emerging. At the time of writing, artificial intelligence is the hot topic throughout society. Machine learning methods for detecting archaeological sites have been tested with varying degrees of success in Norway and other countries. There are also projects that use AI for artifact analysis and reconstruction. TexRec, a project by the Museum of Cultural History and Colourlab at NTNU Gjøvik, aims at reconstructing and interpreting the extremely fragile tapestries from the Oseberg find. These are examples of research that can be supported by digital documentation and AI. Now, we are seeing AI providing use cases for solving real world problems. The years to come will be exciting times for the cultural heritage sector.

In conclusion, the new technologies have given us a wealth of new possibilities in documenting cultural heritage, for management, conservation, research and outreach to the public. There are exciting research projects going on for the adaptation of new methods and there are technologies available in other sectors that can be made available for documentation of cultural heritage. Also, some technologies are becoming cheaper and more accessible for non-experts. We are becoming more adept at asking why we must use advanced methods of documentation. There is no need to collect huge amounts of data if there is no practical use for it. What is needed in the years to come is a more robust approach to data management. I am sure this handbook will be an excellent resource for anyone looking for information on new ways to document cultural heritage, and those looking for guidance on managing the data from these methods.

# USE OF THE LATEST 3D TECHNOLOGY IN MANAGING AND RESEARCHING CULTURAL HERITAGE IN LATVIA: NATIONAL HERITAGE BOARD EXPERIENCE

**Simona Čevere**

Cultural heritage cannot be protected without documenting assets, objects, locations, and events. The beginnings of cultural heritage research in Latvia date back to 1818, when the Kurzeme Literature and Art Society founded the Kurzeme Provincial Museum. The Baltic German intelligentsia was the primary driver in the activities for the identification and preservation of old artefacts. Public interest in the presentation of cultural historic landscapes grew, which is confirmed by the invaluable work of Johann Christoph Brotze in documenting cultural heritage. His drawings and descriptions of objects and sites of cultural historic significance are still an important source for researchers.

The year 2023 was the centenary of Latvia's cultural heritage protection system: the Law on the Protection of Monuments was adopted, and the Monuments Administration was established in 1923. Active gathering of information about potential cultural heritage sites began back then, in the form of photographs, surveys, drawings, and notes. The documenting of cultural heritage sites continued during the Soviet occupation. The archives of the National Heritage Board (NHB) contain an excellent collection of some 16,000 survey units. These include detailed pencil or ink, sometimes coloured, drawings of cultural heritage sites, their fragments, details, and individual objects, made on the basis of the technologies available at the time, some of which are of very high artistic value. Even today, these drawings are used in the practical restoration and research of cultural heritage sites.

Dannenšterns house main facade survey, 1945, NHB collection

After the restoration of independence, the State Inspectorate for the Protection of Cultural Heritage Sites (since 2018: the National Heritage Board) continued to identify and document items of cultural heritage.
It is only natural that these documenting activities evolve with the times, with changing techniques and technologies, even though the main purpose of recording cultural assets has remained the same.
In 2014, recognising the importance of documenting cultural heritage, NHB launched a planned survey of cultural heritage sites using modern technology and setting specific goals:

- produce precise documentation of cultural heritage sites, with data on the substance, volume, shape, and material nature of the cultural heritage site that can be used in preserving and restoring it, as input information for producing replica parts and as a basis for developing construction designs;
- accurately document the state of preservation, defects, wear, and deformation of cultural heritage sites for future monitoring;
- obtain cultural heritage site information that is as precise as possible, using non-destructive methods;
- provide government support and set an example to owners of cultural heritage sites, ensuring that they have access to documentation data free of charge;
- present the potential of new technologies in the protection of cultural heritage sites and promote Latvia's cultural heritage among the public.

Surveys of the most endangered and important cultural heritage objects have been conducted every year since 2015, with an average of 12-15 objects surveyed annually, subject to available funding. A total of 198 cultural heritage sites have been surveyed using 3D methods so far.
Given that NHB possesses neither the necessary technical assets (equipment) nor specialists with appropriate qualifications, the survey data are obtained exclusively through outsourced service providers, contracted via public procurement.
When it began procurements for the survey service, NHB did not have sufficient experience and knowledge for defining the requirements and preparing the technical specifications for this purpose, and the results of the first procurement were not as detailed as originally hoped.
However, we must admit that this initial experience has had its value as it has enabled us to substantially improve our quality requirements, taking into account the errors and inaccuracies we committed.
Because 60% of all immovable cultural heritage sites in Latvia are buildings, it is important to choose the survey technologies best suited to the recording of this type of heritage. Looking at the internationally used current and traditional survey methods, NHB chose

three-dimensional laser scanning with a fixed 3D scanner as the main method for documenting built heritage, as it makes it possible to save the most accurate information about these cultural heritage sites. In order to obtain data about an object that are as complete as possible, we combine methods, for example by using photogrammetry to capture parts of roofs and towers, as well as the immediate surroundings, with a drone, or by recording individual details of buildings with a handheld scanner.
A strategic decision was taken as part of our ongoing activities to use our yearly, and not particularly extensive, funding on the surveying as much as we can, gathering data on as many cultural heritage sites as possible, without creating 3D models, as these are very expensive to produce and do not play such a decisive role in the practical process of restoring a cultural heritage site.
In the technical specifications for the surveying of every building or structure, we set the scope of the survey (e.g. external volume of the building, individual indoor spaces, specific details of interior design) and the precision requirements (e.g. the point cloud density of the external volume of the building being at least 10 points per cm2, the survey point 3D precision being at least 2 mm/10 m, the absolute precision of the roof planes survey being up to 50 mm, while for interior details where precise shape and finish techniques are important, the precision of the survey must be 0.1 mm). In addition to that, we typically require facade and roof plane views, building layout plans, flat drawings of interior walls, and cross-sections of architectural details at a set scale, also indicating the main dimensions. For cultural heritage sites in poor technical condition, survey data are often used to analyse the displacement and tilting caused by deformations relative to the original vertical and horizontal axes of the parts and structures of the buildings. Practice shows that repeated laser scanning done at known intervals and compiling the data produced by this method makes it possible to successfully diagnose the progress of the deformations and analyse their causes.

Nereta manor house survey, 2018, NHB collection

Sometimes, an object has not had an owner for a long time and is in poor technical condition, and surveying it feels like hopping onto the last carriage of a departing train, anticipating that soon enough, the data from this survey might represent a cultural heritage object already lost. This makes it all the more satisfying whenever these surveys commissioned by NHB become the basis for the revival of a cultural heritage object, as its new owners successfully use them to restore its lost parts and to plan its restoration and reconstruction.

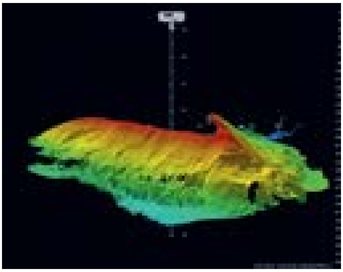
Surveying the art heritage associated with built heritage is often very challenging, too. Because interior decor usually has to be surveyed in churches, the process and results of this work can be affected by the possibility of reaching certain elements of the interior (e.g. large altars, high organ lofts) as well as the material of the object measured. The frequently gilded and otherwise reflective elements often found in churches cause a particular headache here.

A very important and complex group of cultural heritage sites in addition to built heritage is archaeological heritage, and for identifying it, NHB uses indirect, non-destructive, and non-invasive methods: terrain analysis and geophysical methods. The main geophysical method used is the ground-penetrating radar (GPR). The purpose of geophysical studies is to determine the location of ancient structures, burials, or their remains underground in areas where there is no visible aboveground evidence, and to identify other features (remains of buildings, voids) that can be interpreted using GPR data (geometric layout patterns of objects, their depth, dimensions, etc.) in order to predict the actions necessary for the preservation, protection, and future use of the objects.

However, using this research method often means running into problems. One of these is the difficult conditions of the surface of the ground above the archaeological site. For example, there can be tall grass, fallen trees, shrubs, and stones significantly obstructing the process of conducting a high-quality survey across the entire area of the site. The other problem is the interpretation of the data and the need to analyse results during the survey itself and make decisions based on that analysis, such as adjusting the area of the survey. For these reasons, NHB makes it a requirement for an archaeologist to be involved in geophysical surveys of archaeological sites.

So far, the geophysical surveys with the most successful results have been those concerning the presence of burials sites or their remains. In the case of castle ruins, however, the results of the surveys are strongly influenced by the presence of remains of buildings and construction waste in the ground, making it difficult to identify ancient structures.

Given the diversity of cultural heritage sites, the ways in which they are documented can also be fairly different. In 2021, bathymetry was used for the first time as part of a survey, studying the underwater part of Koknese Castle, covering the 10 m zone below the aboveground wall part. The survey revealed areas of coastal corrosion, as well as the subsidence and washing out of soil in the immediate vicinity of the site. This is an excellent example of how modern technology can be used to determine the technical condition of castle ruins and the circumstances that affect their preservation that would not have been visible to the specialists monitoring the cultural heritage objects as part of usual inspections of the object.



Koknese Castle, bathymetry data, 2021, NHB collection

In the future, NHB plans to use bathymetry to detect and investigate items of underwater archaeological heritage, including shipwrecks and lake settlements.

In 2021, looking for new way to take advantage of the capabilities of new technologies, NHB successfully implemented one virtual reconstruction project. Before the Second World War, there was house at Lielā Monētu iela 11 in Riga with a remarkable Mannerist portal of which only one image exists. The building was destroyed during the war, and only a few pieces of the portal remain. Finding the pieces preserved in various places and surveying them in a precise manner made it possible to create a digital replica of the portal: the specialists created its 3D model, reconstructing the portal's historical appearance.

This story had an unexpected sequel, as more fragments of the portal were found in the summer of 2024. NHB surveyed these at the end of that year, with plans that could possibly be added to the model created previously.

A more ambitious plan for the future is to physically reconstruct the collected fragments in one place based on this virtual reconstruction model, and to display them outside.


Preserved portal fragments in their original locations.
3D model of the portal , NHB collection

Given the experience accumulated over these ten years, we conclude that in order for a government institution to achieve a successful result in commissioning a cultural heritage site survey service it needs to take a whole range of measures, with appropriate expertise among its staff. The most important aspects to note:

- clearly identified goals regarding why the object in question needs a high-precision survey;
- well-designed scope and definition of precision parameters for the work aimed at producing high-quality results;
- careful planning of the work, because surveying is affected by weather, lighting, tree foliage, snow, etc.;
- cooperation with the object owner to ensure that the object is prepared if possible (with respect to long grass, tree branches, removing furniture that obstructs an indoor survey, etc.) and accessible during the survey;
- support by competent procurement and legal specialists as part of procurements: NHB has had to deal with quite a few attempts by potential contractors to force it to reduce its quality criteria, disputing technical specifications and tender regulations, deeming them too strict. In these cases, the institution's ability to provide reasoned justifications and wording its requirements in a legally precise manner is critical.
- high-quality verification of data: this means that NHB should have access to a competent specialist capable of assessing them;
- continuous development of knowledge and collaboration with practitioners in the field;
- ensuring long-term storage of data;

- convenient solutions for using, viewing, and distributing data;
- capacity to integrate 3D data in other solutions (e.g. GIS products);
- fostering of more use of the accumulated data in the daily work of NHB (necessary staff training, software);
- ability to use a single source (not only within NHB itself) to obtain information about what objects have been 3D-surveyed, to what extent, with what precision, and what the conditions of use are.

The experience of NHB in the use of 3D technologies for the management and research of cultural heritage has demonstrated its significance and potential. A few projects have been successfully implemented, making it possible not only to document and preserve cultural assets in digital format, but also to improve their accessibility and suitability for research. 3D scanning and modelling have been successfully used to digitise architectural, artistic, and archaeological heritage sites, with better capability for the long-term preservation of cultural heritage, as well as fostering the development of education and tourism.

However, further developments are needed in several areas in order to use the full potential of 3D technology. One of the most important aspects is increasing the funding and human resource capacity, providing specialist training and access to technology for national and municipal institutions. It is also important to promote cooperation among various institutions and scientific centres in order to pursue a single standard and long-term storage strategy for data.

In the future, 3D technologies could become not only a documenting tool, but also the foundation for interactive digital platforms and virtual reality solutions that make it possible for the wider public to access cultural heritage in an innovative and engaging way. More work needs to be done towards integrating artificial intelligence and automated analysis tools to streamline the processing of large datasets and the classification of objects.

Finally, it is worth emphasising that Latvia's use of 3D technology in the field of cultural heritage has been an significant step forward; however, future development calls for a long-term strategy, government support, and international cooperation in order to work towards a sustainable and innovative approach to preserving our cultural assets for future generations.

# 5 | PURPOSE, CLASSIFICATION, AND CAPABILITIES OF SURVEYING CULTURAL HISTORIC HERITAGE

When planning surveying work, it is important to define the purpose of the survey and to plan further activities with the survey data. Setting a precise goal makes it possible to choose the surveying method that is most suited and most effective in achieving it.

**Possible cultural historic heritage activities that require a survey:**

- documenting, recording the actual condition;
- scientific research, analysis of surfaces and cross-sections;
- restoration, restoration of historical condition;
- reconstruction, rebuilding;
- monitoring of preservation status;
- digitisation for presentation online;
- production of scale copies, 3D prints.

The types of objects and survey purposes can vary, and the precision requirements for surveying cultural heritage (cultural heritage objects) are based on the specific nature of the cultural heritage in question and the particular features of the use of modern technologies.

## MEASUREMENT PRECISION LEVELS/CLASSES

**A Ultra-high** precision for very precise surveying, in situations where it is not enough to record the exact shape of the object or part of it, and the work must cover the finest details, engravings, material texture, as well as colour, which usually is relevant for small objects (0.01–0.1 mm).

**B Very high** precision for precise surveying with a high degree of shape accuracy and detail, including the recording of colour and decorative features, highlighting minor damage, wear, deformations (0.1–1.0 mm).

**C High** precision for precise surveying with a high level of shape accuracy for buildings, often with the recording of colour (2–5 mm).

**D Average** precision for surveying with relatively high shape accuracy, sometimes also recording the colour (5–10 mm).

**E Moderate** precision for surveying with relatively high shape accuracy (10–20 mm).

**F Low** precision for surveying larger planes with sufficient shape accuracy (20–50 mm).

**G** **Very low** precision for surveying general geometry or surroundings (50–100 mm).
**R** Structure survey and documenting using a ground-penetrating radar.
**S** Underwater surveys (bathymetry).
The most commonly used survey precision levels are added to the proposed typological breakdown. They are indicated approximately, and in practice one must always check and choose the level that best suits the purpose of the survey and the intended use of the data obtained.

## 5.1 ARCHITECTURAL HERITAGE (BUILT HERITAGE)

Western facade of Nidaros Cathedral. Photo: Anders Amlo, Riksantikvaren/ Directorate for Cultural Heritage Norway

Rundāle Palace entrance gate, NHB collection

### 5. 1.1. Buildings, structures:

1.1.1. external appearance **D**;
1.1.2. facade details **C D**;
1.1.3. layout **D**;
1.1.4. interior finish **C D**;
1.1.5. interior details **B C**;
1.1.6. roof structures **C D**;
1.1.7. underground structures, walls **R**;
1.1.8. utilities and equipment **D R**.

Modern 3D surveying technologies are increasingly used for surveying historical buildings and structures because they generate more precise and diverse survey data and accurately record the condition and deformations of buildings and their parts. The surveying of buildings can encompass all aspects, covering all rooms and facades (including roofs), or focus on individual details. Laser scanning and photogrammetric surveying methods can be combined when measuring the entire volume of a building, with the most important aspect being that, in the deliverables, the survey data are combined in a single point cloud or placed in a single coordinate system. The 3D point cloud is the main dataset on the basis of which the deliverables are then prepared. The most common next steps for a building point cloud are:

- Preparation of 2D CAD drawings and plans (facades, roof and floor plans, cross-sections and longitudinal sections, individual assemblies of the structure);
- Preparation of 3D survey models (parametric models). In the survey models, the elements of the building (walls, slabs, beams, other structures, stairs, windows, doors, plumbing, utilities, etc.) are modelled as individual elements, observing their true geometry and location. Before developing a model, it is important to define the model's level of detail (what elements need to be modelled and in how much detail), which directly affects the cost and the time required;
- The 3D model can also be built as a single surface consisting of triangular polygons (mesh model). A real-life texture based on photographs can be added to a model like this. These models are used for designing lighting and producing project visualisations. The detail of the model is increased by increasing the number of polygons in it;
- 2D wall drawings with characteristic dimensions enclosed;
- analysis and research reports on the deformations and verticality of the structures of the building.

In some cases, where only the facade of a building needs to be surveyed (e.g. for a renovation and lighting project), photogrammetry can be used as an additional survey, with the preparation of a high-resolution 2D orthophoto or 3D surface (mesh) model of the facade.

For projects that call for higher precision in the facade or interior details, it is recommended that these are surveyed separately, adapting the method and resolution to the specific conditions of the object.

### 5.1.2. Urban development objects, historic city centres, building complexes, ensembles:

1.2.1. spatial layout (layout structure, architectural spatial system, arrangement) **G**;

1.2.2. external appearance of the development **F**;

1.2.3. architectural, design, and artistic elements of the environment **C D**;

1.2.4. greenery system **G**.

Røros mining town, Trond Isaksen, Riksantikvaren/Directorate for Cultural Heritage Norway

Kuldīga Old Town, Kuldīga Municipality

Laser scanning and/or aerial photogrammetry (using a drone or helicopter) are generally used for surveying groups of historic buildings and building complexes. If more detailed facade surveys are necessary, they can be supplemented by surveys from the ground, using the same methods. It is important when using different devices to combine the surveys into a single coordinate system so that they are compatible and the corresponding data can be used as a single set. As with buildings, the primary deliverables for larger objects (development areas) are 3D point clouds and 2D orthophotos. Possible further actions with these survey data:

- 3D model of the site with terrain and building volumes at LOD1 or LOD2 level;
- 3D model of the area with real building outlines and textures (mesh model);

Both of these deliverables are to be used in the spatial analysis of sites, especially in relation to new building volumes or those to be demolished, showing how the view of the city will change with the addition of a new building volume, or with the demolition of a building volume.

- 3D digital terrain model (DTM) and surface model (DSM), often used for flood and noise analysis in urban planning;
- 2D orthophoto maps and the resulting 3D data are a valuable source of data for creating or updating topographic maps;
- regular aerial surveys of the area make it possible to effectively monitor changes in the roofs of its buildings. This is especially true in old towns, where, looking from street level, it is difficult to see changes in building volume at roof level;
- mapping of trees and greenery. Modern software can be used to identify tree position, trunk diameter, and crown size based on a point cloud.

### 5.1.3. Cultural historic landscapes:

1.3.1. spatial and landscape development **G**;
1.3.2. external appearance of the development or its elements **F**;
1.3.3. individual architectural, design, or artistic elements **C D**.

Historic landscapes usually are large (spanning several square kilometres) areas, and any surveying of them requires the use of the most effective methods available, such as aerial laser scanning and photogrammetry. The resulting survey data are in the form of a 3D point cloud and a 2D orthophoto map. For large areas, it is critical to perform a 3D point cloud classification. The classification is typically used to distinguish the terrain, structures, roads, and vegetation points, representing them in different colours. In order for a survey to result in terrain data that are as detailed as possible, conducting it during the leaf-free period (early spring or late autumn) is recommended. The best time for the flights is spring, when there are long periods of good flying weather. The primary deliverables are a classified 3D point cloud and an orthophoto of the area. Further actions with these survey data:

- preparation of 2D maps of the area for tourism and recreation;
- 3D model of the area with real outlines and textures (mesh model);
- monitoring of changes in terrain in areas where the sliding of the upper layer of land is observed. Monitoring of riverbed and coast erosion.

## 5.2. ART HERITAGE AND OBJECTS

### 2.1. Immovable art:

2.1.1. paintings, murals **A B**;
2.1.2. interior decor, equipment **B C**;
2.1.3. sculptures, sculptural formations **C**.

### 2.2. Movable art, objects:

2.2.1. art and household objects **A B**;
2.2.2. paintings and drawings **A B**;
2.2.3. printed works, books **A B**;
2.2.4. musical instruments **A B**;
2.2.5. textiles **B**.

Works of art come in many shapes and sizes, from paintings to sculptures, as well as other forms. When documenting them in 3D format, it must be ensured that their aesthetic quality is preserved, an approach which encompasses a precise reproduction of the shape and look of the object. This creates challenges related to complex and detailed geometry, and complicated surface features. The overall appearance of a material is determined by its shape and surface features, such as colour, gloss, texture, and transparency.

Ornate, Alsunga. Photo: L. Skujāne, NHB collection

When measuring an art object in 3D format, its shape and its surface are equally important. 3D-scanning the shape of a small, glossy painted ceramic vase can present completely different challenges than 3D-scanning a large granite statue.
The reflective surface of the vase can become an impediment in surveying it, while the size of the statue can make even accessing it difficult. The choice of surveying method is decisive in achieving the best result possible. It is recommended to consult specialists or try the different methods available to find the best solution. The main result of the survey is a surface (solid, mesh) model of the object, with a real-life texture, as well as a 3D point cloud. The models can later be used:

- to archive the state of the object at the time of the survey;
- for integration in websites and presentation to a wider audience via 3D panorama tools;
- to make 3D prints or other copies;
- to digitally restore, e.g. by modelling missing or damaged parts.

## 5.3. ARCHAEOLOGICAL HERITAGE:

3.1. archaeological sites **F G R**;
3.2. archaeological sites with buildings **D E R**;
3.3. archaeological objects **A B**.

Viking helmet from Gjermundbu
Photo: Ellen C. Holte, KHM

## USE OF MODERN TECHNOLOGY AND METHODS IN TERRESTRIAL ARCHAEOLOGY

### Artjoms Zelenkevičs

Modern archaeology increasingly integrates various technologies for studying underground objects. This significantly increases the precision of cultural heritage research. One of the basic tools actively used in this field is the ground-penetrating radar. However, in order to achieve the best results, GPR data are often combined with other geophysical and digital methods such as laser scanning (LIDAR), photogrammetry, and magnetometry.

GPR can be used to detect underground structures with high precision, although its capability can be enhanced significantly by combining it with other techniques. For example, LIDAR is used to create a highly accurate model of surface topography, helping visualise changes in the landscape, often pointing to such archaeological features as the underground foundations of buildings or hillforts. GPR is then used to examine the objects identified by LIDAR in more detail. This approach makes it possible for researchers not only to see the outline of an object above ground, but also to obtain information about its underground part.

Photogrammetry helps expand GPR data with visual information, producing accurate 3D models of objects. This is especially useful when investigating large archaeological objects or areas with extensive pieces of built structures underground. Photogrammetry can also be used to regularly document excavations, helping record changes taking place over the course of the investigation.

Magnetometry is another important geophysical method that is often combined with GPR. It can detect anomalies in the Earth's magnetic field possibly caused by the presence of objects made of iron or objects with different magnetic permeability. For example, if there are large underground iron artefacts or metal elements of old structures, magnetometry helps locate them, while GPR determines their depth and shape in more detail. In Europe, magnetometry has been used to make many Second World War discoveries.

The integration of data obtained through different methods opens up new possibilities for archaeological research. Combining GPR, LIDAR, and photogrammetry data into a single coordinate system makes it possible to create an all-encompassing map of the area that shows the exact location of its aboveground and underground features. Such maps can be used to plan excavations in a way that reduces the risk of damaging cultural heritage objects to a minimum.

GPR data are also often used to analyse deeper soil layers and identify objects that may be at depths that cannot be reached by other methods. For example, integrating GPR with other technologies, archaeologists can reconstruct a complete picture of an ancient settlement, finding its aboveground structures as well its underground tunnels or burial sites.

# USE OF MODERN TECHNOLOGY AND METHODS IN UNDERWATER ARCHAEOLOGY

**Kaspars Markus Molls**

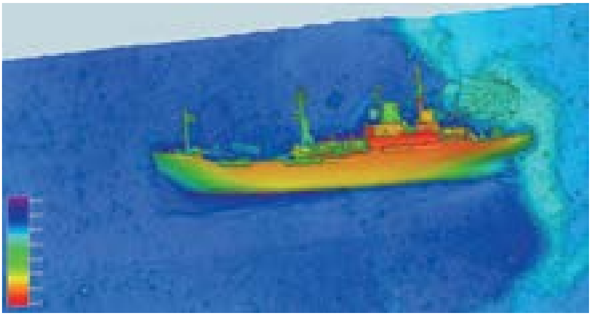
The category of underwater cultural heritage objects can include objects that are terrestrial in nature and have ended up in an underwater environment (ancient burial sites, settlements, buildings, etc.), objects that were built specifically in relation to water infrastructure (harbour sites, bridge foundations, docks, etc.), defensive objects related to bodies of water (lake settlements, castle defences, etc.), as well as shipwrecks, aircraft crashed at sea, etc. and their cargo. These sites are particularly valuable because, unlike the situation with archaeological materials on land, the wet and oxygen-free environment underwater enables good preservation of organic materials over long periods, which is why activities related to the study of underwater cultural heritage sites require particular care.

When organising surveys of underwater objects, it is important to consider different approaches, depending on the goals of the study. In surveying, it is important to arrange for the use of digital technologies that are capable of delivering the necessary precision, so that individual objects or details are not missed during the work. There are three types of study goal in underwater work:

- finding unknown objects within a specific area;
- detailed surveying and documenting of known objects;
- monitoring of cultural heritage objects.

If the goal is to identify new underwater cultural heritage objects or to look for historical objects (e.g. lost shipwrecks) based on archival records, it is typically necessary to survey relatively large underwater spaces using devices that cover as wide an area as possible. In such a case, the objects visible in the measurements can be surveyed at relatively low resolution, making it difficult to identify the object. In these situations, it should be borne in mind that the measurements may need to be repeated to gain more accurate data. The data most important for the identification of large areas are the overall dimensions and outline of the object, with sufficient precision to make the identification of the object possible. The goals of searching for unknown objects are mostly subordinated to projects related to the economic development of marine areas, such as the construction of offshore wind farms, which requires the investigation of the entire wind farm construction area in order to prevent the destruction of important cultural heritage objects during the construction.

When conducting detailed surveys of known objects, the goal generally is to obtain data that are as detailed as possible, covering all aspects of the investigated object. The structural solutions, colour, texture, materials, dimensions of parts and their arrangement in various positions, etc. are recorded in such a case. An important indicator of the quality of a measurement is the consistent use of a single system and describing of the work process, which makes it easier to identify errors and correct them after the study. Research teams mostly perform the detailed documenting task for scientific purposes, in order to obtain new information about the objects, their origin, and their state of preservation. In other cases, researchers do this to document information about objects that will be destroyed or moved due to natural phenomena or economic activity.



FMV Sevan shipwreck survey using a multibeam sonar (author: Latvian Institute of Aquatic Ecology)

Shifting conditions in marine or inland water environments affect underwater objects, which in the field of cultural heritage management is referred to as the site formation process. Regular monitoring of the cultural heritage object is important for following this, in order to understand why the object is in its current condition and state of preservation and to predict what it may look like in the future. If such monitoring takes place, one of the bathymetry methods is the most common approach here, as it can provide the most comprehensive information about change in the site's environment. These methods are often combined with others to obtain more data. For example, once a year a shipwreck is surveyed using a side-scan sonar and visually inspected with an underwater drone. During monitoring, it is critical to detect changes in the environment and their effect on the object, so it is important to choose a method that produces comparable data, such as photographs or depth measurements. Monitoring is usually conducted by cultural heritage management institutions and owners of cultural heritage objects, recording changes and preparing plans for how to best preserve the object in the long run. This type of study is also often used by nature researchers, especially marine biologists who are mainly interested in the habitats located within underwater heritage objects. In most cases, this happens when the object poses an environmental hazard: for example, if there is a military shipwreck with on-board explosives that release harmful chemicals into the water, so it is important to conduct the monitoring in order to determine the effects on fish and other underwater flora and fauna.

The environmental conditions and the depth at which the studied object is located play a key role in the choice of methods and technologies for surveying underwater heritage objects. If the object is at a depth of more than 40 m, it is not possible for humans to manually survey the shipwreck in detail due to water pressure. Using an underwater drone, however, is a suitable survey method in such conditions (this method can also be used in shallow waters). In shallow waters, methods and technologies used in surveying terrestrial cultural heritage sites can often be adapted to underwater surveying, for example:

- photogrammetric surveying of structures and shipwrecks and creation of 3D models using underwater cameras;
- surveying of objects using various GPS measuring devices (in shallow waters), such as a tachymeter;
- scanning with a GPR, placing the device on a boat or other watercraft;
- locating of metal objects using an underwater metal detector.

In addition to these, there are technologies designed specifically for underwater studies. These include bathymetric measurement technologies (sonars), and camera-equipped underwater drones. The choice of methods is rarely based on financial considerations, and is more a result of environmental conditions and the qualifications of the people involved. The technologies and methods used will always be a function of the goals, but the more that different types of technology are available for the study, the wider the range of data that can be used in future research. When conducting any underwater work, the health and safety of people must be a primary concern. It is the measures to ensure safety that account for the bulk of the increase in cost. Although survey-

Underwater camera photographic record of a shipwreck (author: Underwater Cultural Heritage Association)

ing underwater objects does not always require a person to go under water, many methods can be used from a boat or ship, reducing the risks to the safety of the people involved. However, the quality of the data obtained in such a situation does not always meet the goals set. Every method depends on various environmental conditions that need to be taken into account. For example, documenting a shipwreck if there is a water current is likely to be more accurate if it is done by a diver with an underwater camera, capable of paying more attention to manoeuvring and using their senses to gain an awareness of the environment, as opposed to an underwater drone, which does not always have a good enough motor to maintain stability in the current and at best only has one mechanical arm to use for the work. However, in situations where the object is at depths that are difficult or impossible for humans to reach, drones can gather information in much less time and with far fewer resources. The use of drones has become increasingly common in recent years, as technological advances have made the use of more and more diverse methods possible, with not only visual surveys, but also automated photogrammetry, taking of samples, bathymetric measurements, etc. There are two types of underwater drones: remotely operated vehicles (ROV) and automatic underwater vehicles (AUV). ROV are most commonly used for site surveys because they are easy to control from a distance and can reach great depths. For conducting the mapping or photogrammetry of larger areas, AUV are the more typical choice. The route to be surveyed and the task to be performed can be set manually, and then the vehicle can be left to carry out its task without the need for remote control. The industry developing drones is fairly advanced, so there is a lot of choice in terms of technical parameters and operating features. *Deep Trekker, Fugro NV, Chasing,* etc. are some of the best-known manufacturers. In Latvia, underwater drones are made by *Submerge Baltic* and *Eprons ROV.*
Bathymetry measurements almost always require good weather and low wind speeds. The best results can be obtained whenever the wind blows from the coast. Underwater photogrammetry requires good visi-

Surveying and photographic recording of a shipwreck using an underwater drone (author: K. M. Molls) bility under water, and this is affected by weather conditions and underwater fauna. The best conditions for this method are in spring, when the aquatic plants are not yet green. These factors can make the quality of the photographs produced unsuitable for the set goal of the survey.

From a financial point of view, documenting underwater cultural heritage objects is more viable than recovering the object from the water, because if it has spent decades or hundreds of years under water, the object will have to undergo preservation and long-term storage measures once it is raised from the water. Even after preservation measures, a shipwreck pulled from the water will continue to degrade, which is a major challenge in terms of resources and financing. Using technology to document these objects underwater can be a far cheaper task that takes fewer resources.

The choice of survey methods can sometimes be subject to national laws and regulations. For example, in a few European countries and elsewhere in the world it is prohibited to dive and conduct physical investigations of shipwrecks of warships that are recognised as burial sites due to the remains on-board of military personnel. In such a situation, the only way to investigate an object is to use remote-control technologies that do not interfere with the structures of the object. However, they do not always produce the most effective results: for example, bathymetric surveying methods do not provide information about the colours and textures of an object.

Depending on the surveying method, the raw data need to be processed before they can be published or publicly used. If bathymetric measuring devices are used for the work, one needs to learn how to use the appropriate software to process the data, otherwise only point clouds will be available. Since there are different bathymetric measuring devices and the respective software for them, this is covered in more detail in the bathymetric measurement section of Chapter 6.

Images obtained in underwater work usually need to be enhanced using image processing software (e.g. *Adobe Photoshop, Corel PhotoPaint*, etc.), because even under good visibility conditions under water, the water can change the apparent texture and colours of objects. Recently, a few AI-powered underwater image enhancement applications and models have been developed to automate this process(*NVIDIA Jetson AGX Orin, Underwater Image Enhancement Benchmark Dataset and Beyond*, etc.).

The images obtained can be used in a variety of publications and for building photogrammetric 3D models. Given the large number of photographs necessary for a 3D model, making it possible to use automated image enhancement software to process them is the most convenient solution. The principles for building the photogrammetric model of an underwater object are the same as for a terrestrial object (see Chapter 6).

3D model of a shipwreck washed up on a beach (author: M. Kalniņš)

The data obtained can mainly be used for research or for presentations of the underwater world to the public. Given the very small amount of data about underwater cultural heritage, it is good practice to publish everything whenever possible, so that it can be used by researchers around the world, as well as by the public seeking to learn more about mostly inaccessible cultural heritage assets. One of the desirable solutions is to submit the data to the National Heritage Board and the Latvian National Museum of History, thus providing researchers with direct access to the data. The data can also be published on open-access websites such as *Sketchfab* (for 3D models), *Academia.eu, ResearchGate* (for scientific publications), or *Latvijas pilskalni un senvietas* ('Latvia's Hillforts and Ancient Sites', for enthusiasts interested in prehistoric and medieval sites), etc.

## 5.4. INDUSTRIAL HERITAGE

Hakavik, Stig Storheil /NVE

Drabeši windmill.
Photo: E.Šulcs, NHB collection

### 5. 4.1. Movable objects B C.

### 5. 4.2. Immovable objects.

Immovable objects are included in the scope of built heritage.
The range of industrial heritage objects is extensive. Some of the objects are special-purpose buildings with corresponding equipment and machinery: these include hydroelectric power stations and windmills. Others are various types of objects, machine assemblies, and even vehicles. For more on industrial heritage surveying practices, see Chapter 9.

# 6 MODERN SURVEYING METHODS AND TECHNOLOGIES

**Jānis Heinsbergs**

This chapter offers an overview of the survey technologies currently in use, their principles, capabilities, and advantages. In order to accurately choose the surveying method the satisfies your needs, it is essential to understand the range of available technologies and their specific features. The previous chapter discusses the types of objects and the possible necessities associated with surveying them.

## 6.1 HANDHELD AND FIXED CONTACTLESS REFLECTION LIGHT SCANNERS

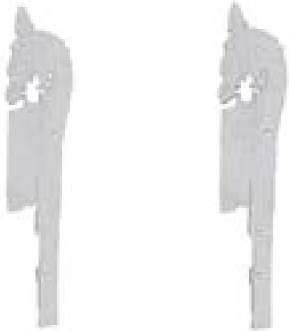
### Operating principle

The operating principle of these scanners is based on emitting light towards an object and analysing the speed of the reflected light. The scanner sensor records the time it takes for the light to be reflected off the surface, which makes it possible to determine the distance between the scanner and the surface in the XYZ coordinate system, for each survey point.

Handheld 3D laser scanner operating principle (author: J. Heinsbergs)

These scanners perform an average of two million measurements per second.

Scanners can vary in terms of the light spectrum they use, which directly affects the precision of the survey. The scanners of this group, too, come in various precision classes, ranging from 0.01 mm to 1 mm. The measurement resolution, which is the distance between the survey points on the surface of the object, is also an important indicator in the performance of a scanner. It is important that in the scanning work assignment, the client specifies the smaller details of the object that is to be surveyed (to be visible). The survey specialist must



Low and high-resolution 3D models.
Kulturhistorisk museum

use the instrument and surveying technique appropriate to the precision and resolution requirements.
Most scanner surveys produce a model that shows only the surface of the object, without true colours. With the development of the technology and the market, most manufacturers try to include scanners that can scan both the surface and the texture of the object. For now, though, colour scanners come with a precision of up to 0.1 mm.
Scanner manufacturers and service providers usually have different models of scanners available, intended for objects of different sizes. For example, a scanner measuring a historical door key will not be suitable for scanning a sculpture that is two metres tall.

**Survey procedure**

The survey is usually conducted by one scanner operator moving the scanner around the object. If the object is small, it can be placed on a rotating platform. During the scanning, the operator monitors the amount of the surface surveyed on the computer or device monitor. It is important for the operator to see the surveyed area in real time in order to see any areas not yet surveyed.
The time it takes to survey an object is directly affected by its nature and how difficult it is to access. However, it does not take more than a few hours for even complex objects to be scanned with a handheld scanner. In areas that are difficult to access, the operator needs an assistant. It is important that at the time of the survey, the scanner is in immediate proximity to the surface of the object, so that the data obtained are of proper quality.
Depending on the object and the type of scanner, the operator may use additional markings. The markings in this case are round black and white stickers irregularly laid out on the surface. The markings are placed on the object or on a specially prepared surveying surface if the object can be put onto it.
The surface of historical objects is typically uneven or has a distinctive texture, so additional markings are generally not placed onto the object itself.
In order to obtain 3D survey data for all the surfaces of an object, multiple separate survey fragments are prepared during the survey and then combined to produce a complete surface survey of the ob-

Surveying process using a 3D handheld scanner (author: A. Ābele)

ject. It is important to make sure that the edges of the survey fragments overlap, to allow accurate combining.

**Site requirements and undesirable conditions**

In order for an object to undergo 3D surveying, any dirt on it that can change the surface topography and directly affect the matching of the survey with the actual shape of the object must be removed. Particular attention must be paid when measuring glossy objects, as their surface inaccurately reflects the rays emitted by the surveying device. Prior to survey, glossy surfaces are matt-coated with a special matt-coating spray.

**Survey result**

As a result of the survey, a 3D solid surface model of the object is prepared, at true scale. Depending on the type of scanner, the surface of the object is either colourless or has true texture (colours).

The file format of solid survey models is *.stp*. Solid model file sizes depend on the size of the object and the resolution of the model, and typically do not exceed 100 MB. Mesh models in *.obj* format are most commonly used for publishing objects online. S*ee 'Secure long-term storage of data' section.*

Free viewing software can be used to open, rotate, and zoom 3D models.

3D model of an object from different points of view (author: A. Ābele)

Further processing of the model for printing, scaling or modification requires specialised software and advice from a specialist.

**Defining survey requirements.**

**Information necessary for the person performing the survey.**

| ***Object information for the service provider to prepare a quote*** |
|---|
| Object image, dimensions |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |
| Indicate the fine details that must be visible in the survey |
| Portability (if the object cannot be moved to the service provider, its location must be specified) |
| Location (indoors or outdoors, preferably with a photo) |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Minimum precision* | *0.02–0.1 mm* |
| *Colour* | *Colour/black-and-white* |
| *Primary formats for deliverables* | |
| *3D solid model* | *.stp* |
| *3D mesh model* | *.obj, stl., fbx* |
| *3D point cloud* | *.e57, .xyz* |

## 6.2 SCANNING WITH A CAMERA

### 6.2.1 Photogrammetric method

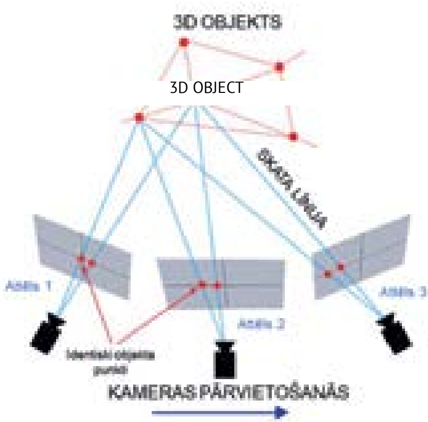
#### Operating principle

This surveying method, also known as photogrammetry, uses high-resolution photographs of an object taken from different angles. The 3D survey requires at least a 60% overlap between the photographs, such that individual points on the object are visible in at least three photographs. The 3D shape data for the object are extracted from the photographs using modern computer algorithms. Colours in photographs are a great source of information when assigning photorealistic colours/textures to 3D objects surveyed.

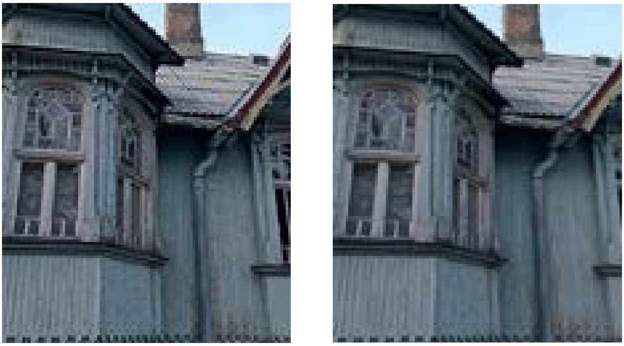
#### Precision and resolution

In photogrammetry, the typical range of camera resolution is between 1 and 10 mm. Higher resolution is also possible, using specialised photographic equipment. There are a few factors that affect the precision and resolution of a survey. Let us review the most important ones.

**Image resolution.** Number of pixels in the image. The higher the resolution of an image, the greater the capacity to achieve high precision. Photogrammetric work typically involves cameras with sensor sizes above 8 MP.




Moving the camera around an object, with consistent image overlap (author: M. Kaļinka)



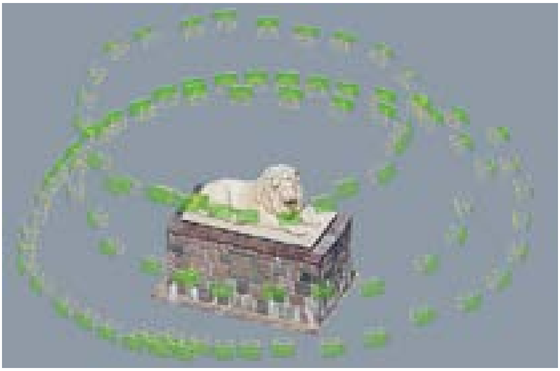
High and low-resolution photograph of a facade element (author: J. Heinsbergs)

**Lighting.** The object must be evenly and well-lit when taking the photographs, in order to make the most of the exposure time and depth of field settings of the camera.

**Camera calibration.** Calibration is the process of determining the focal length, format size, main point, and lens distortion of a camera. There are two sub-factors associated with it: (a) some cameras cannot be calibrated precisely enough (fisheye lenses) and (b) calibration in some cameras is unstable (calibration changes). Both of these reduce precision. A high-quality lens and a stable camera deliver better results.

**Camera position spread.** Points and objects that appear only in photographs taken at very low angles (e.g. a point appears only in two photographs taken very close together) have much lower precision than points in photographs taken from angles closer to 90 degrees. Ensuring a good spread for camera positions leads to better results.

**Image overlap.** The position of a point or object is calculated more accurately if it appears in more than one photograph. The recommended overlap is at least 60%, meaning that the element of the



Layout of photographs around an object for a 3D survey (author: M. Kaļinka)

object is visible in at least three photographs from different angles, with good spread.

**Scale markers.** The accuracy of a 3D point is related to the precision of its position in the image. The positioning of these images can be improved by using markers. Photogrammetric processing software uses image data to mark a point at the sub-pixel level, increasing the accuracy of its position and the relative precision of the whole object surveyed. Markers are also used to increase the absolute accuracy of a survey, i.e. how well it matches the actual dimensions of the object in the field.

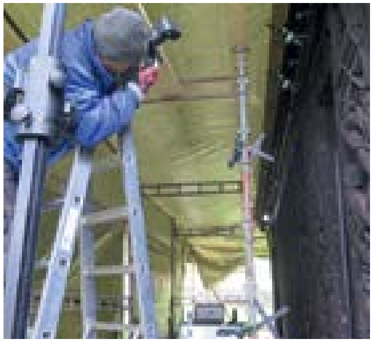
With the availability of photographic equipment and software, photogrammetry is a common method for surveying various historical objects, building facades, and interior details.

The number of photographs per photogrammetric object varies from 50 to several thousand, depending on its size. Note that the post-processing of photographs in photogrammetric software demands considerable RAM and graphics card resources. Photogrammetric software cloud services are common because of this, enabling users to enjoy unlimited data post-processing resources. See 'Data processing software' chapter.

Digital images can be saved in various formats: JPEG, TIFF, PNG, RAW. The format most commonly used is JPEG. It should be kept in mind that JPEG compresses data, with quality loss, in order to reduce file size. Lossless file formats such as RAW and TIFF can be used, but using these formats means handling large amounts of data. Practical experience shows that JPEG, too, delivers good-enough results.

## Survey procedure

The photographing of an object is usually performed by one operator, moving around the object or rotating the object in front of a fixed camera. The position of each successive frame is 10–20 degrees relative to the previous one. It is important that the surveyed object always remains in the centre of the frame. The distance between the camera and the surface of the object is determined by the size of the object. The bigger the object, the longer the distance needs to be for proper framing of the object. For larger objects, higher level detail can be achieved by using a higher resolution camera.



Photographing wall decor and survey result (author: Leif Anker, Riksantikvaren/ Directorate for Cultural Heritage Norway)

Having uniform, diffused light that does not produce high-contrast shadows is essential for the process of taking photographs. If it takes place indoors, the camera operator must pay close attention to the exposure time of the frame so that the photographs are not too dark or too bright.

The post-processing of the 2D photographs that turns them into a 3D object is almost fully automated and is performed by modern photogrammetric software. See 'Data processing software' chapter.

### Site requirements and undesirable conditions

In order for an object to undergo a photogrammetric 3D survey, any dirt on it that can change the surface topography and directly affect the matching of the survey with the actual shape of the object must be removed. Particular attention must be paid to the illumination of the object. Outdoor objects are best surveyed on overcast days, or with the use of sunshields to diffuse sunlight and eliminate shadows.

### Measurement result

The post-processing of the photographs results in a 3D survey with colour point cloud and a mesh model. The size of the files directly correlates with the density of the point cloud and the size of the object. File sizes can range from tens of MB to a few GB. It must also be taken into account that there can be multiple files that contain texture information and they must always be used in a single archive.

**Defining survey requirements.**
**Information necessary for the person performing the survey.**

| ***Object information for the service provider to prepare a quote*** |
|---|
| Object image, dimensions |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |
| Indicate the fine details that must be visible in the survey |
| Portability (if the object cannot be moved to the service provider, its location must be specified) |
| Location (indoors or outdoors, preferably with a photo) |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Minimum precision* | *1–10 mm* |
| *Colour* | *True texture* |
| *Primary formats for deliverables* | |
| *3D mesh model* | *.obj, .dxf. (as necessary)* |
| *3D point cloud* | *.e57, .las* |
| *Photos* | *.jpeg or .tiff, .png, .raw (as necessary)* |

## 6.2.2 RTI method
### Operating principle

RTI (Reflectance Transformation Imaging) is a relatively new method used for mapping the surfaces of objects and studying their micro-topology. The method is based on taking multiple high-resolution photographs, while changing the angle of the lighting and keeping the position of the camera the same. The photographs are processed by computer software, which results in a 2D photograph that can be used to dynamically change the lighting and reveal the fine details of the surface. The method has been successfully used in archaeology, art studies, and palaeontology (Jager et al., 2018; Hammer et al., 2002).
RTI surveys are conducted under different conditions and in different ways, depending on the size and arrangement of the object. For small objects, a special light dome is used with a built-in mount for a camera and LED lights, for high-quality results.
The RTI method can also be successfully used to survey objects even without a light dome, by following the principles of RTI photography. The resolution of the photographs necessary for RTI depends on the size of the object and the size of the camera's sensor. The resolution most commonly used in RTI projects is 4000 x 3000 pixels: this produces a sufficient level of detail for an optimum file size.

Photographing a mural using the RTI method.
Photo: Gunnar Almevik

## Survey procedure

High-resolution digital cameras are used for RTI surveys. The position of the camera remains unchanged during the shooting. Before taking the photographs, it must be ensured that the object is stable and does not move. RTI is used for surveying small individual objects as well as pieces of walls. Multiple photographs are taken during the process, changing the angle of the source of light for every image. Typically, this involves taking 40–60 photographs of the object at different light angles.

During the post-processing of the images, it is important for the algorithms of the software to precisely identify the angle of the source of light relative to the object, which is why special reference ball markers are used. The markers are arranged in the immediate vicinity of the object.

The post-processing of the photographs taken is performed using specialised computer software (such as *RTIBuilder* and *RTIViewer*) that analyses how the object reflects the light in each of the images, creating an interactive 2D file containing all the photos taken as the final outcome.

## Site requirements and undesirable conditions

If the object cannot be moved to a room specially equipped for RTI surveys, it is essential that its surface can be accessed freely, so that the camera can be placed on a tripod, and the operator can move unobstructed along the surface of the object.

## Measurement result

The post-processing done by the software results in an interactive 2D file that can be used to view the object, with the option of changing the angle of the lighting around it. The most common formats for RTI deliverables files are:

– PTM (*Polynomial Texture Maps*), extension: .ptm. The file contains information about the factors for the reflection of light from the surface of the object;

– HSH (*Hemispherical Harmonics*), extension: .hsh. This format offers a more detailed and accurate depiction of surface lighting.

Both the formats can be viewed using the free RTIViewer software.

| *Measurement requirements* | *Options* |
|---|---|
| *Resolution* | *Standard 4000 x 3000 pix* |
| *Colour* | *True texture* |
| *Primary formats for deliverables* | |
| *RTI interactive file* | *.ptm, .hsh (as necessary)* |
| *Photos* | *.jpeg or .tiff, .png, .raw (as necessary)* |

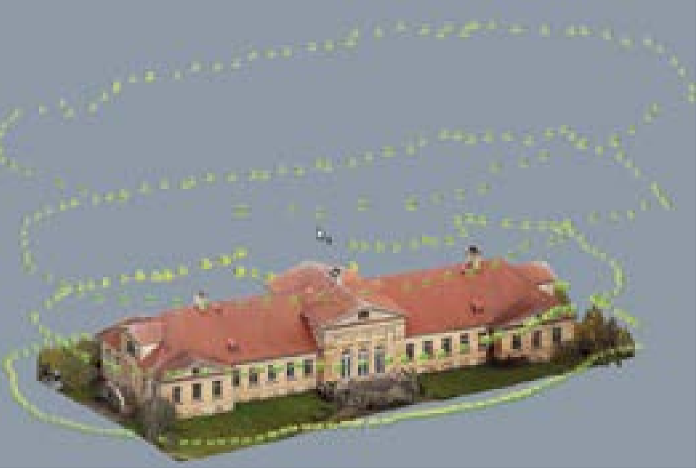
## 6.3 PHOTO-SCANNING WITH A MULTIROTOR UNMANNED AERIAL VEHICLE

### Operating principle

Multirotor unmanned aerial vehicles (UAV) can be used for the photographic scanning of historical objects as they can be easily manoeuvred from one position to another. They also have the important advantage of being able to maintain a static position in the air.

UAV with a camera (Adobe stock)

UAV are equipped with a high-resolution camera, and the principle for the photographic scanning of an object is the same as with a handheld camera. The photographs must be of high resolution and have an overlap of at least 60%. UAV are used to take higher-vantage-point photographs of such objects as building facades, roofs, monuments, etc.: anywhere that cannot be reached with a handheld camera. When surveying a building with a UAV, the pilot controls it manually, trying to maintain the same distance between the vehicle and the object, as much as the surrounding vegetation or buildings allow. UAV are not suitable for very narrow and dark areas.
This method cannot be used to survey very dark areas (high-contrast shadows, hollows, corners) as the data obtained in these areas are unusable for further activities.


Position of photographs around an object for creating a 3D survey (author: M. Kaļinka)

In surveying larger objects, it is possible in photogrammetry post-processing software to combine photographs made with a handheld camera and UAV photographs into a single project.
As with the photogrammetry of smaller objects, markers are used for surveying larger ones, placed both on the ground and on the facade. For objects considered immovable, linking to a coordinate system is critical. If the markers are geodetically surveyed and their centres have known coordinates and absolute elevation values (above sea level), then the object has a known location.


Survey markers when surveying buildings (author: M. Kaļinka)

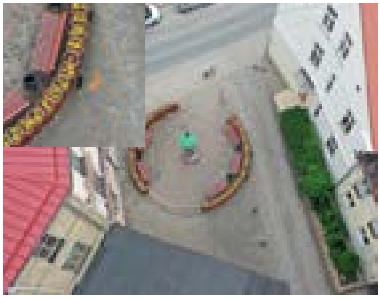
## AREA SURVEYS

UAV photographic scanning is also widely used for surveying larger areas with the vehicles flying pre-set routes over the area surveyed. The photographs taken can be used to make a 3D survey of the area, as well as a high-resolution 2D orthophoto image. Flight settings can vary a little depending on the main purpose of the flight. The UAV pilot sets the altitude of the flight, primarily by assessing the conditions for conducting a safe flight.

Arrangement of photographs above an object for producing an area model (author: M. Kaļinka)

Area survey flights usually take place in autonomous mode, following a pre-set flight plan. Flight plans can be prepared using a variety of online applications that are often free of charge. The flight plan must be opened in that specific computer application during the flight. So it is important that the software selected is compatible with the specific UAV model. Autonomous flights are controlled and activated via the UAV control unit, in which the flight plan is opened.
Main flight plan settings:
– flight altitude, which has a direct impact on the resolution of the photographs in the field and the duration of the flight;
– flight speed: 2–3 m/s. This value is reduced if the flight has to be performed in low-light conditions. Thanks to advanced sensors, the latest UAV models can take photographs at flight speeds as high as 5 m/s.
– camera angle: For 3D surveys, an angle of 60–65° is typically used. A camera angle of 90° (Nadir) is more suitable for orthophotos;
– 75% front overlap and 80% side overlap. This directly affects the duration of the flight, and these settings are usually not experimented with;
– flight line direction. One flight direction is enough to make orthophotos. For 3D surveys, two flight directions are recommended, in order to create a consistent flight line grid over the object.
In order to achieve precision in 3D surveying or 2D orthophotos, it is important to use ground control points (GCP) during the post-processing stage. For this method to deliver a precision of 2–3 cm, the markers must meet the following basic requirements:
– even distribution around and in the centre of the object;
– open placement in areas not covered by tree canopies and buildings. If possible, it is better if markers are arranged at different height levels, both on the ground and on the roof;
– appropriate size and design. Markers that are too small or of the

Flight plan diagram for photographing a city block with a UAV (author: J. Heinsbergs)



Object markers for a UAV survey (author: J. Heinsbergs)

wrong colour make it difficult to identify the centre and correctly assign coordinates;

– centre surveyed. In this case, all markers must be measured using an electronic tachymeter or GNSS device.

### Survey procedure

Depending on the size and location of the object, a survey can take from a few hours to several days. Before arriving at the object, the pilot makes preparations associated with obtaining flight permits (if required), positioning the ground control points, and drafting the flight plans. At the beginning of the survey, ground control points (GCP) are placed and surveyed in the area, and the flight plan is updated in accordance with the actual conditions.

Once the preparations are over, the pilot performs controlled survey flights over the object, with the UAV either controlled manually or autonomously following the flight plan. In order to be able to react to hazardous situations and take full control of the UAV, the pilot must maintain constant visual contact with the UAV. When surveying objects where this is not possible, an assistant pilot observer is assigned to be at another location and take over the visual monitoring of the UAV as necessary. It is important that the observer has continuous voice communication with the pilot during the flight, to enable the transmission of operational commands.

The best weather conditions for taking photographs are: a slightly cloudy day without precipitation, which makes it possible to have photographs without any shadows. When surveying densely vegetated areas (estate parks, cemeteries), it must be kept in mind that no survey data will be obtained from under tree canopies. These areas must be surveyed using UAV photogrammetry when the trees are without leaves, the ground is not covered in snow, and there are no other conditions that affect safe flying.

## Flight safety

When using UAV, it is mandatory to know the risks to human health and third-party property that are associated with this survey type. The main factors affecting flight safety are:

- flight altitude and speed inappropriate for the conditions;
- inappropriate weather, such as wind and precipitation;
- flying beyond the visual range of the pilot or pilot assistant;
- lack of piloting skills;
- interfering with the pilot during the flight.

With the increasing use of aerial vehicles for commercial and non-commercial purposes, governments have introduced strict laws and regulations governing their use. Applicable laws and regulations of Latvia and EU member states: https://droni.caa.gov.lv/normativais-regulejums/
Regulations for the use of drones in Norway: https://luftfartstilsynet.no/droner/veiledning/fly-drone-trygt/

## Site requirements and undesirable conditions

If an individual object (building, monument) is surveyed, then wherever possible, any overgrowth directly adjacent to the surface of the object or blocking close-up views of it must be removed.
There are no specific preparatory requirements for surveying areas.
The performance of UAV surveys directly depends on weather.
Flights do not take place if there is precipitation and strong winds. In order to achieve best photogrammetric results and obtain good-quality photographs, it is advisable to plan the flight to take place in the middle of the day when the sun is in its highest position and the object has smaller shadows. Depending on the time of year, the best time for this is 11:00 to 15:00. This period may be longer if the day is cloudy.

## Defining survey requirements.

## Information necessary for the person performing the survey.

| ***Object information for the service provider to prepare a quote*** |
|---|
| Object image, address |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Minimum precision* | *30–50 mm* |
| *Colour* | *True colours* |
| *Primary formats for deliverables* | |
| *2D orthophoto* | *.jpeg, .tiff* |
| *3D mesh model* | *.obj, .dxf (as necessary)* |
| *3D point cloud* | *.e57, .las* |
| *Photos* | *.jpeg or .tiff, .png, .raw (as necessary)* |

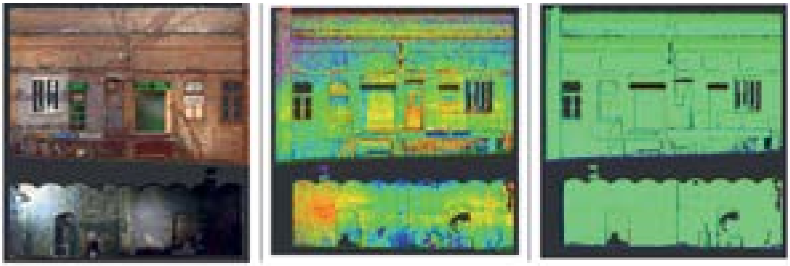
## 6.4 LASER SCANNING FROM A FIXED POSITION

### Operating principle

This chapter describes laser scanning using a fixed 3D scanner, extensively used for surveying historic objects, as this type of surveying can be conducted even in difficult on-site conditions while maintaining high precision. Laser scanning involves measuring the distance from a surface using a visible or invisible laser beam. Laser scanning is a surveying method that makes it possible to quickly obtain high-precision three-dimensional data on the geometry of an object and its surroundings. The survey results in a three-dimensional point cloud that consists of millions of points, each with its own X, Y, Z coordinates. During the survey, the scanner also records the intensity at which the laser beam reflects, which varies depending on the object's surface material.
For the scanning, the 3D scanner is placed in a fixed stable position, and then it makes a full 360-degree revolution around its centre axis, taking up to two million measurements per second.


Fixed-position laser scanner rotation during a survey (Adobe stock)

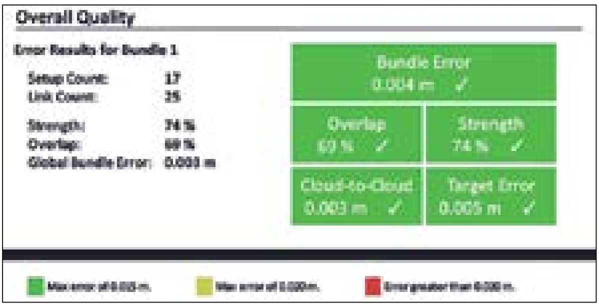
In contrast to photogrammetry, laser scanning has the advantage of not requiring light to produce precise measurements. It should be taken into account that laser scanning without colours can be two or even three times faster (depending on the model of the scanner) than scanning with colours. If the point cloud needs to have true colours, the scanner performs another full revolution, with 360-degree photographing. During the post-processing, the survey points obtained from the photographs are assigned a colour that matches that in the photograph. Illumination is only important if the point cloud must have true colours. The example shows pieces of a point cloud for a facade and a basement in different colour scales. RGB/ Intensity/Neutral



Possible colours of a laser scanning point cloud. Coloured, intensive, and neutral (author: J. Heinsbergs)

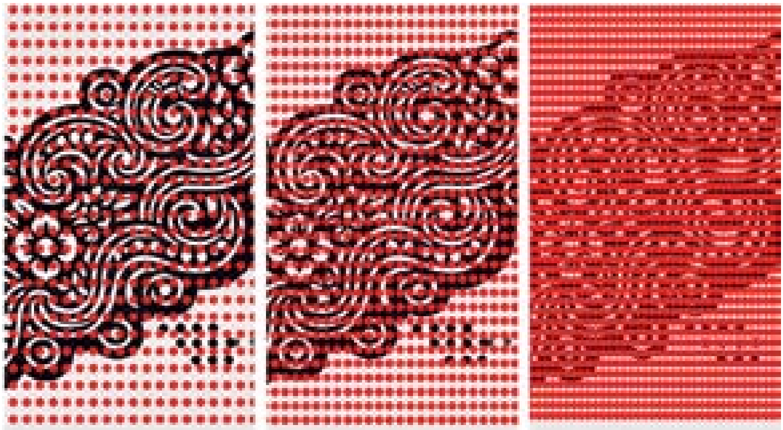
### Precision and point density

The survey precision of most commonly used 3D scanners is 2–3 mm per 10 m. This means that precision decreases the further the scanner is from the surface of the object. However, the most important factor when surveying with a fixed 3D scanner is the correct positioning of the scanning stations, which provides sufficient overlap for the survey point clouds. In order to achieve a high final survey precision, the recommended overlap between point clouds is 30–50%.
The overall 3D survey point cloud for an object is created by combining the point clouds from all the survey stations used in the project. The precision of the combined point cloud (cloud-to-cloud) is usually set to 15 mm or better: it is specified in the deliverable documentation (combining report).




Illustrative example of a point cloud combining report summary table (author: J. Heinsbergs)

The second most important factor for laser scanning is the density of the survey points, i.e. the distance between individual survey points on the surfaces of the object. If point density is insufficient, the geometry of finer details of the objects become difficult to identify in the point cloud. Meanwhile, if point density is excessive across the entire point cloud of the survey, the point cloud file size becomes too large for convenient use in the later stages of the project. In practice, the optimum point density for the surveying of buildings is 5–10 mm. For rooms with distinctive wall or ceiling details, point cloud density can be increased and a separate post-treatment cycle can be conducted, maintaining this increased point cloud density.



Point cloud density illustration (author: J. Heinsbergs)

| Point density | Description | Application |
|---|---|---|
| 2 mm | Very dense | Individual rooms or walls with large amounts of detail |
| 5 mm | Dense | Interiors with details |
| 10 mm | Optimum | Regular interiors, facades |
| 20 mm | Scarce | Roof and facade planes with details of over 20 cm |

## Laser scanning markers

The point clouds produced by laser scanning represent the true size of the object, so the use of regular markers is not always necessary. Markers are used in laser scanning to control the precision of the combined point cloud and to position the survey in accordance with its true coordinates and elevation above sea level. The markers are placed both indoors and on the facade, where they are measured by a geodetic engineer using an electronic tachymeter (precision up to 1 mm).

The need for markers is determined by the scanner operator, based on the scope of the project, the geometry of the object, and the associated risks in obtaining accurate and reliable survey data.

Placement of laser scanning markers on an object (author: J. Heinsbergs)

## Survey procedure

The laser scanning of an object is usually performed by one scanner operator. If the object is large, and markers are used, a geodetic engineer and an assistant may also be involved. It is important that the rooms surveyed are freely accessible and open without obstructions in order for the scanning work to take place in a speedy manner. The scanner operator usually conducts a survey of the rooms within one floor in a sequence, using one or more laser scanning devices. A full survey cycle for a single scanning station can take from 30 seconds to several minutes, depending on the type of the scanner and its settings (colour, dot density). This enables the scanner operator to work with multiple scanners at the same time. The main tasks of the assistant operator in this process are to prepare the rooms for conducting a high-quality survey, to communicate with the building's owner regarding the availability of the rooms, and to clean up the premises after the survey.

## Site requirements and undesirable conditions

Before surveying a room, one must make sure that the most important elements are visible and can be surveyed:

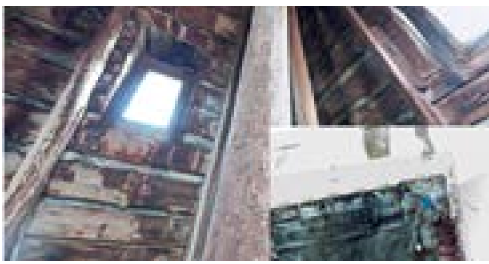
- wall planes (these can be partially covered by furniture, but it is important that they are not completely concealed by curtains or draperies);
- window openings, lintels (curtains must be opened and blinds raised);
- window sills (it is important that they are not completely buried in objects);
- real ceiling (if the room has a suspended ceiling, at least one of its tiles must be opened);
- before scanning the facade, any construction protective meshes, banners, or concealed construction fences immediately adjacent to the facade must be removed. If the facade is covered by scaffoldings, then it is only possible to survey the general shape of the facade, but not the details covered by the scaffoldings, or walkways on the upper floors of the building.

When surveying a room, the operator determines the number of stations needed in it so that there are no significant blind spots in the survey. For example, if the room has more than one window, multiple stations must be set up to survey all the window openings. In order to ensure that the point clouds from different rooms can be combined together, a scanning station is usually placed in an open doorway.
Outdoors, laser scanning is not possible in heavy rain and snow. In winter, snow cover is an obstacle, and it must be removed from the object before surveying.

## Measurement result

The raw data of the survey are a set of survey files produced by each survey station. The post-processing of the raw data is performed using the software provided by the scanner's manufacturer, whereas the process of combining the data is referred to as registration. Once the registration is done, it is possible to export the combined data in the post-processing software using such various point cloud formats as *.e57* and *.las*. When exporting the data, the operator can set the point cloud density again for the final product. This is typically done to reduce the size of the deliverable files. If reducing the point density is not allowed, the deliverable file size can be as high as 100 GB. So it is recommended to split files into parts (e.g. floor-by-floor in a building), so that it is not difficult to work with the files further on. The recommended maximum size of a single deliverable file is 20 GB.
Another key component of deliverables are 360-degree images, shown as spherical objects in the point cloud at the actual positions of the scanning stations. These images are available both for colourless scan data and for coloured point clouds. For colourless scanning, the 360-degree images are black-and-white, and the colour scale is based not on the photograph, but on the reflection intensity data. These images can be very useful in further work with the point cloud (3D modelling or preparation of drawings),

360° top view of the images and view from a specific position (author: J. Heinsbergs)



enabling a better understanding of complex areas in the survey data and a more accurate identification of the necessary objects or object details. 360-degree photographs can usually be viewed in the software specific to the manufacturer of the scanner, available free of charge.

**Defining survey requirements. Information necessary for the person performing the survey.**

| ***Object information for the service provider to prepare a quote*** |
|---|
| Object address, for buildings – room plans, current exterior and (preferably) interior photographs |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |
| Primary users of survey data and their tasks, e.g. research, design, or planning |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Scanner precision requirements* | *2–3 mm per 10 m* |
| *Combined point cloud precision* | *No more than 15 mm* |
| *Colour* | *RGB or black-and-white* |
| *Point cloud density* | *Adjustable, from 2 to 20 mm* |
| *360-degree photos* | *Yes (can be separated)/No* |
| *Primary formats for deliverables* | |
| *3D point cloud* | *.e57, .las* |
| *360-degree images* | *Format depends on the make of the scanner* |

## 6.5 HANDHELD AND MOBILE LASER SCANNERS

### Operating principle

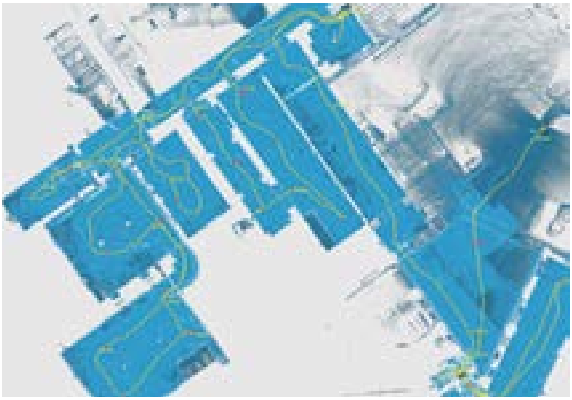
The operation of handheld mobile laser scanners is based on the SLAM (simultaneous localisation and mapping) algorithm that makes it possible for the scanner to continuously track its position in space by measuring the laser scanner's measurements of the distance from the laser sensor of the device. During the survey, the SLAM algorithm continuously calculates and records the surrounding geometries using the laser scanner's data on reflections from the surfaces around it. This means that the device accurately records the position of objects in the environment during the survey itself, mapping the area in real time.

The advantage of these devices, given the ability to perform the survey in motion, is speed. The scanner can also be used to survey hard-to-reach areas in an object where fixed scanning equipment cannot be set up (such as shafts, spaces above suspended ceilings, and other hollow areas).

Types of mobile scanning devices (authors: A. Ābele, E. Dzenis)

Today, the precision of such devices starts at 6 mm, which seems very high given the surveying speed and their other advantages. However, in order to achieve high absolute precision in the overall 3D point cloud, a number of important conditions must be met:
moving evenly and slowly during the scan, without rapid rotations, as this enables the SLAM algorithm to track the scanner's position in space more accurately and to assign more precise coordinates to the measurements;
it is recommended that scan routes overlap, which makes it possible for the SLAM algorithm to identify locations that have already been surveyed and adjust the data if there were any deviations on a previous route;
control points must be placed in an evenly spread pattern, geodetically linked to specific coordinates.
Following these conditions, it is possible to achieve high (up to 20 mm) absolute precision in the point cloud. The effective range of the devices is usually up to 50 metres. Points from measurements at longer distances are deleted during the post-processing.
Control points are not required for smaller objects if an entire object can be surveyed in a single attempt (up to 20–30 minutes), and it is not planned for the point cloud to be matched with other survey data. However, if control points are not used, it is important before performing any further actions with the point cloud to verify the absolute precision of the survey results by comparing control measurements at the object with the respective dimensions in the point cloud.



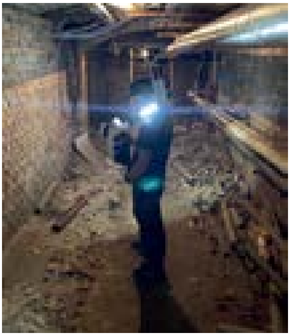
Mobile laser scanner route pass and control points in a building (author: J. Heinsbergs)

For mobile scanners, unlike fixed-position laser scanners, point density is only updated during post-processing. The pre-set point density levels offered for processing depend on the manufacturer of the device and the post-processing software used, at 5 mm and less.
The post-processing software for mobile scanners is usually specific to the device and is provided by its manufacturer together with the scanner, to be used as part of a single workflow.
Most portable laser scanners are equipped with photo or video cameras used to assign RGB colours to the point cloud. Some scanner models are equipped with at least four cameras that take 360-degree photographs simultaneously with the survey.

**Survey procedure**

In most cases, a survey can be performed by one operator. Sometimes an assistant is brought in if help is needed in order for the machine and the operator to work safely in more challenging environments. The surveying of larger objects is usually divided into survey passes. These are usually 20–30-minute survey periods during which a continuous survey is made of a specific part of the building (floor, unit, facade, roof, etc.). Because scanning is conducted in continuous motion, the operator makes sure that there are no obstacles along the entire route of the pass that could prevent free movement and prepares the rooms for the survey (uncovering window openings and opening up ceiling panels) before it takes place. Control points are set up at the object before the survey.
During the survey, the operator moves along the pre-defined route, monitoring the operation of the device on its screen and recording the control points. The referencing to control points during the survey takes place by physically positioning the scanner on the control point.
As with other laser scanners, mobile ones can take measurements in

unlit spaces. However, it must be taken into account that the colour of the point cloud will be black in unlit spaces and RGB in spaces with lighting. The point cloud can, of course, also be viewed using a colour palette to represent reflection intensity.
In order to illuminate unlit spaces, the scanner operator can equip the device with additional lights, to produce a coloured point cloud.



Working with portable laser scanning equipment in darker spaces (author: J. Heinsbergs)

Example of the point cloud precision referencing to control points for a portable laser scanner (author: J. Heinsbergs)

| Control Point | Delta X [mm] | Delta Y [mm] | Delta Z [mm] |
|---|---|---|---|
| c2 | 0.02 | -0.74 | 0.65 |
| c2 | -0.25 | 0.14 | -0.43 |
| c1 | -1.60 | 1.28 | -0.31 |
| c1 | -0.96 | 1.46 | 0.15 |
| z1 | -1.71 | 0.96 | -0.89 |

Control point used — Green ≤ +5mm, Green ≥ -5mm — 5mm < Yellow < 10mm, -10mm < Yellow < -5mm — Red ≥ +10mm, Red ≤ -10mm

During the post-processing, special software recalculates the scan route and survey data, making corrections in locations where the SLAM processor lost its precision. The 3D survey data are arranged based on coordinates in keeping with the surveyed control points. The post-processing quality control is confirmed with a report that can be a part of the deliverables.

## Site requirements and undesirable conditions

It is not recommended to conduct surveys if there is heavy precipitation, as it can affect the long-term operating capacity of the device's electronics. Before the survey takes place, the premises at the object must be opened up and cleared of any obstructions in passageways that could interfere with the movement of the scanner.

For this type of scanner, it is essential to preserve the capacity of the SLAM algorithm to accurately determine its position during the survey. Principal factors or circumstances that make it difficult for the device to operate or completely disorient it:
– large number of moving objects in a confined space (e.g. a public building with many people moving near the scanner);
– areas with a limited number of planes (e.g. the flat roof of a building with no adjacent roofs or buildings);
– rooms with many highly reflective surfaces (e.g. mirrors);
– various types of curtains, if they are directly within the scanning route and immediately adjacent to the device during scanning;
– outdoor spaces without distinct built surfaces and tall shrubs (e.g. in parks or cemeteries).

### Measurement result

The raw data of a survey are a structured set of files for every pass of the survey that can only be opened in post-processing software.
The post-processing of the data results in a cleaned-up combined point cloud in *.e57*, *.las*, or other point cloud formats. The colour of the point cloud depends on the scanner's capabilities and settings. When exporting, the operator can set the point cloud density again for the final product. This is typically done to reduce the size of the deliverable files.

### Defining survey requirements.
### Information necessary for the person performing the survey.

| ***Object information for the service provider to prepare a quote*** |
|---|
| Object address, for buildings—room plans, current exterior and (preferably) interior photographs |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |
| Primary users of survey data and their tasks, e.g. research, design, or planning |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Scanner precision requirements* | *6 mm* |
| *Point cloud absolute precision* | *No more than 20 mm* |
| *Colour* | *RGB or black-and-white* |
| *Point cloud density* | *Adjustable, from 5 to 20 mm* |
| *360-degree photos* | *Not available for all SLAM scanners* |
| *Primary formats for deliverables* | |
| *3D point cloud* | *.e57, .las* |
| *360-degree images* | *Not available for all SLAM scanners* |

## 6.6 MOBILE LASER SCANNING SYSTEMS (CAR, DRONE OR HELICOPTER)

This section discusses two related mobile laser scanning technologies, because their operating principle is very similar, and the only different element is the vehicle used for moving the LiDAR sensor(s). The device can be placed on a road vehicle or attached to an aircraft. Working with each of these has its own specificities, and these will be discussed separately.

### 6.6.1 Mobile laser scanning, with the device mounted on a road vehicle

#### Operating principle

Mobile laser scanning (MLS) is modern technique that uses laser technology to conduct 3D surveys of traffic ways, buildings, and surfaces. A laser scanner is mounted on a vehicle and emits laser beams that are reflected off surfaces. The time it takes for the laser beams to be reflected and received by the device is used to determine the distance, enabling the production of a detailed 3D point cloud.

Using GNSS receiver data and an internal IMU (inertial measurement unit) sensor, the device accurately detects its position, route, movement speed, and elevation changes as it moves through its environment. The IMU data play the most important role in accurately assigning coordinates to surveyed laser scanning points. An odometer is also installed on the wheels of the vehicle, as a source of additional data.

The device usually also includes two or more cameras, mainly used to capture the colours for the point cloud. 360-degree photographs can also be available, depending on the features of the device and its model.

The relative (within the specific area) precision of measurements for modern MLS devices is 1 to 3 cm. Their absolute precision (with linking to the national coordinate system) is usually between 2 and 5 cm. There are a few factors that affect the precision of the surveys.

- GNSS (GPS) signal quality. GNSS signal is weaker in populated and forested areas;
- IMU sensor operating performance quality and its precision in route sections with poor GNSS signal;
- vehicle driving speed. Scanning at higher speeds reduces the density of the point cloud and its detail;
- area and weather conditions.

In order to improve GNSS signal coverage in the survey area, an additional base station is placed near the scan route, operating in transmit mode.

No special area markers are put in place for MLS surveys. However,

in order to provide an additional control point to ensure the accuracy of the point cloud, landmarks are recorded that stand out at the site and can be clearly identified in the point cloud. These are often distinctive corner elements of road markings.
The survey distance of the devices is up to 150 metres, although 60 to 80 metres can be considered effective survey distance. During post-processing, measurements made from a longer distance are deleted or disregarded.
The density of points is adjusted via driving speed. The average target point density on surrounding surfaces at 50 km/h is 5 mm. This is nine points per 1 cm2. As the technology of these devices advances, the performance of LiDAR sensors rises.

MLS point cloud visualisation (author: M. Kakko)

## Survey procedure

The survey is usually performed by a single road vehicle manned by two people: device operator/driver and technician/surveyor. The driver follows the planned route, monitors the survey speed, and makes sure the MLS system is stable. The technician is in charge of installing, setting up, and calibrating the device before the work. During the scanning, the technician also monitors the quality of the survey data.

MLS device equipment on a road vehicle (author: M. Kakko)

In populated areas, 3D surveying can usually be conducted at speeds of up to 50 km/h. Outside populated areas, survey speeds usually do not exceed 80 km/h. Surveying can also be done at night; however, it should be taken into account that RGB colour will not be available in the 3D point cloud.
Compared to other methods, MLS makes it possible to quickly survey large and complex areas. However, when surveying historical sites, one should carefully consider the effectiveness of the devices and the possibility of combining the 3D data with other methods, in order to produce a complete 3D survey of the site in question.

**Site requirements and undesirable conditions**

No special preparations for the objects and areas to be surveyed are needed. It must be made sure that the planned route is fully accessible to the vehicle and that no visual obstructions obscure important objects. If there are pedestrian streets in the area of the object, there must be proper planning to ensure that the scanning is safe for the public.
Adverse conditions that directly affect the quality and precision of the surveys include:

- area or route segments with poor GNSS reception (sections under large trees, in tunnels or narrow streets). Prior to the survey, these areas are identified and assessed by the specialists, making changes in the surveying procedure and conducting additional control surveys);
- very rough road sections that are unsuitable for conducting MLS surveys while driving. In old towns that often have cobblestone streets, the STOP & GO surveying method is used. The car is stopped for performing the surveying work and, once the scanning cycle is over, is moved to the next scanning position. Depending on the terrain, the distance between such positions can be 10–20 m. In using the STOP & GO method, one must follow the same rules as for the fixed laser scanner (see Chapter 6.4);
- heavy rain or blizzard that renders surveying impossible;
- It is also difficult to obtain good-quality data when the road surface is too wet or, conversely, too dry. In both these cases, the vehicle raises a cloud of dew or dust behind it, obscuring the view of the LiDAR sensors on the roadway.

**Measurement result**

The post-processing of the data produces a 3D point cloud covering the entire survey route. Before the point cloud is delivered, extensive cleaning work must be performed to remove redundant points (e.g. reflections in windows, passing cars and pedestrians, as well as other moving objects along the scanning route). The colour and density of the point cloud must be specified based on the further needs in keeping with the work assignment.

It must be noted that point clouds with high point densities that cover large areas can take up tens or even hundreds of gigabytes. So, in the deliverables, it is recommended to break them up into sections or areas.

**Defining survey requirements.**

**Information necessary for the person performing the survey.**

| ***Object information for the service provider to prepare a quote*** |
|---|
| Required road section or area map |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey technology and scope of deliverables, taking into account good practice)* |
| Primary users of survey data and their tasks, e.g. research, design, or planning |

| ***Measurement requirements*** | ***Options*** |
|---|---|
| *Scanner precision requirements* | *10–30 mm* |
| *Point cloud absolute precision* | *No more than 50 mm* |
| *Colour* | *RGB or black-and-white* |
| *Point cloud density* | *Adjustable, from 5 to 20 mm* |
| *360-degree photos* | *Not available for all MLS scanners* |
| *Primary formats for deliverables* | |
| *3D point cloud* | *.e57, .las* |
| *360-degree images* | *Not available for all MLS scanners* |

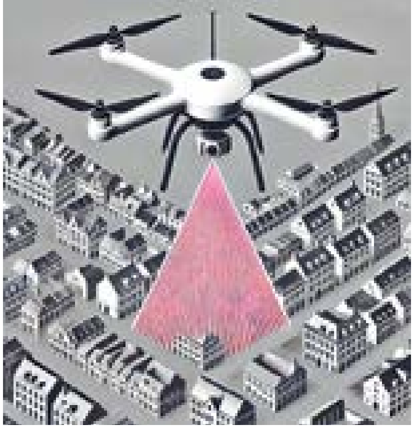
### 6.6.2 Mobile laser scanning, with the devices mounted on an aerial vehicle

There are two types of aerial vehicles: manned and unmanned. Manned ones, such as light planes and helicopters, have been used in 3D surveying for decades. With advances in technology and rising scanner performance, manned aerial vehicles are typically used to survey large areas (hundreds or thousands of square kilometres). The 3D data obtained are mainly used to map cities, regions, and countries. In this chapter, we offer a more detailed look at 3D surveys using a LiDAR sensor mounted on an unmanned aerial vehicle (UAV), which has its advantages as well as differences compared to a UAV equipped with a camera sensor (Chapter 6.3).

**Operating principle**

UAV 3D laser scanning, too, is classified as a mobile laser scanning system (MLS), and it works following the same principle. The laser sensor emits laser beams and captures their reflections. The reflection time is used to calculate the distance between the sensor and the object.

Unlike other LiDAR sensors, this type of scanner is set at the factory for a downward field of view with a specific number of laser beams.



Unmanned aerial vehicle equipped with a LiDAR sensor (author: M. Rutkovskis)

LiDAR laser scanning diagram (author: J. Heinsbergs)

So for these devices, the density of the survey is adjusted by changing the altitude of the flight.

Owing to the development of LiDAR technology, the latest laser scanner models have a 'multi-pulse' feature, making it possible for the scanner to emit several pulses in a row before receiving the reflection. This creates more reflections and a denser point cloud, which is essential when scanning in densely vegetated or mountainous terrain. This method and the multi-pulse feature are particularly useful when LiDAR data are used to search large areas looking for terrain features that could indicate the presence of undiscovered historical sites. The main advantage of the method is the ability to accurately survey the ground surface over large areas, thanks to the density of the laser beams, and to reveal their true topology, even under moderately dense vegetation.

As with other MLS systems, the position of the UAV in the area is determined using GNSS and IMU (Inertial Measurement Unit) sensor data. In areas where satellite coverage is poor, a ground GNSS transmitter is often used as a base station for better data precision.

The relative (within the specific area) precision of measurements for these MLS devices is 1 to 3 cm. Their absolute precision (with linking to the national coordinate system) is between 2 and 5 cm.

There are a few factors that affect the precision of the surveys.

- GNSS (GPS) signal quality. GNSS signal is weaker in populated and forested areas;
- IMU sensor operating performance quality and its precision in route sections with poor GNSS signal;
- flight altitude and speed, which directly affect the resolution of the point cloud. For historic areas, a lower altitude (20–50 m) and speed (1–3 m/s) are recommended, in order to produce a high-resolution 3D point cloud;

- the quality of the laser scanner, which is determined by two parameters:
  - laser pulse frequency, within a range of 100 to 500 kHz (how many measurements can be carried out per second. The higher the frequency, the higher the performance),
  - laser beam deviation, within a range of 0.3–1.5 mrad (distance error);
- weather, which plays a critical role in the use of this method. Rain, fog, and bright sunshine all affect the quality of the data. The best time for using the method is when there is no precipitation or strong wind;
- ground control points (GCP). These are appropriately-sized markers with surveyed coordinates placed on the ground. Their use is essential specifically in ensuring and improving the absolute precision of the survey.

A 3D point cloud can be made to have true colours (RGB) if aerial photographing of the object is performed in addition to the laser scanning.

**Survey procedure**

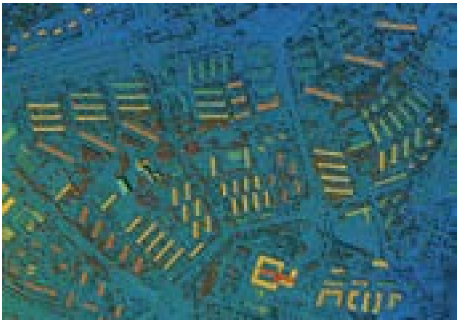
Several preparatory works are carried out at the object prior to the survey:

- preparation of the flight plan using specialised software. During the flight, the UAV follows a pre-defined flight plan that sets the route of the flight, its altitude and speed, and ensures the necessary overlap data and uniform coverage of the entire area of the object;
- identification of primary base station and control point locations, the suitability of which is then tested in the field.

The surveying work is usually conducted by the UAV pilot alone or, for larger areas with limited visibility, together with an observer who can monitor the UAV in areas where the pilot has no visual contact with it. UAVs equipped with a laser sensor are usually much larger and heavier (up to 25 kg), meaning that these surveys must be conducted in strict compliance with all safety rules and local laws and regulations.

The post-processing of data is an important stage in which several key tasks are carried out using the raw data of the survey:

- removing redundant points ('noise'). These are points caused by reflections from moving objects (vegetation, vehicles, birds, people);
- merging multiple datasets for different flights;
- classification of points (land, buildings, vegetation);
- matching of the point cloud with the coordinate and elevation systems.



Classified LiDAR point cloud (Adobe stock)

## Flight safety

When using UAV, it is mandatory to know the risks to human health and third-party property that are associated with this survey type. The main factors affecting flight safety are:

flight altitude and speed inappropriate for the conditions;
inappropriate weather, such as wind and precipitation;
flying beyond the visual range of the pilot or pilot assistant;
lack of piloting skills;
interfering with the pilot during the flight.

With the increasing use of aerial vehicles for commercial and non-commercial purposes, governments have introduced strict laws and regulations governing their use. Applicable laws and regulations of Latvia and EU member states: https://droni.caa.gov.lv/normativais-regulejums/

Regulations for the use of drones in Norway: https://luftfartstilsynet.no/droner/veiledning/fly-drone-trygt/

## Measurement result

The post-processing of the data results in a classified 3D point cloud for the area of the object. If the object covers an area of a few square kilometres, with the point cloud having high density and large size, it is recommended to divide it into individual squares. If splitting the data, attention must be paid to the naming of the split-up pieces and to ensuring clear file numbering.

## Defining survey requirements.

## Information necessary for the person performing the survey.

| ***Object information for the service provider to prepare a quote*** |
|---|
| Required road section or area map |
| Description of the goal of the survey *(this is essential because it helps the consultant better understand what the need is and to select the best-suited survey mode)* |
| Primary users of survey data and their tasks |

| *Measurement requirements* | *Options* |
|---|---|
| *Classification requirements* | *Land, vegetation, buildings, roads, etc.* |
| *Point cloud absolute precision* | *No more than 50 mm* |
| *Colour* | *Not possible for all* |
| *Primary formats for deliverables* | |
| *3D point cloud* | *.las/.laz, .e57* |

## 6.7 GEOLOCATION WITH GROUND-PENETRATING RADARS

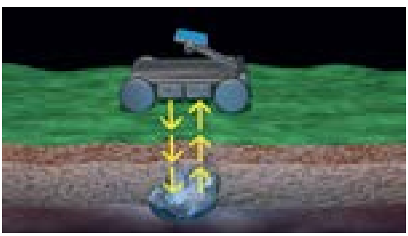
### Artjoms Zelenkevičs

### Operating principle, operating description

Ground-penetrating radars (GPR) are devices that use electromagnetic waves to survey the upper layers of the soil and objects located underground. Their operating principle is to transmit high-frequency radio waves into the ground and record the signals reflected from various objects or layers of the soil.

A GPR consists of two main parts: the control unit and the antenna. For better precision, the radar system can be fitted with a GPS device that records the route of the radar using global or local coordinates. The control unit is used to determine the basic settings and survey data, while the rest of the physical work is performed by the antenna. The antenna of a GPR transmits radio waves of a certain wavelength in to the ground hundreds of times a second. Whenever a radio waves comes into contact with an object whose dielectric properties differ from those of its surroundings (e.g. ceramics, metals, or even different-density soil), some of the waves are reflected back and received by the GPR antenna when it is in the receiver mode. The part of the wave that was not reflected continues to travel deeper into the ground, creating more and more reflections until it dissipates. The physical behaviour of GPR radio waves in the ground is similar to the optics and refraction of light.

The depth of an object can be judged from the time it takes for the reflected signal to return, while the properties of the object can be determined based on the features of that reflection. The shape of

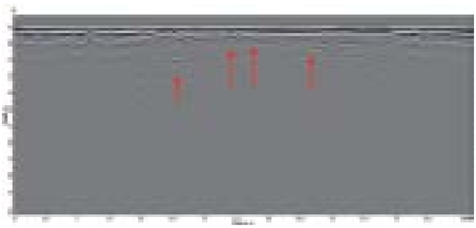


GPR operating principle (Adobe stock)

the anomaly caused by an object is the most common main characteristic used. A small elongated object appears as a parabola, while a change in layers is represented by straighter lines. GPR have high resolution and can detect both large and small objects underground. Experience shows that an individual brick is the smallest object size that a GPR can detect.
The technology is extensively used in fields ranging from geology and construction to forensic science and, of course, archaeology. Researchers of cultural history use the radar to search for the ruins and foundations of old buildings around the world: in deserts, in jungles, and in permafrost regions. Their experience shows that radar can also be used search for human remains and other objects from various periods. Whether the object has been in the ground for 10 days or 10 thousand years, the most important factor is that it is different from the layers of soil surrounding it.

## Equipment

Modern GPR have a broad range of applications and offer a high level of process automation, making them an indispensable tool for archaeological research. Today, there are active advances in drone technology, which works very well in combination with radars. Using drones as platforms for the antenna, researchers no longer have to walk kilometres through swamps, glaciers, and other difficult terrain to collect data. Description of the operation of some GPR.
***RadSys Zond*** offers a range of GPR, such as ***Zond 12e*** and ***Zond 16e,*** which are easy to use and have a particularly high sensitivity to objects in the ground. The company produces devices with different-frequency antennas that make it possible to study both the upper and the deeper layers of the soil. Zond GPR can also operate in complicated environments, such as difficult-to-access or heavily contaminated sites. They have also demonstrated their reliability on numerous expeditions to the glaciers of Greenland and Svalbard. The company also develops drone technology, producing radars that can be used in combination with a drone. The end result that can be obtained using RadSys GPRs is most often 2D profiles or sections (Figure 2). Individual objects in these data are shown as parabolas.



Example of a GPR profile produced using RadSys *Zond 12e*, with marked parabolas, most likely indicating underground utility lines (author: A. Zelenkevičs)

**IDS GeoRadar** offers RIS MF Hi-Mod systems, also used in archaeological studies. These GPR systems have multi-frequency antennas and are capable of operating in multiple frequency bands at the same time. This enables different layers of the soil to be explored and offers a more complete picture of the structure underground. The high scanning speed and the ability to integrate GPS into the system make IDS radars the most sought-after instruments on the market. The radar often features not just one antenna, but two or even four at once. The company also offers radars for trailers, which makes it possible to scan roads with great precision and speed, without blocking traffic. This is fairly sophisticated technology that helps eliminated noise caused by vehicles, buildings, and other aboveground objects. IDS GPR can even be used to produce 3D representations of the situation underground, with various sections and depth maps (Figure 3). Depth maps help understand the situation from a different perspective, improving the interpretation of the result.

Depth map with marked old structures or pieces of foundations produced using IDS GeoRadar RIS MF Hi-Mod (author: A. Zelenkevičs)

## Method advantages

The use of GPR in archaeology has opened up new horizons for research without conducting excavations. This enables scientists to study ancient structures and artefacts without touching or exposing them. This method has a number of significant advantages over traditional archaeological excavation and cultural heritage site investigation methods.

First and foremost, GPR studies are non-invasive, meaning that the method does not involve exposing the objects. This is particularly important when working with heritage sites where physical intervention can damage valuable historical artefacts. GPR can be used to quickly survey large areas, creating three-dimensional maps with underground objects. Both of these factors make it possible to preserve the landscape or land surface and to significantly reduce the cost of excavating in locations without too much promise.

Secondly, this technology can be used to detect objects not visible through other means. For example, GPR can reveal underground tombs, remains of old buildings, walls, roads, and artefacts left by lost civilisations (if they are large enough). Other geophysical methods, such as electrical surveys or magnetometry, can also be used to try to obtain similar results. However, GPR is still the fastest, most convenient, and easiest to use tool for obtaining this information. It helps archaeologists to plan excavations with high precision, focusing on the most valuable areas.

A third advantage is the ability to use GPR repeatedly in the same area under different conditions. For example, if for some reason it is necessary to stop a dig, GPR data can be used later without losing their meaning. GPR is also virtually unaffected by external factors such as rain or magnetic storms. This means the ability to work without interruption in snow or rain and at almost any temperature.

### Site requirements and time necessary for a survey

The performance of GPR is indirectly influenced by many site-specific factors. First, it is the condition of the surface. Ideally, the area surveyed should be flat or at least not have large rocks, vegetation, and other surface objects that could interfere with radio waves or obstruct the work of the specialists. Rough terrain, slopes, presence of water can interfere with radio transmission and complicate the interpretation of data; however, working in rough terrain is possible, with a few successful examples.

Depending on the size and complexity of the area surveyed, fieldwork with a GPR can take from half an hour to several days. For example, a 1–2 hectare site may take one to three days to survey, if the surface is prepared surface and there are minimal disruptions. Meanwhile, complex sites, such as urban areas with many underground utilities, can take much longer. In simple cases, one survey profile is enough to complete the task. So fieldwork can take as little as one hour.

The GPR operator's experience is also an important aspect. An experienced specialist can not only perform a high-quality survey, but also quickly identify possible anomalies and adjust the device to obtain the most accurate results. An geophysics expert can try to identify various anomalies in the soil already during the study of the area and carry out additional inspections in locations with multiple anomalies.

### Data obtained and survey results

Data obtained using a GPR are a collection of reflected signals, and their analysis is based on the interpretation of data. Every signal represents the speed of a wave moving through space. Combining hundreds of such signals results in radar profiles, which are post-processed to identify and visualise underground objects. The post-processing includes filtering out noise, smoothing the data, geometry corrections, and other signal processing techniques. It is also important to understand the terrain of the area and to adapt the data to it.

Modern software makes it possible to automate a few post-processing steps, although the human still plays the main decision-making role, because it is the expert that reads the visual information. AI is already close to the scientific applications of GPR, but it is still not functionally usable in real practice. Today's geophysicists and trained archaeologists need to interpret the data correctly themselves, distinguishing between real objects and noise caused by, for example, variations in soil structure. This is a very important aspect when it comes to relatively fresh burials or other sites with excavated soil. In such an environment, disturbances in the soil structure created distorted reflections.

### Primary deliverables formats, file sizes, and factors affecting size

The data formats used in GPR surveys depend on the hardware and software in question, but the most common are GPR, DZT, and SEG-Y. These formats can be used to save both raw and processed data with the possibility of later analysis and visualisation. There are a large number of data formats used in the industry, as each manufacturer has its unique format for the data, and post-processing is only possible using that manufacturer's software. So it is often the case that raw data from one manufacturer's GPR cannot be post-processed in another manufacturer's software due to the incompatibility of the files. Some raw data formats can be post-processed in open source software written in *Python* , but this should rather be considered experimental post-processing. For the post-processing of raw data, the most reliable option is to use the processing flow recommended by the GPR's manufacturer.

The size of the files produced by GPR surveys can vary depending on a few factors: antenna frequency, scan density, survey area size, and duration of the survey. For example, a high-frequency antenna can capture several gigabytes of data, even in a small area of one hectare. It should be noted that the post-processing and storage of raw data requires high computer processor power and large amounts of storage space. Manufacturers usually release and support their applications for the Windows and sometimes Linux operating systems.

### Scope and quality checks of deliverables

In archaeology, GPR results offer a unique opportunity to look into the past without interfering with the cultural layers as a whole. However, a thorough quality check must be carried out to confirm the reliability of the data obtained. This is usually done by the same geophysicist who processes the data.

First, one must take into account the conditions of the survey: weather, surface features, possible noise, and other factors that may have influ-

enced the results. The GPR operator must always tell the data analyst of the situation at the site. The data analyst must know if there are holes, structures with deep foundations, and other fine details.
Second, in some cases, it may be important to repeat a survey in the same area, to confirm the presence of anomalies found. One can more precisely define the area of the site or expand the area of the survey, in order to locate large objects underground. Also, in a situation where a professional operator is involved in the fieldwork, they can complete the task during that same expedition if characteristic anomalies are detected in time.
GPR survey results are also often compared with the results produced through other methods, such as magnetometry or electrical surveys, which increases the reliability of the information obtained. It is important to note that the quality of data interpretation depends to a large extent on the experience and qualifications of the expert. Even with the most sophisticated equipment, careful analysis is necessary for drawing definitive conclusions about the objects identified.

## Defining survey requirements.
## Information necessary for the person performing the survey.

| ***Object information for the service provider to prepare a quote*** |
|---|
| Site location. Site dimensions and area that needs to be surveyed |
| Underground utility and sewer line plans (if any) |
| Description of the goal of the survey and its expected result (e.g. whether the search is for old structures or burial sites) |
| Results of previous studies (if any) |
| Cultural and historical context of the area (construction materials, burial traditions, etc. if known) |

| ***Survey requirements*** | ***Options*** |
|---|---|
| *Minimum horizontal precision* | *0.10–0.50 m* |
| *Minimum vertical precision* | *0.05–0.20 m* |
| *Underground object dimension identification* | *0.20–0.5 m* |
| *Primary 3D study deliverables* | |
| *Depth maps* | *.pdf, .jpg* |
| *Radar data* | *Format by GPR manufacturer (.sgy/.dt/.rd3/.dzt/...)* |
| *Report on work carried out* | *.pdf, .docx* |
| *Primary 2D study deliverables* | |
| *Radar profiles* | *.pdf, .jpg* |
| *Radar data* | *Format by GPR manufacturer (.sgy/.dt/.rd3/.dzt/...)* |
| *Report on work carried out* | *.pdf, .docx* |

## 6.8 BATHYMETRIC MEASUREMENTS WITH A SIDE-SCAN SONAR

### Kaspars Markus Molls

### Operating principle

Bathymetric or acoustic remote measurements are a non-destructive method for documenting cultural historic heritage under water. It was originally created and used by the shipping industry for mapping waterways and detecting potential underwater obstacles. However, its operating principles can also be easily adapted to the identification and study of underwater cultural historic heritage.
Bathymetric measurements are performed using an echo sounder/sonar that emits sound waves towards the bed of the body of water. The distance between the sonar and the bed or an object located on it is calculated based on how long it takes for the wave to travel from its surface back to the devices. Sound waves bounce off all surfaces and obstacles, resulting in data about the depth of the bed and the objects that are on it. Bathymetric measurements detect not

Scanning from a motorboat in Lake Araiši (author: J. Meinerts)

only objects on the bed but also those floating in the water, such as fish, which is a significant factor for error.

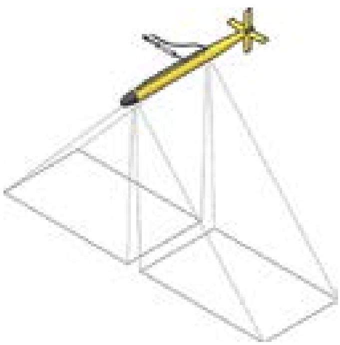
### Selection of devices, brief description of latest ones

Devices that use remote acoustic sensing methods are used for civil as well as military applications, so they are available in various technical specifications. The simplest use the single-beam sonar principle, emitting a single beam that produces a depth measurement at a specific point that is only useful for determining the depth of a body of water. Imaging sonar installed on a ship or ROV can be used for locating underwater objects. It emits signals around itself, forming a real-time image on a screen connected to the device. It can be helpful for navigation under water. However, it should preferably be considered a support device for underwater drones and vehicles than a form of technology for research.

Side-scan sonar is one of the most effective tools for detecting underwater heritage. The device emits acoustic signals at an incline in the direction of the bed, creating acoustic shadows when the signal comes into contact with an object, which helps identify the type of object surveyed. The data can be used to create depth maps and visualisations of objects found.
One of the more sophisticated devices is the multi-beam sonar. It emits many acoustic signals at the same time, producing a point cloud with depth topology information (like LiDAR data on land). These data can be processed to create 3D surface models. This method is widely used in marine geology and biology, but is also essential for surveying underwater archaeological sites.
A sub-bottom profiler can be used to detect objects that have been washed or buried in the bed of the body of water. Its signals penetrate the surface of the bed, displaying the data as a cross-section of its profile (similar to GPR on land). However, there are a few limitations in its use. For example, it can only be used in relatively shallow waters and it tends not to register wooden structures.

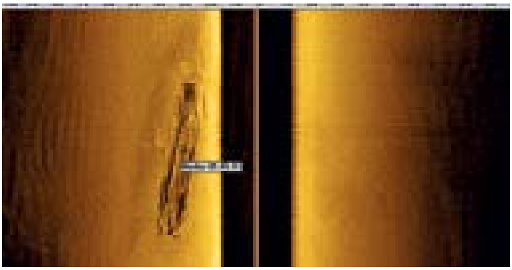
**Survey procedure**

Side-scan sonar is the most common option for surveying underwater cultural heritage sites. Researchers use it to look for new objects and for various monitoring activities in the sea as well as inland waters. It is also one of the affordable and most mobile technologies. Depending on the depth of the body of water surveyed, a side-scan sonar can be set up in two ways: at depths of up to 10/20 m, the sonar can be attached to the side of the watercraft, and, if necessary, lowered into the water and lifted out if held by a handle. However, at depths of more than 20 m, the signal emitter of the device is attached to a torpedo-shaped system, which is connected to a tow line, put in water, and dragged behind the ship: this is referred to as the tow fish.



Side-scan sonar surveying principle
(Adobe stock)

When making a measurement, the sonar emits two spherical signals in the direction of the bed. The area covered by the measurement can be adjusted on the screen connected to the sonar device. The data obtained are displayed on the screen as two parallel visualisation columns, with a black space dividing them, which represents the part of the bed directly below the sonar that is not picked up by the signals. The resulting image shows the bed on a plane. When a sound wave is transmitted through an object and reaches the surface of the object, part of that signal scatters. The scanner calculates the scatter angle to detect the outline of the object. Meanwhile, there is shadow cast behind the object on the side opposite to the direction of the signal, giving the impression of a three-dimensional image in the visualisation. Side-scan sonar measurements do not provide information about the materials and texture of objects; however, metal, stone, and wooden objects reflect the signals better and appear darker in the scan than sand or other materials of the bed. At the same time, the measurement process produces data about depth, water temperature, etc.



Survey visualisation
(author: A. Vilks)

Measurements are most often taken from a boat or a small ship capable of effectively performing the necessary manoeuvres. The optimum watercraft speed for data collection is 3–4 knots, although if the body of water is more than 40 m deep, the speed should be no more than 2 knots. The scanning route must be planned before the measurements are taken. Depending on the settings of the device, the middle zone below the sonar where data are not collected is typically 10–15 m wide on each side, resulting in a 30 m wide zone without data. To compensate for this and to collect data that are as complete as possible, the route must include zone overlaps, to eliminate the risk of losing important information about the area studied. The most convenient approach is to plan the route in parallel lines, U-turning the watercraft around at the ends of the lines. The route can be prepared in advance and entered into the vehicle's navigation system for easy tracking. Handheld navigation devices can also be used for tracking the route.

## Survey requirements for an object and expected actual work time

Weather is important in surveying work as it can affect data collection quality. When scanning with side-scan sonar at sea, the maximum permissible wind speed for a successful and high-quality collection of data is 6 m/s, and the best direction of the wind from the coast towards the sea, as this causes less disruption due to waves. In inland waters, wind speed mostly has no effect on surveys. Precipitation also largely does not affect the quality of the scanning data, although it is a major factor that reduces the comfort of workers during the process. Underwater currents and other natural phenomena can affect data precision: for example, sound waves propagate faster in freshwater than in denser saltwater, while freshwater often contains a much larger amount of organic microparticles, which can reduce the quality of the data. If the water contains a high quantity of microparticles, it is recommended to scan at a lower signal frequency, of around 400 kHz. In bodies of water where organic matter does not interfere with the scanning, surveys can be conducted at a frequency of 900 kHz, for higher data resolution. If such high-frequency scanning is performed in water with a high concentration of microparticles, there is a risk that the measurement detects these particles, significantly degrading the measurement results. Scanning is best done in late spring or early summer, before organic microparticles propagate.

In terms of the location where it can be performed, side-scan sonar scanning is usually possible in bodies of water with depths of up to 70 m. The lowest depth at which the side-scan sonar can perform measurements is about 2 m. The duration of the work is relatively difficult to predict accurately as it depends on the weather (wind speed, etc.), the distance of the area from the boat's mooring location, the size of the area studied, and other factors. Sometimes it is necessary to repeat measurements at certain locations to obtain more precise data about an object detected during the scanning. Surveying an area of 1 km2 takes on average about 8–9 hours. Arriving at the scanning location is usually the most time-consuming part. It is recommended to organise the work in shifts, ideally with multiple drivers.

## Raw survey data and necessary post-processing

The measurements of a side-scan sonar are initially displayed on the screen connected to the device, viewable from the top and the sides in real time. The visible information is a sufficiently reliable representation of the data obtained to make it possible to take decisions on immediate corrections, i.e. whether to re-scan something if certain measurements were of low-quality.

After the scanning, the data can be viewed and processed in the corresponding software. Raw data cannot be viewed on a computer without processing. Once they are imported into the software, they can be used to create depth maps and obtain visualisations of scanned objects for the purposes of research or simple viewing. Data processing can mostly be learned through various free tutorials online. The software most commonly used includes *SonarWiz* (*Chesapeake Technology*), *HIPS and SIPS*(*CARIS*), etc., some of which available for free. After pre-processing, the data can also be saved in other formats, such as images or geospatial data, and integrated into geographic information systems.

### Linking to a coordinate and elevation system (as necessary)

The device that receives the scanner data is linked to the navigation system and automatically determines the exact location of the scanner. However, it is important to have a universal coordinate system installed for navigation, which in most cases is WGS84. This makes it easier to convert the data in post-processing, for later work with the respective geographic information systems. When later importing the data into software, one must specify the corresponding coordinate system.

### Primary deliverables formats, file sizes, and factors affecting size

The scanning process produces data in various file formats, which usually differ depending on the manufacturer, but the most common one is XFT, which is one of the industry standards for hydrographic data and, because of this, is also easy to convert. This format is the most convenient option for saving and using in various software, including with a time offset.

### Defining survey requirements.

### Information necessary for the person performing the survey

| ***Object information required for the service provider to prepare a quote*** |
|---|
| Coordinates of the area surveyed, cartographic materials |
| Survey goal description |
| Frequency at which the measurements should be made |
| Coordinate system for the measurements |
| Desired file format for deliverables |

| ***Survey requirements*** | ***Options*** |
|---|---|
| *Minimum precision* | *400 kHz/900 kHz* |
| *Colour* | *coloured (mostly yellow/black)/black and white* |
| *Primary formats for deliverables* | |
| *Cartographic material* | *.pdf, .xml (as necessary)* |
| *Raw bathymetric data* | *.xft* |
| *Photos* | *.jpeg or .tiff, .png, .raw (as necessary)* |

# 7 SECURE LONG-TERM STORAGE OF DATA

Secure long-term storage of large volumes of 3D survey data necessitates following a number of best practices that ensure the integrity and availability of the data, and their protection against hardware failure or obsolescence. The principles and recommendations for the long-term storage of 3D data are provided below.

## 7.1 USING DIFFERENT DATA STORAGE METHODS AND BACKUP COPIES

It is always recommended to keep multiple backup copies and to store your data in at least three different locations:

- primary storage (where data are used on a daily basis),
- local backup copy (e.g. external hard drives or a network-connected server),
- external/global backup copy (cloud storage for emergencies).

The 3-2-1 backup rule: save 3 copies of your data, store them on 2 different types of storage media, and keep 1 copy off the local system. This principle guarantees access to your data even if one of the systems is not available.

## 7.2 CLOUD FOR LONG-TERM STORAGE

Cloud services offer a scalable, reliable, and affordable solution for storing large amounts of data. Choose the service providers that offer:

- automatic backups and copying across multiple geographic zones;
- data integrity checks to prevent data corruption;
- cold storage solutions for archival data that do are not accessed frequently, but require secure storage.

## 7.3 CHOOSING FILE FORMATS AND DATA COMPRESSION

Use open and well-supported formats. For long-term storage, choose file formats that are more likely to be supported in the future. Common 3D data formats include:

- .PLY (polygon file format),
- .OBJ (object file),
- .LAS/.LAZ (LiDAR data) point clouds,
- .E57 (open format for 3D point cloud data).

Lossless compression. Compress your 3D data using .LAZ (archived LAS) or ZIP formats to reduce file size without losing information.

## 7.4 METADATA AND DOCUMENTATION

When storing metadata, make sure they contain all data and accompanying files with information about the source, equipment used, settings, coordinates, and any other processing details. The structure of the metadata must remain constant: exactly as they are immediately after the survey and after they are exported from the survey device. This will ensure that the data can also be used in the future. Keep a clear folder structure and consistent file names to make data easy to manage and find.

## 7.5 STORAGE MEDIA FOR LONG-TERM ARCHIVING

**Magnetic tape.** LTO (linear tape-open) magnetic tape is a reliable and affordable solution for long-term archiving. It offers high capacity and, if properly stored in a controlled environment, lasts for more than 30 years.

**Optical storage** (*Blu-ray*). Archive-grade *Blu-ray* discs (e.g. M-DISC) offer long durability (up to 1000 years) but may not be suitable for very large data amounts due to their lower capacity.

**SSD and HDD**. These should be regularly replaced with newer discs every 5–10 years, as their durability and reliability diminish over time.

## 7.6 DATA RECOVERY PLAN

Develop a 'Emergency data recovery plan' for your 3D data that includes:

- procedures for recovering data from backup copies;
- a plan to migrate the data to newer formats or systems as technologies advance;
- regular inspections of backup copies to confirm they are functional.

## 7.7 DATA SECURITY

Encrypt sensitive data before saving them, especially when using cloud services, to protect them against unauthorised access.

Use password-protected archived data when transferring them between different storage systems.

## 7.8 DATA MIGRATION AND FUTURE ABILITY TO USE

Regularly update storage media and software to avoid their obsolescence. Hard disks and other storage media have a limited service life, so migrate your data to new storage media from time to time.

It is critical to be aware of the latest storage technologies that can offer better performance, reliability, or cost-efficiency.

In order to enable the storage, management, presentation, and distribution of the collected 3D data, in 2025, it is planned to add a 3D data management and visual support module for the Mantojums cultural heritage management information system (https://mantojums.lv/) controlled by the NHB. This module will provide a number of important functions.

– The 3D visual data of cultural heritage sites will be stored in a single file store at the Swift data centre (Open Stack Object Store).

– The system will have a mechanism for authorised system users (cultural heritage site owners or NHB staff) to upload 3D data through the system's user interface, and make it possible to produce metadata, in keeping with the needs of business users. Authorised users will be able to upload full-format 3D datasets and reduced-format files that will be used to preview the system visualisation model. Data checking and updates will also be made possible.

– The reduced-format 3D files will be linked to the respective cultural heritage site, enabling system users (both authorised and public) to preview the data and, on request, view the visualised data using the built-in 3D model/point cloud viewer.

One of the goals of the NHB is to collect and securely store in a single resource the 3D data of cultural heritage sites obtained based on a commission by the institution, also making it possible for owners of cultural heritage sites to save these extensive data in a secure environment and easily access them when needed. If public interest in such a service arises, then in the future, the system could also be used to store 3D data for other sites of cultural and historical significance that do not have the status of a cultural heritage site protected by the state.

The second goal is to enable the public to view 3D data on Latvia's cultural historic heritage without the use of special tools (specialised software), possibly eventually also integrating these data into geospatial data solutions. This would be an important contribution to the popularisation of cultural heritage, promoting educational processes and tourism, which could encourage the creation of new private-sector services.

# SPECIFIC EXPERIENCE IN THE USE OF MODERN TECHNOLOGIES IN NORWAY AND LATVIA

## 8 | LIDAR DATA IN MANAGING AND RESEARCHING ARCHAEOLOGICAL HERITAGE

**Jānis Meinerts**

**KEYWORDS:** ***LIDAR IN ARCHAEOLOGY, GIS IN ARCHAEOLOGY, ARCHAEOLOGICAL SURVEY, HILLFORTS***

Remote sensing plays an important role in modern archaeology, as it can be used to remotely study large areas, enabling the organising of targeted expeditions to sites where identified objects have certain features. Airborne laser scanning and the 3D data it produces (LiDAR) serve as a valuable source of information for specialists, as it provides an accurate and detailed representation of the topology of the ground surface, with high precision and point density. This chapter looks at two examples of how LiDAR data have been used in practice, discovering 77 new hillforts in Latvia and 12 Stone Age sites around Lake Burtnieku.

### NEW HILLFORT DISCOVERIES IN LATVIA USING LIDAR DATA, 2018–2021

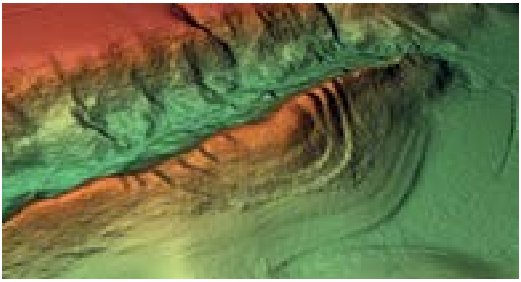
**Site history.** The systematic survey of hillforts within the territory of Latvia began in the second half of the 19th century, but experienced a particular rise in the 1920's. Most of the known hillforts were recorded before the Second World War, mainly based on folklore sources and information provided by the local population. Active archaeological research was carried out alongside the discovery of the hillforts. As visually recognisable and folklore-related items of archaeological heritage, they have become nationally significant symbols in literature and art. By 2018, approximately 480 hillforts were known in Latvia, although not all of them met the formal characteristics of hillforts. In the preceding decades, the discovery of new hillforts had been a rare occurrence.

**Method used.** Freely available continuous LiDAR scanning data of the territory of Latvia, commissioned by the Latvian Geospatial Information Agency (LGIA) and produced between 2013 and 2019, were used for the identification of the hillforts. The scanning was primarily done to facilitate the production of topographic and specialised maps and to obtain information relevant to the defence sector. The precision of the scanning, given the area scanned and the primary goals, can be considered very good, with at least 1.5 points per 1 m2, vertical precision of at least 12 cm, and horizontal precision of at least 36 cm. Most of the time, the data coverage achieved is well above the minimum requirements for a scan, although the density of the data varies from one region and local area to the other. This is the primary and almost the only LiDAR scan dataset used for detecting, researching, and protecting archaeological heritage in Latvia. In addition to the visual review of LiDAR maps, the process of discovering hillforts involved extensive use of 3D terrain visualisations based on LAS point cloud files. The shape of the terrain of the hillforts was measured digitally, because the availability of LiDAR data made it possible to omit the necessity to survey the terrain of the hillforts using time-consuming and not always fully precise traditional methods.

The FugroViewer software was used to quickly view point clouds in a three-dimensional environment and perform various measurements. This software can open freely downloadable LAS files without having to convert the data to other formats. It is a piece of free software that is easy to learn and can excellently perform all the assigned tasks: switch on and off various point layers (buildings, terrain, high and low vegetation, etc.), generate a two- or three-dimensional surface model in different colour palettes, make vertical measurements, and create hillfort profiles.

Unfortunately, FugroViewer cannot be used to export images and other file formats of a quality high enough to be used in publications and as illustrations in communication with the public. The paid planlauf/TERRAIN software was, therefore, used for this purpose. This software makes it possible to work with very large areas and data amounts, and is perfect for three-dimensional visualisations of hillforts. It can also be used for a very broad range of tasks, modifying and editing the point cloud. It has a few ways of visualising the terrain and many options for exporting the visuals in different file formats and sizes: as images, videos, rotatable 3D models.

Most point cloud processing software allows you to use the elevation value set for every point to automatically generate elevation contour lines similar to those commonly seen on topographic maps and traditional surveys of hillforts or other archaeological sites. Creating a terrain model with contour lines based on LAS files like this takes only ten or twenty minutes, compared to surveying in the field and the subsequent preparation of the survey data, which all in all can take up to several days.



3D elevation model of a hillfort discovered in 2018, prepared using LGIA LiDAR scan data and planlauf/TERRAIN software (author: Jānis Meinerts)

**Results obtained.** The search for new hillforts on LiDAR maps was done by dozens of enthusiasts of Latvia's earliest history without any particular incentives or institutional framework; a few professionals in the field also joined the process on their own initiative. These volunteers studied the LiDAR maps and showed locations with hill-fort-like terrain to professional archaeologists. This information was handed over to Juris Urtāns, an archaeologist and professor at the Latvian Academy of Culture, who coordinated and conducted further surveys of the hillforts discovered. Between 2018 and 2021, 77 new hillforts in Latvia were found, inspected in the field, and identified as genuine archaeological sites. This work, largely based on the initiative of citizen scientists, made a significant contribution to the map of hillforts in Latvia, especially in the Latgale region, where the number of known hillforts increased by more than a quarter. As in the case of other similar uses of LiDAR data, the study of hillforts revealed that only experts in the field can make a reliable judgement on the archaeological significance of a site by inspecting and assessing it in the field. The catalogue of the hillforts created as a result of the survey primarily uses three-dimensional models of hillforts prepared from LAS files as illustrative materials, replacing traditional surveys.

## ARCHAEOLOGICAL SURVEY OF STONE AGE SITES IN THE LAKE BURTNIEKS AREA

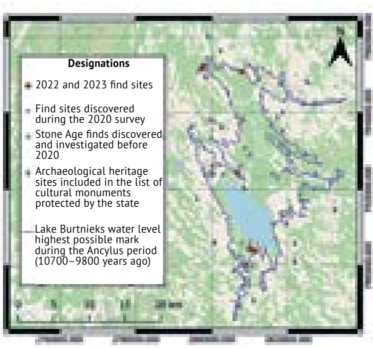
### Site history

The earliest evidence of Stone Age settlements in the area of Lake Burtnieks dates back to the 19th century, when the first archaeological research was done of the Riņņukalns settlement. This research continued in the 1960's and 1970's, with extensive excavations in the Zvejnieki settlement and burial complex. The outstanding scientific significance of these Stone Age sites in the context of Northern Europe as a whole, as well as the unique preservation conditions of the Zvejnieki burial site, contributed to the continued interest of researchers in these sites well into the 21st century, when new research was carried out using innovative excavation and recording methods. Simultaneously with the archaeological research, the first decade of the 21st century saw the first geological studies under the leadership of Guntis Eberhards aimed at reconstructing the shoreline of the Burtnieks palaeolake, opening up new opportunities for the identification of Stone Age sites and the need for more extensive surveying in the shore areas of the palaeolake.

## Method used

Freely available continuous LiDAR scan data of the territory of Latvia were used for the modelling of the shorelines of the Burtnieks palaeolake. In 2020 and 2022, the shorelines of the palaeolake were modelled on the basis of a LiDAR DEM model (the survey was led by archaeologists Mārcis Kalniņš and Aija Macāne), whereby the level of the lake was raised in the QGIS software to the elevation marks discovered as part of G. Eberhards' studies, which varied from 42 to 47 m above sea level during the various Stone Age periods (in the LAS 2000.5 Latvian normal elevation system). Afterwards, areas where the ground surface was not covered by vegetation were surveyed in the field, with probing and test excavations in the discovered potential settlement areas.

The work revealed the need to improve the study methodology, and in 2023 geographer and GIS specialist Edijs Breijers was involved in the project to develop new models of the shorelines of Lake Burtnieks that take into account the glacial isostasy feature characteristic of the region, i.e. the uneven rising of the Earth's crust during the retreat of the ice cover (previously, the Lake Burtnieks area was thought not to have been affected by this process). For modelling the shorelines of the Burtnieks palaeolake, E. Breijers used the methodology he developed during his studies of the shorelines of the ancient Ventspils lagoon on the Baltic Sea coast. The essence of the method is to repeatedly perform the automated processing of LiDAR LAS point clouds, with the resulting data then processed using the various capabilities




Shoreline model of the Burtnieks palaeolake (highest lake level: 50 m above the sea level) and ancient sites discovered along the shores of the lake developed in 2023
(authors: Edijs Breijers un Mārcis Kalniņš)

of various QGIS software and other modelling tools, to finally produce a new shoreline model tailored to the local conditions that takes into account glacial isostatic processes, among other things.

### Results obtained

The archaeological survey, based on the shoreline patterns of the palaeolake, revealed a total of 12 Stone Age find concentration sites, 4–5 of which are deemed Stone Age settlements. Preliminary excavations were carried out at several of the discovered archaeological sites, adding to our understanding of the Stone Age settlement structure around Lake Burtnieks and confirming the accuracy of the method used. In 2023, during the survey using the updated shoreline model developed by E. Breijers, the palaeolake shorelines at the northern end of the lake were inspected at the modern absolute elevation level of 50 m above sea level, recording new Stone Age sites. These sites had not been checked during prior discovery expeditions because they were not within the shoreline zone of the lake's highest water level at 47 m above sea level. Precise modelling of ancient shorelines, which is a methodologically and technologically complex process, highlighted the need for collaboration among researchers in different fields. Although good results had been achieved even with simpler methods (raising the water level in the lake using an unedited DEM model), which the archaeologists were able to apply themselves, using a specifically designed and highly detailed shoreline model demonstrated clear advantages.

## DATA MANAGEMENT, FUTURE USE

The raw LiDAR scan data used are stored by LGIA, and anyone interested can freely download them in LAS file format on the LGIA website [1]. LiDAR maps are available as map layers in the LGIA [2] and LVM GEO [3] map browsers, and, in derived and republished form, in several other public map browsers as well.

### Hillfort discoveries in 2018–2021

The descriptions, maps, and photographic record materials of the identified sites are stored in the archives of the NHB Cultural Heritage Information Centre (CHIC), while the locations of the recorded sites are mapped in the NHB Geographical Information System (GIS) database. Information about the discovered hillforts has been published in the field's research literature. Archaeological investigations have already been done in several of the discovered hillforts. In terms of cultural historic heritage protection, in 2022, the Latvian Academy of Culture proposed that the discovered hillforts be included in the list of state-protected cultural heritage sites. In the context of the hillforts discovered, LiDAR data significantly facilitated not only their precise mapping in the GIS database, but also the preparation of the documentation necessary for their inclusion in the list of cultural heritage sites, including the establishment of their individual protection zones. In everyday archaeological heritage protection activities, LiDAR maps also make it much easier to assess the impact of various construction-related work on archaeological heritage.

### STONE AGE SITES AROUND LAKE BURTNIEKS

Archaeological survey and research reports are kept in the archives of NHB CHIC. The results of these studies have been published in research literature.

[1]https://www.lgia.gov.lv/lv/Digit%C4%81lais%20virsmas%20modelis?fbclid=IwAR1PIaFfaN-dRuu9J4Nng_8nwOoxPRFKEOZAmH-fk2-rZw73o5AFv5FQrrlQ
[2] https://kartes.lgia.gov.lv/karte
[3] https://www.lvmgeo.lv/kartes

# 9 | 3D SCANNING IN INDUSTRIAL HERITAGE MANAGEMENT AND RESEARCH

**Unn Eide, Stig Storheil, Åsne Dolve Meyer, Dag Endre Opedal**

The Norwegian Water Resources and Energy Directorate (NVE) has a responsibility to help preserve cultural heritage of national significance within the sector. In cooperation with The Directorate for Cultural Heritage, the NVE has listed some 230 sites related to watercourses and energy that we follow up in our case management.
The NVE's Museum Initiative was launched in 2003 in collaboration with the Norwegian Forest Museum and the Norwegian Museum of Hydropower and Industry. Our aim is to preserve the cultural history of Norwegian water resources through documentation and dissemination.
All the NVE's listed sites are technical and industrial cultural heritage, which brings some challenges in terms of preservation. Hydropower schemes and energy transmission systems are in constant development while in operation, expansive in extent and expensive to maintain once production shuts down. Documentation is therefore an important means of preserving the knowledge of the sites and the history of changes made to them. Part of the Norwegian Museum of Hydropower and Industry's work is documenting buildings/facilities as a follow-up for the listed facilities for which the NVE is responsible.

## DOCUMENTATION STANDARD AND REGISTRATION FORM

In most cases, it is the owners who are responsible for documenting the changes they make to their sites. In order to ensure a certain consensus and level of quality, the NVE has developed a standard for the documentation of sites in our sector (Yilmaz and Snekkenes 2019). The standard is mainly based on guidelines from Historic England, Historic American Building Survey/Historic American Engineering and The Directorate for Cultural Heritage. Standardisation makes the process of documentation more predictable and efficient for both owners and the NVE's case management.

The standard is incorporated into a digital registration form with links to examples and is also integrated with our media base and archive system. This ensures appropriate storage and accessibility, and facilitates the use of the documentation both in the present and in the future.

## METHODS

Before starting a project and choosing a documentation method, it is important to have a clear understanding of why documentation is necessary, who the documentation is intended for, what it will be used for, and the level of detail needed.

### Drone:

Photos taken from drones are useful for documenting large facilities and providing an aerial overview. Drones can be used externally, as well as internally in large spaces such as power stations and large industrial buildings. Compared to helicopter use, drones are cheaper, more flexible, and environmentally friendly, although both the range and photo quality are lower. However, drone photography requires access to expensive equipment and its use is more dependent on weather conditions. Regulations for drone use in Norway have been tightened in recent years, and it is important that all certifications and permits are obtained before proceeding. For an institution such as a museum or an owner of a site with limited resources and staff, keeping up to date with such certifications can be challenging.

### Photogrammetry:

Photogrammetry is using multiple overlapping photos to visualise a facility in three-dimensional form. This method is suitable for creating user-friendly models but requires large amounts of photo files that demand significant storage space. Therefore, careful planning and a conscious approach to what needs to be documented are essential. The lightning conditions should ideally be neutral when photographing. Practical implementation in the field requires thorough planning and awareness of the purpose. Models created with

photogrammetry can be georeferenced. Photogrammetry has a steep learning curve, and the most used software can be difficult and expensive to use. The detailing can be very good. However, to archive the most detailed models with good texture, one could combine photogrammetry with laser scans. This is, of course, an extensive and more expensive method. Some projects may need this kind of detailing, while others may not.
Example Longerak (*Longerak*), which is produced from photos from drone and dslr and Hakavik (*Håkavik*), which is only compiled from drone photos.

Hakavik power station.
(author: Stig Storheil/NVE)

Longerak power station.
(author: Stig Storheil/NVE)

## 360-degree photography and 3D models:

360-degree photography is well-suited for documenting and conveying indoor spaces. It can be combined with VR equipment, making it suitable for presentation to the public. 360-degree photography is essentially a 2D image composed of a series of overlapping photographs to allow users to pan sideways, up, or down. 360-degree photography can be combined with drone photography to comprehensively document and convey a facility from the outside and inside.
To incorporate depth data into the image, a 3D camera must be used. 3D-cameras are expensive, and often the models must be stored on 3rd party sites. The Norwegian Museum of Hydropower and Industry (Kraftmuseet) uses a Matterport 3D camera, both for documentation and for making models intended for the public.
Example Folgefonngata, Odda (*Oda*) https://kraftmuseet.no/arbeidarboligane


Model of Folgefonngata 11, worker housing with information for educational programmes. Kraftmuseet/ Norwegian Museum of Hydropower and Industry collection

## REGARDING STORAGE ISSUES FOR 3D FILES

When it comes to storing individual files, compilations of files and finished models, there is no simple and obvious way to best practice. For 3D files, as for the safeguarding of all types of media files, good principles for Digital Asset Management apply – good metadata, suitable systems for storage and safeguarding, as well as a consistent policy for storage.

All businesses that need to manage their own 3D files should make some important choices.

A central choice will be whether you want to store finalised 3D models as master files in your own system, or whether you want to entrust the storage to external web platforms, such as Sketchfab.

Another choice to consider is how to save the base files for models, which are often in the form of various photographic file types such as Jpeg, TIFF or raw files. You will need to consider what opportunities you have to compile the individual files that will form the basis for 3D models. These files can be saved as individual files with common metadata so that they can be easily compiled. There are alternative methods of compilation, for example, the use of virtual folders.

If it is desired to store finalised 3D models internally, there are several relevant formats such as OBJ, PLY, STL, gLTF/GLB. Many of these are so-called neutral formats with open-source code. However, they are often proprietary, with the main problem being that they are less widely used across systems. This also applies to raw format photographic files, except for Adobe's DNG format: the only de facto standard. Other formats are proprietary – being owned by manufacturers such as Canon, Nikon and Sony.

Different types of 3D software also produce their own project files such as Pix4D's .p4d files. For example, OPF is an open and freely available file standard for photogrammetry.

In general, the choice of 3D file format will depend on several factors; for example, which software both you and your collaborators will use. You should also think about the end use you envision for the models, for example 3d web or VR/AR.

Public enterprises must also comply with handover requirements to archive authorities for long-term storage of documents. This, of course, varies between different countries' legislation. In Norway, for example, there are no approved file formats for submitting 3D files as photogrammetric models. The Norwegian authorities also ask the timely question of whether it is even possible to define suitable file formats without any form of information loss.

## DISSEMINATION/3D MODELS AND MAPS

One way in which we use the documentation is in the presentation of the listed cultural heritage on the NVE's website. In addition to descriptions of the sites' history and development, photos, film and drawings, we also use maps and animations.

The combination of 3D models and maps especially help to visualise the different elements of the schemes, as well as their expanse and context in the hydropower landscape. We use GIS and mapping tools like ArcGIS Pro and ArcGIS Online to place 3D models into scenes, or 3D maps.

With ArcGIS Pro, you can upload one or more 3D models and place them into a scene. We have tested uploading models of the various elements of a hydropower scheme, and making animations which follows the water from reservoir to power station. Animations can be exported out in different film formats, and, e.g., presented on websites. As an example, Hakavik power plant dates from 1922 and was commissioned to produce power for the railway. It is one of Statkraft's oldest plants in operation, and a protected site (3D animation of Hakavik hydropower scheme ).

It is also possible to export 3D models and scenes to ArcGIS Online, or upload your own 3D models directly into an online scene. The advantage with ArcGIS Online is that it is web-based, and dynamic maps and scenes can be easily shared with project partners or the public.

## 3D-MODELS AS A PART OF A MUSEUM'S ACTIVITIES:

One way the Norwegian Museum of Hydropower and Industry has used 3D models is to provide digital access to buildings and facilities that are normally inaccessible to the public but have high educational and experiential value. This could include power stations or factory buildings still in use or closed for other reasons. It can also be an opportunity to give the public a preview of what they will experience in an already accessible museum building, allowing them to familiarise themselves before a potential visit. During the pandemic, museums all over the world opened their doors in this way to the public confined in their homes. 3D representations of museum

buildings can also be used to provide insight into buildings not normally open to the public, where the model becomes a kind of "24/7" museum.
360-degree photos and models created with 3D cameras can also be used to reach individuals with mobility issues, providing access to parts of buildings they would otherwise not be able to enter. Models can be presented on a separate screen in the exhibition or accessed via QR code links on visitors' own phones. The choice between 360-degree photography and 3D photography depends on several factors.
360-degree photography may be easier for the public to navigate and is often sufficient when presenting a room or a smaller part of an exhibition or a building. For an entire building, where visitors are invited to explore from their own PCs or phones, a 3D photo model is suitable. Both 3D models and 360 photos also allow for presenting the model on VR glasses, providing a more immersive experience than can be achieved on a screen.
The Norwegian Museum of Hydropower and Industry has used 3D models in several arenas for public use, ranging from entire buildings to parts of buildings. The models are available on our website and on Google Maps to reach a wider audience. During the pandemic, one of these models was adapted as the basis for an educational programme intended for students stuck at home. The advantage of 3D models is the ability to incorporate information points into the model, using museum archival and visual material for further exploration.
As a museum, it is also important to document our own exhibitions. In some cases (for small, simple exhibitions), regular photos may suffice, but primarily, the Norwegian Museum of Hydropower and Industry uses 360-degree photography for this purpose. This type of documentation is normally not intended for the public but can be presented to partners, artists, and others who have contributed material to the exhibition.

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# 10 | 3D DATA IN RESEARCHING AND MANAGING ARCHITECTURAL OBJECTS AND THEIR ELEMENTS

**Artūrs Lapiņš**

The management of built heritage objects and locations consists of working with existing buildings and structures. For this reason, documenting their current situation as accurately and comprehensively as possible is an essential and integral part of research, preservation, and restoration. The documenting task here is to conduct comprehensive 3D surveys of the object. This produces an up-to-date set of 3D data and a digital copy of the original cultural heritage site that can be archived. This significantly expands the scope of information about the cultural historic object. Meanwhile, the architect's task is to propose a solution to a specific problem associated with the preservation of the object, and to present it in a way that is as clear and understandable as possible. Surveying the existing environment using traditional methods is undeniably time-consuming, therefore, in design practice, which is the most efficient available technological solutions are used to document structures. Both traditional flat plane and spatial instrument surveys are used to document and plan the preservation of built heritage objects. The examples described demonstrate the potential for interdisciplinary collaboration between geomatics and architecture.

The demolition of **KULDĪGA CASTLE** (Jesus Castle) in the first quarter of the 19th century marked the end of an important medieval object that had existed for more than 600 years. It began in the 13th century as the castle of the Livonian Order's commander, was rebuilt for the Duke of Courland in the 17th century, and served for a long time as the economic and administrative centre of the region. Its complex, located on the road between Livonia and Prussia, also had a representative function. The layout of the historical centre of Kuldīga still demonstrates the function of the castle as the core element of a concentric defence system, so data on the extent of the lost fortifications contribute to the identity of the town.

A point cloud obtained via the airborne LiDAR ( light detection and ranging) process was primarily used for the analysis. These spatially georeferenced data can be used for surface terrain modelling, as well as for spatial matching. The digital terrain model (DTM) was used as the main tool for analysing the historic locations. The surface model can be used to clearly see the terrain features, making it possible to detect anomalies in the plane: i.e. depressions and protrusions. In Kuldīga, such an analysis revealed unevenness in the terrain, enabling in some cases the identification of surviving underground structures. The terrain model of Kuldīga castle site reveals the elevation above of the vaulted cellar, visible above ground, and the rampart fortifications in the south and west. The south-west bastion, the castle moat and the north side of the star fort are notable in the terrain. For further analysis, a combination of terrain orthographic projection and specialised survey reports was used. The combining of the terrain with the archaeological survey report may necessitate the updating of the line of the surrounding wall proposed in the latter. It probably followed the terrain still visible today, rather than crossing it obliquely, as was inferred from a small outcrop of the foundation in the north-western part. The combining of the terrain with the geophysical survey data, in turn, makes it possible to predict future exploration areas within the castle site. Adding terrain data to historical images and findings of studies of similar sites makes it possible to produce a theoretical reconstruction of the lost castle.

Plane deviations in the surface also enable the visualisation of vertical objects such as wall deformations. The construction of **RIGA CATHEDRAL** began in the 13th century. Between the late 14th and first half of the 15th century it was rebuilt as a basilica by raising the walls of the middle nave. Work on strengthening the foundations of the building revealed irregularities in the wall and ceiling planes. The cross-sections of the middle and lateral naves obtained from a point cloud (engineer: Māris Kaļinka) showed a displacement of the upper part of the northern wall of the middle nave towards the north (i.e. Doms Square), while the southern wall of the middle nave retained its verticality. A set of points (flat west-east drawing) was prepared for the inner plane of the north wall of the basilica part. A visualisation of its north-east coordinates in the form of a height map revealed that the most significant deformations were in the TR16 and TR15 bays, with the TR15 bay tilt forming gradually and the top of the bay deviating almost 40 cm from the vertical.

Converting a point cloud into a mesh makes it possible to carry out area calculations for determining the necessary conservation work. The cylindrical shape of t**HE NORTH TOWER OF CĒSIS CASTLE** with its many historical indentations and irregular side planes makes mapping its surface difficult, which impedes determining the actual area of the surfaces to be conserved. *CloudCompare* software was used for the further processing of the point cloud produced (engineer: Māris Kaļinka). The point cloud is segmented, reducing the number of points per file, thus reducing the size of each file. The classification of parts of the cloud was partly done through automatic detection of horizontal (floors) and vertical (walls) planes. Further classification of the cloud was done manually by extracting the facade planes, the opening board shutters, the roofing, etc., in the corresponding cloud projections and cross-sections. Redundant elements of the interiors (temporary wooden stairs) were removed. The classification of the resulting cleaned-up interior wall point cloud continued, spatially mapping the eroded and reinforced surfaces. The resulting dataset was converted into a plane for further geometric calculations.

In recent years, thanks to the development and availability of technology, the processing, visualisation and analysis of spatial data has become part of everyday practice for restoration architects. At the same time, in practical object preservation work, the software used to process the spatial data obtained from instrument surveys is only a tool that helps the researcher or designer visualise, analyse, and quantify the data associated with the understanding of a particular object. An architect's task, unlike that of a geomatics engineer, is not so much about accurately recording the current spatial situation as it is about creatively solving specific problems.

The instrument recording and architectural research of the Kuldīga Castle, which is not actively present in the cultural circulation, has led to new conclusions about its initial layout, marking possible directions for the possible future research of this site. Through technology, architectural research as an interdisciplinary research method enables a comprehensive approach to documenting, interpreting, and presenting cultural historic heritage, even for partially preserved cultural historic heritage sites.

In architectural research, instrument surveys allow repeated inspections and analyses of individual elements of the object and recording of their overall relationships, in addition to on-site investigations. In the future, as the instrument recording methods improve, such research could distance itself from the historic building itself even more. In castle ruins, this is already done in otherwise difficult-to-inspect and even dangerous areas. For example, the analysis of the silhouette of the upper part of the wall obtained from the instrument survey of the South Tower of the ruins of the Alūksne Castle made it possible to identify the locations of lost wall openings in the upper floor. By creating a detailed spatial survey as a virtual copy of a historic object, research can be carried out by remotely accessing the virtual database of the digital copy. Given the rapid development of data acquisition, processing, and distribution technologies, it cannot be ruled out that remote data analysis will become the future of architectural research and, possibly, of how the world is studied in general.

# 11 | 3D PHOTOGRAMMETRIC DOCUMENTATION OF A SHIPWRECK IN THE HIGH ARCTIC

**Øyvind Ødegård and Eleni Diamanti**

This paper is intended as an introduction to robot-based methods for 3D documentation of underwater cultural heritage. The target group of the paper is non-expert archaeologists and heritage managers with an interest in the state of the art, commercially available tools for data acquisition and data processing.

## *FIGARO* – A FLOATING WHALERY

Soon after Willem Barentsz discovered Svalbard in 1596, the waters surrounding the islands became a hunting ground for European whalers. Over three centuries, many thousands of ships hunted in these waters until the stock of bowhead whales was all but depleted. Around the beginning of the 20th century, the area saw a brief period of modern Norwegian whaling before all focus was on the southern seas from 1912. During these years, new technologies like exploding harpoon grenades and mechanised processing were developed. *Figaro* was the last wooden barque built in the Joh. C. Tecklenborg shipyard in Geestemünde, Germany in 1879. In 1902, it was sold to a Norwegian whaling company and equipped as a floating whalery, a prototype of the factory ships used in Antarctica. It was put into service in Svalbard in 1904, and in August 1908 it caught fire and sank in Trygghamna at the inlet of Isfjorden on the western coast of Spitsbergen. In 2007, it was discovered by the Norwegian Hydrographic Service during a nautical mapping campaign. It is currently the world's northernmost wreck surveyed by archaeologists.

## SURVEYING THE *FIGARO*

In September 2015, the wreck was surveyed by UNIS and NTNU with a REMUS 100 Autonomous Underwater Vehicle (AUV) using side scan sonar (SSS) for acoustic imaging (fig.1) and a small Seabotix LBV 200 Remotely Operated Vehicle (ROV) for visual inspection. The visibility was not great, but the wreck could positively be identified as the *Figaro* and appeared to be relatively well preserved. The wreck lies upright on its keel on a slight slope at a 20-30 m depth. Due to suspended sediments in the runoff from glaciers, visibility in the fjords in Svalbard is typically very poor during the warmer summer months. Conditions are likely to be better during the colder winter season when there is less runoff. In 2016, the UiT-NTNU Polar Night interdisciplinary research cruise aimed to do a close-range investigation of the *Figaro*, including a full coverage photo documentation for 3D reconstruction (Mogstad et al., 2020). For this purpose, a medium sized work class ROV (Sperre Subfighter 7500) with a stereo camera system was deployed (fig.2). A rough bathymetry model based on multibeam echosounder (MBES) data, SSS images and video from previous surveys was used to create a mission plan for the ROV operations (fig.3).

ROV operations were conducted from the Research Vessel Helmer Hanssen. The RV Helmer Hanssen does not have dynamic positioning capabilities, and operations had to be planned for anchoring as close to the wreck as possible, without risk of anchor chains disturbing the wreck site. Currents moved the ship, and the ROV was mostly outside the range for the acoustic positioning system. As a result, the planned ROV survey transects could not be navigated using the advanced features of the control system software but had to be piloted manually based on visual situational awareness and dead reckoning. Even with the a priori knowledge of the wreck site, and the printed map (fig.3) showing salient features for guidance, it was often challenging for the pilot and archaeologist to track the ROV's orientation and position relative to the wreck. Limited visibility and the large extent of the site could cause confusion and features of the wreck could appear visually similar, causing the same areas to be covered multiple times and other areas less than desired. In addition to ensuring coverage and data


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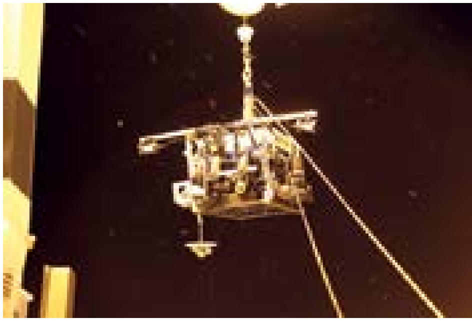
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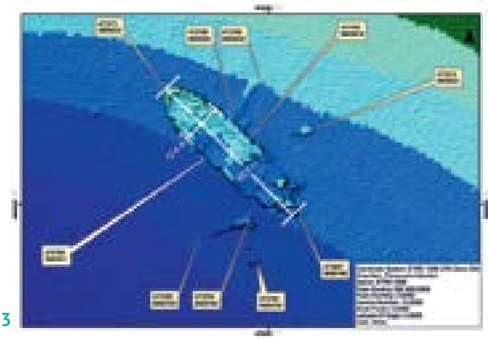
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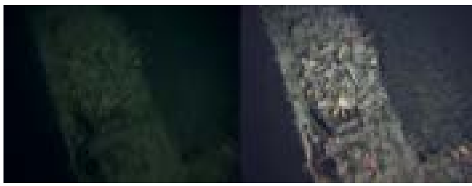
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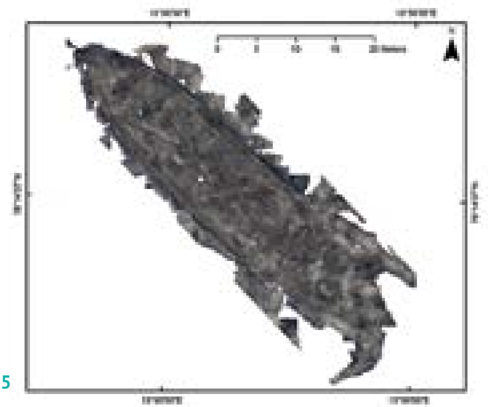
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quality, the pilots also had to keep track of the tether connecting the ROV to the surface to avoid it becoming entangled and possibly disturbing the wreck site. Over several hours of operations, the total cognitive workload of the two pilots and the co-piloting archaeologist was a strain and the survey efficiency degraded over time. The stereo camera system consisted of two Allied Vision GC1380 cameras spaced 31.5 cm apart at a 45 degree downward facing angle at the front of the Minerva ROV (fig.4). Two forward facing HMI lamps were positioned on the top of the ROV frame to provide illumination for the field of view (FOV) for the stereo cameras and the pilot's camera. The stereo cameras were synchronised to capture images at 0.5 frames per second. During two dives, 6:30 h on 12 January and 4:00 h on 17 January, 33,228 images of 1360x1024 resolution were acquired with the stereo camera system. A computer dedicated to capturing images from the stereo cameras was positioned in the control room next to the pilot's control station. The co-pilot or archaeologist could then keep an eye on the quality of the images in real time and advise the pilot accordingly.

All images from the stereo cameras, HD video and navigational data from the ROV were stored on their dedicated computers during operations. Immediately after end of mission, data was also stored on backup drives for redundancy. The research vessel was outside internet range for the whole mission, and no cloud services were available. Copies of image sets were put in work folders for processing during the campaign. All data from the missions were stored on NTNU servers after returning to Trondheim.

Underwater camera imaging is different from imaging in air. While you can have almost unlimited visibility in air, underwater imaging is typically limited to tens of metres or less. This is due to scattering and absorption of light caused by the inherent optical properties of the water and its constituents (phytoplankton, coloured dissolved organic matter, and total suspended matter). Scattering will mainly affect sharpness and contrast, while absorption will cause light at different wavelengths to be attenuated at different ranges. In shallow waters, the ambient light (the sun) can provide an evenly distributed illumination of a scene, while in deeper waters, or at night, placement of proper camera lamps is very important for how well your camera system captures underwater scenes. Features close to the lamps can "be burned" out with too high brightness, while features that are more distant in the same image can be too dark. Choosing camera systems with a high dynamic range and adjusting the ISO (light sensitivity) settings can, to a certain degree, mitigate such problems. In post processing, it is possible to reduce brightness in some areas while enhancing details in darker areas, thereby improving the image quality with regard to 3D reconstruction. How-

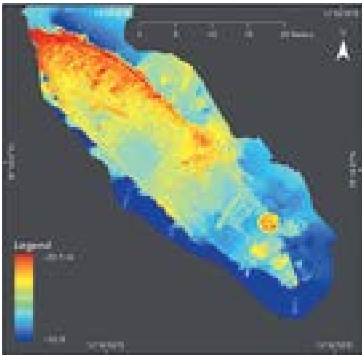
ever, doing this manually is a time-consuming process and using algorithms for batch adjustments is recommended (Nornes, 2018). For the image sets acquired from the *Figaro* a Contrast Limited Adaptive Histogram Equalization (CLAHE) algorithm was used to enhance details and even the brightness (fig.5). Deploying camera systems underwater also introduces refractions that can introduce geometrical errors in the 3D reconstruction. In addition to the geometrical properties of the optics in the camera system, salinity and temperature in the water medium are also determinant factors for refraction. A proper calibration of the camera system before data acquisition (typically using a calibration board) is required for the software to compensate for refraction errors.
The 3D reconstruction is done in much the same manner as for terrestrial sites, using the same software (e.g. Agisoft Metashape) for photogrammetric processing. However, images of underwater scenes can have environmental idiosyncrasies that demand extra manual efforts in the processing pipeline towards 3D reconstruction. Shallow water wreck sites are often covered with biological organisms such as kelp and seaweed. These tend to move with waves and currents and can make feature matching challenging during the photogrammetric processing. It is often necessary to do extensive manual tagging of salient features in images to improve the alignment accuracy and consistency and compensate for the featureless areas. Crustaceans, starfish, etc. also move around on the seabed and can sometimes introduce errors even in the manual feature tagging. The latter was particularly challenging on the *Figaro* when trying to merge image sets acquired five days apart. Several models were made after iterations of manual tagging and selection of images, gradually creating a more coherent 3D reconstruction of the wreck site. Georeferencing was done by matching stems and other prominent features in the images and photogrammetry model with the existing MBES data.

## RESULTS

A nearly complete 3D reconstruction of the *Figaro* was made based on the data acquired during the 2016 Polar Night research cruise (fig.6). The wreck measures 54 metres long and 11 metres wide, with a field of debris and detached structures surrounding it. Based on the 3D reconstruction, it was possible to compose a comprehensive site plan and other derived visualisations of the wreck site for archaeological interpretation (fig. 7-10)

## CONCLUSIONS

Planning is of high importance for successful 3D documentation of large areas and structurally complex wrecks. Typical goals for UCH sur-



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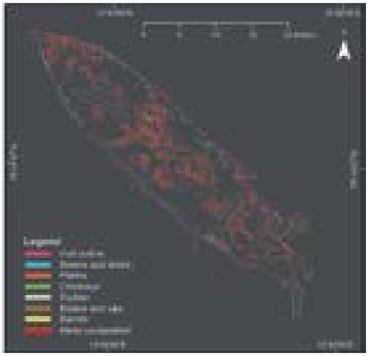

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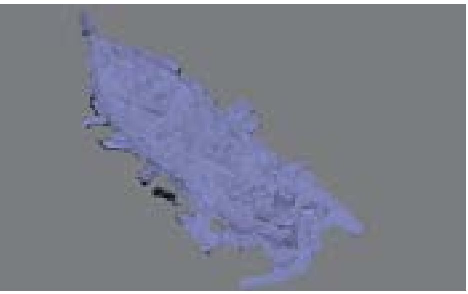
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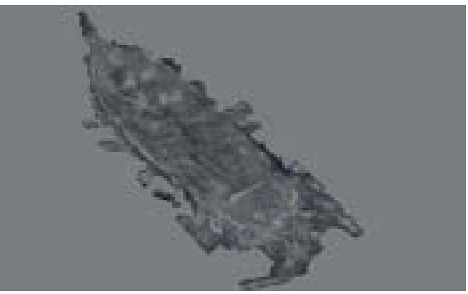
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veying and mapping are to ensure full data coverage and sufficiently high data quality for meaningful interpretation. In a structurally and spatially complex underwater environment with both natural and cultural features, an ROV pilot may easily become disoriented and lose track of their own position related to the area and objects of interest. A good positioning system to guide systematic coverage of the seabed by overlapping transect lines is very helpful. Superposing the position and orientation of an ROV on georeferenced images from SSS or MBES in the control interface can be very helpful for the pilot when surveying complex scenes. Poor visibility may negatively affect image quality, in turn impairing the ability to do accurate 3D reconstruction and mosaicking. Besides careful configuration and setting of lights and cameras, this challenge is usually best mitigated by navigating the camera closer to the object of interest. A lower altitude means a reduced camera FOV, requiring narrower spacing between transect lines, which again emphasises the need for good positioning and planning.

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# 12 | ACCURATELY DOCUMENTING ART OBJECTS IN A LABORATORY AND IN SITU

**Markus Sebastian Bakken Storeide and Jon Yngve Hardeberg**

**KEYWORDS:** ***#HERITAGE #MATERIAL CHARACTERISTICS, #LIGHTING, #RESOLUTION #LIGHT***

Pieces of art come in many shapes and sizes, ranging from paintings to sculptures and beyond. Documenting these in 3D involves retaining their aesthetic quality, which includes the shape and appearance of the object. This creates challenges in terms of complex and detailed geometry, as well as complicated surface characteristics. The complete appearance of a material is typically divided between the shape and the surface characteristics of colour, gloss, texture, and translucency. In a situation where we want to document an art object in 3D, both the shape and the surface are equally important. 3D scanning the shape of a small, glossy, painted ceramic vase might have very different challenges compared to those presented by a large, granite statue. The vase might be hard to capture due to its reflective surface, while the statue might be hard to access due to its size.

In research, when analysing the way light interacts with an object and how this is used in capturing both the 3D shape and the surface characteristics, specialised equipment is used to capture different features separately at high accuracy. In a controlled laboratory environment, we can set up the lighting conditions to fit our situation and acquisition system/method, but the lighting attributes are harder to control when acquiring data in-situ. In such situations, a more general approach can still provide satisfactory results, while having limited accuracy. Here, we describe the processes we used to analyse two very different objects that propose different challenges. One is a baptismal font with small, local surface details and rough surface material, and the other is a colourful surface with some 3D shape. One was analysed in situ, and the other in a laboratory.

For both cases, two different structured-light scanners were used. The Artec Eva has a 3D point accuracy specification of 0.1mm, with white light flashbulb illumination and a built-in colour sensor. It uses an internal LED array consisting of 12 white diodes as illumination for the colour acquisition. All Artec data is processed in the proprietary software Artec Studio 15.

Contrastingly, the Einscan Pro HD has a 3D point accuracy specification of 0.045mm using blue light illumination. Blue light illumina-

tion is less susceptible to geometric errors caused by surface colour and gloss, due to the narrower bandwidth of the projected light. Colour is aquired from a Colour Pack attachment connected through a USB 3.0 placed at a slight angle from the 3D cameras and the projector. It provides no specification for the illumination during 2D acquisition, so it is assumed that it uses ambient light during colour capture. All Einscan data is processed in the proprietary software EXScan Pro.
Eidskog Church is located in Matrand, Eidskog Municipality. The current church dates from 1665 but there is proof to show that the site has previously featured two stavechurches from as early as the early-1200s. One of the surviving objects is a soapstone baptismal font assumed to be nearly 1000 years old. It features various signs of damage and repair from over the years, but has many of the engravings still visible. Additionally, the font features carvings in the surface that are nearly invisible to the naked eye due to the rough surface texture of the object, but which become clearly apparent when the object is inspected in 3D without colour information. The soapstone material has a rough texture with high specular reflectance from certain angles, obscuring these small-scale details in the noisy variation of colour and gloss.
In both cases the baptismal font was scanned in the natural illumination of the church interior, coming mostly through large windows in the sidewalls. Due to the large space and the font's location in the middle of a large room, the illumination was mostly uniform. The font was uniformly scanned from all directions, dividing the surface into 8 different scans with approximately 40% overlap. These scans were subsequently fused to create the final 3D model. The results of the scans next to the original object can be seen in Figure 1.

1

Real image | *Artec Eva* | *Einscan Pro HD*

As for the specifications, the Einscan Pro HD generated a denser 3D point cloud than the Artec Eva, but both yielded satisfactory results due to the number of scans used to generate the final point cloud.
For colour information, both structured light scanners featured simultaneous colour acquisition during scanning. The final colour texture is a fusion of several hundred images of the object from various angles that are projected onto the surface. However, due to the different specifications of the scanners, they generated quite different results for the final colour texture. Colour from the Artec Eva scan seems to be good on a perceptual level, while the Einscan Pro HD texture has a clear green tint. We suspected this was due to the undocumented lighting conditions of the church, so we tested the colour output of both scanners in a controlled enviroment.

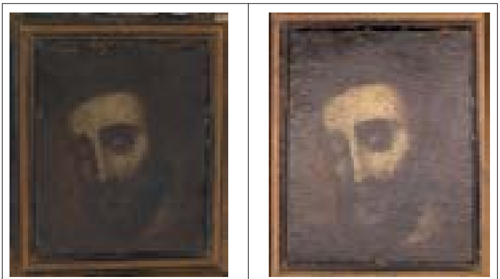
2

*xRite* Colourchecker | *Artec Eva* | *Einscan Pro HD*

Here, two standardised colourcheckers are scanned in the controlled illumination of a light booth, granting a uniform spatial and spectral light distribution across the surface. We can see that, while the colour differences between the two scanners are lessened, they are still apparent due to the differences in the acquisition tool itself. This example shows how some cameras are more sensitive to lighting changes than others, resulting in possibly very varied colour results. Each scanner's internal colour processing is different, but unfortunately, due to colour being an afterthought in most 3D software, there was little option to do colour correction without adding another manual step to the pipeline.
The second case study is an old painting possibly by the Spanish baroque painter Jusepe de Ribera. It is a portrait painting with very dark pigments, and the surface features several cracks and patterns due to age and wear. Even though the pigments are very dark, they

also have a very glossy surface, making it hard to capture the colour correctly with image-based techniques directly. Scanning was conducted in a laboratory setting under the controlled illumination of a lighting booth.

3



*Artec Eva* | *Einscan Pro HD*

The captured geometry of this object is much smaller than that of the baptismal font, and distributed over a smaller area. Using both scanners, we captured 3 different scans with 100% overlap to factor out the possible geometric errors generated by the glossy material from different angles. For each scan, the painting was rotated 90 degrees to yield a different imaging direction. In this situation, we saw a clear improvement in geometric accuracy using the Einscan Pro HD scanner, due to its increased 3D accuracy and blue-light projection. But still the colour image of the Einscan Pro HD scanner is more affected by the gloss than the other, even though the 3D geometry is less affected.
These case studies show that the results of any 3D acquisition are highly dependent on the acquisition system, the lighting conditions, and the appearance properties of the object in question. Understanding the intricate interactions between appearance characteristics allows us to select the best tool for the job, and set up lighting conditions that adhere to the advantages of our acquisition system while limiting the disadvantages. No system can provide complete documentation of an object with the correct shape, colour, and other appearance characteristics. However, focusing on specific attributes and designing the acquisition process thereafter can provide very good results, regardless of challenges.
If one wishes to have the most accurate 3D data along with accurate surface characteristics like colour and gloss, we recommend trying to limit the interactions of these characteristics with each other during segmented acquisition of each individual feature. Subsequent fusion of the isolated data should create a cleaner and more accurate final digitisation of the objects compared to a complete one-time acquisition.

# 13 AFTERWORD

With the gradual integration of modern technologies, the field of surveying, documenting, and restoring of cultural historic heritage has undergone significant changes. Innovations such as 3D laser scanning, photogrammetry, reflectance transform imaging (RTI), and advanced digital modelling techniques have significantly improved the way we perceive, analyse, and preserve cultural heritage. These technologies, methods, and devices offer a new level of precision and access, enabling more precision in cultural historic heritage preservation projects and facilitating the greater involvement of the public.

This handbook explores a range of modern technologies and methods that combine traditional approaches to heritage preservation with modern technological solutions. With today's capabilities, heritage specialists and heritage site owners can document historic buildings, artefacts, and landscapes in an accurate manner, which in turn contributes to their sustainable restoration and management.

Although technology offers vast opportunities, it also requires continues adaptations and responsible implementation. The cultural heritage sector must be flexible, balancing innovation with ethical considerations and long-term sustainability. As new tools and technologies develop, it is essential for experts, institutions, and policymakers to work together in making effective use of these opportunities.

We hope that this handbook will be a good reference for heritage specialists, managers, and practitioners who seek to integrate modern technologies in their work. By adapting to new trends, we strengthen our capacity to protect and preserve cultural heritage, ensuring its sustainability for future generations.

This handbook has been created through a collaboration between the Riksantikvaren (Norway) and the National Heritage Board (Latvia) as part of the EEA and Norway Grants 2014-2021 Bilateral Relations Fund Strategic Initiative titled "3D Scanning and New Technologies in Cultural Heritage Management." This initiative reflects our shared commitment to preserving and protecting cultural heritage through innovative digital technologies.

# 14 DATA VIEWING SOFTWARE

Data processing involves the use of a variety of specialised software, the choice of which often depends on the device used and the format of the raw data. The most extensive range of software is available for the post-processing of photogrammetric data (photographs), in which images are used to produce point clouds, 3D models, or orthophotos. The post-processing of raw data obtained through other technologies is most often done using software supported by the manufacturer of the device.

In order to use the work carried out by specialists, it is important for the end-user of 3D surveys to know about free-access software that makes it possible to view different types of 3D deliverables. Below, this section offers an overview of the most common types of 3D data deliverables, their formats, and the corresponding viewer software.

### Overview of free 3D point cloud viewer software

| Software | User level | Supported formats | Best For |
|---|---|---|---|
| **CloudCompare** | Intermediate+ | .las,.laz, .57 u.c. | Advanced editing and analysis |
| **Potree** | Beginner | .las, .laz | Quick and easy web-based viewing |
| **FME Data Inspector** | Intermediate | .las,.e57 u.c. | Data visualisation within workflows |
| **LASzip and LASview** | Beginner | .las, .laz | Simple LiDAR data inspection |
| **Fugro Viewer** | Beginner | .las., laz | Lightweight and simple inspections |
| **Plas.io** | Beginner | .las, .laz | Web-based, drag-and-drop viewer |
| **Point Cloud Viewer by Autodesk** | Beginner+ | .57, .rcs, .rcp | Easy .e57 and Autodesk file viewing |

### Overview of free 3D mesh and solid model viewer software

| Software | User level | Supported formats | Best for |
|---|---|---|---|
| **Blender** | Intermediate+ | .obj,. stl, .ply, .fbx u.c. | Advanced modelling and rendering |
| **MeshLab** | Intermediate | .obj,. stl, .ply u.c. | Mesh cleaning and processing |
| **View3D (Windows 3D Viewer)** | Beginner | .obj,. stl, .gltf, .fbx u.c. | Basic viewing on Windows |
| **Open 3D Model Viewer** | Beginner | .obj, .stl, .ply, .3ds u.c. | Lightweight and simple viewing |
| **GLC Player** | Beginner | .obj, .stl, .ply, .3ds u.c. | Quick and easy mesh inspection |

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| **Autodesk Viewer** | Beginner | .obj, .stl, .fbx, .gltf u.c. | Online viewing and collab-oration |
| **Wings 3D** | Begin-ner+ | .obj, .stl, .ply, .dae u.c. | Entry-level modelling and viewing |
| **Online 3D Viewer** | Beginner | .obj, .stl, .ply, .gltf u.c. | Web-based mesh inspection |
| **Paraview** | Interme-diate+ | .obj, .stl, .vtk u.c. | Scientific data visualisation |
| **FreeCAD** | Interme-diate | .obj, .stl, .step, .iges u.c. | CAD-based 3D viewing and editing |

### Overview of free 3D parametric model viewer software

| **Software** | **User level** | **Supported formats** | **Best for** |
|---|---|---|---|
| **BIM Vision** | Begin-ner-In-termedi-ate | .ifc | BIM model analysis |
| **Autodesk Viewer** | Beginner | .rvt,.dwg,.ifc,. nwc u.c. | Online collaboration |
| **Navisworks Freedom** | Interme-diate | .nwc.,nwd | Coordination models |
| **BIMcollab ZOOM** | Begin-ner-In-termedi-ate | .ifc | Issue management |
| **Tekla BIMsight** | Interme-diate | .ifc,.dwg | Collaborative BIM review |
| **Solibri Anywhere** | Begin-ner-In-termedi-ate | .ifc | Inspecting BIM models |
| **Vectorworks Viewer** | Begin-ner-In-termedi-ate | .pln,.ifc,.dwg | Reviewing Vectorworks designs |
| **FreeCAD** | Interme-diate | .step,.ifc,.dxf u.c. | Parametric CAD/BIM model viewing |
| **DDS-CAD Viewer** | Beginner | .ifc,.dwg | Viewing architectural models |

# GLOSSARY

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| Absolut accuracy | How close a measured value is to its true or actual value. |
| Aero laserscanning | A remote sensing method that uses laser beams from an aircraft to create detailed 3D maps of the Earth's surface |
| AUV | A self-operating underwater robot used for ocean exploration, mapping, and data collection without human control |
| Bathimetry | The measurement and study of the depth and shape of underwater surfaces, such as ocean floors, lakes, and riverbeds. |
| CAD (Computer Aided design) | Computer-Aided Design (CAD) is the use of software to create precise technical drawings, models, and designs for engineering, architecture, and manufacturing |
| Cloud to cloud registration | A process in 3D scanning where two or more point clouds are aligned and merged based on their overlapping features to create a unified model. |
| Colour | The appearance of an object resulting from how it reflects light, often categorized by hue, saturation, and lightness. |
| DSM Digital surface model | A 3D representation of the Earth's surface, including all natural and man-made objects, such as buildings, trees, and terrain features. |
| DTM Digital terrain model | A 3D representation of the Earth's bare terrain surface, with all natural and man-made objects, such as trees and buildings, removed. |
| Bathimetry map | A map that shows the depth and shape of underwater surfaces, such as the seafloor, using contour lines or color gradients to represent variations in depth. |
| Electromagnetic vawes | Waves of energy that consist of electric and magnetic fields oscillating perpendicular to each other, capable of traveling through space and matter. Examples include radio waves, microwaves, and light. |
| Photogrammetry | A technique for creating 3D models and measurements by taking and analyzing overlapping photographs of an object, terrain, or structure. |
| Light reflecting scanner | A 3D scanning device that uses reflected light, such as lasers or structured light, to capture the shape and surface details of an object. |
| GCP (Ground control point) | A reference object or marker of known size used in 3D scanning or photogrammetry to ensure accurate scaling and measurements of the captured data. |
| GIS Geographic information system | A system designed to capture, store, analyze, and display spatial and geographic data, enabling the visualization of relationships, patterns, and trends in maps and reports. |
| Gloss | A bright shine or luster on a surface, characterized by the surface reflecting a lot of light in few directions. |
| GNSS Global navigation satelite system | A satellite-based system that provides positioning, navigation, and timing information anywhere on Earth, including systems like GPS, GLONASS, Galileo, and BeiDou. |
| GPS | A satellite-based navigation system that provides location and time information anywhere on Earth, using signals from a network of satellites. |
| Georadar | A geophysical tool that uses radar pulses to detect and map underground objects, structures, and layers by measuring the reflections of electromagnetic waves. |
| Illumination attributes | Properties of a light that affect how objects appear, including color temperature and intensity. |
| IMU Inertial measurement unit | An Inertial Measurement Unit (IMU) is a device that measures and reports a body's specific force, angular rate, and orientation using accelerometers, gyroscopes, and sometimes magnetometers. |

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| LKS-92 | The Latvian Coordinate System (LKS) is the national geodetic coordinate system used in Latvia for mapping and geospatial data processing. It is based on the ETRS89 geodetic reference system. |
| LAS 2000,5 | The Latvian Height System (LAS) is the national vertical reference system used in Latvia to measure and determine heights above sea level, based on the Baltic Height System 1977 (BAS-77) |
| EUREF89 UTM Zone 33 | The standard coordinate system for Norway. Local zones are also used. https://www.geonorge.no/en/references/references/coord-iante-systems/ |
| NN2000 | The national Norwegian height system. https://epsg.io/5941 |
| Laserscanning targets | Specialized markers or objects used in laser scanning to help align scans, improve accuracy, and serve as reference points during 3D data processing. |
| Laserscaner distance accuracy | The degree of accuracy with which a laser scanner can measure the distance to a surface or object, typically expressed in millimeters or fractions of a millimeter. |
| Laserscanning intensity | The strength of the laser signal reflected back to the scanner, which depends on the surface material, angle, and distance. It is used to analyze surface properties or enhance scan visualization. |
| Laserscaner point accuracy | The accuracy of the 3D coordinates for each point captured by the laser scanner, influenced by factors such as scanner resolution, distance, and environmental conditions. |
| Laserscanner | A device that uses laser beams to capture precise 3D measurements of objects, surfaces, or environments by emitting laser pulses and analyzing their reflections. |
| Laserscaning postprocessing | The process of refining and processing the raw data collected by a laser scanner, including noise reduction, point cloud alignment, merging, and converting the data into usable 3D models or maps. |
| Laserscanning noise | Unwanted or erroneous points in the laser scanning data caused by factors such as surface reflectivity, environmental conditions, or hardware limitations, which can affect the accuracy of the final output. |
| Laserscanning point density | The number of data points captured by a laser scanner per unit area, which determines the level of detail in the scanned 3D model or surface. |
| LIDAR | LIDAR (Light Detection and Ranging) is a remote sensing technology that uses laser light to measure distances and create detailed 3D maps of objects, surfaces, or environments. |
| LIDAR clasification | The process of categorizing LIDAR point cloud data into different classes or layers, such as ground, vegetation, buildings, and water, to better analyze and utilize the data for specific applications. |
| Flight plan | A detailed plan outlining the route, altitude, speed, and other parameters for an aerial survey or flight mission, ensuring accurate data collection and efficient execution. |
| Light Geometry | The spatial arrangement and direction of light sources in relation to an object or surface. |
| LOD Level of detail | Level of Detail (LOD) refers to the varying degrees of detail or resolution in a 3D model or dataset, used to optimize performance while maintaining visual quality based on the viewer's distance or application needs. |
| Magnetometrics | The measurement and analysis of magnetic fields to detect and map variations in the Earth's magnetic field or identify magnetic properties of objects, often used in geophysics, archaeology, and environmental studies. |

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| Mesh | A 3D model structure composed of interconnected vertices, edges, and faces, typically used to represent the shape and surface of an object in computer graphics and 3D modeling. |
| Mesh model | A 3D representation of an object created using a mesh structure, composed of vertices, edges, and faces, which define the object's shape and surface geometry. |
| Nadir images | Nadir images are photographs or images taken with the camera or sensor pointing directly downward, capturing the Earth's surface from a vertical perspective, commonly used in mapping and geographic information systems (GIS). |
| Scale targets | Reference objects or markers with known dimensions used in 3D scanning or photogrammetry to ensure the accurate scaling of the captured data to real-world measurements. |
| MLS mobile laserscanning system | A Mobile Laser Scanning (MLS) system is a method of 3D data capture using laser scanners mounted on moving vehicles, such as cars or boats, to scan large areas quickly and efficiently. |
| Mobile scanning control points | Reference points used in mobile laser scanning to ensure the accuracy and alignment of the captured data with real-world coordinates. These points are usually marked on the ground or structures and serve to adjust the data during post-processing. |
| Monitoring | The continuous or periodic observation and measurement of a system, environment, or process to track changes, detect anomalies, or ensure optimal performance. |
| Multi pulse | A technique used in laser scanning or LiDAR systems where multiple laser pulses are emitted and received in quick succession, allowing for better data collection and measurement of objects at different distances. |
| Oblique images | Oblique images are photographs or images taken with the camera or sensor angled at a slant, rather than directly downward, allowing for a broader view of the Earth's surface and useful for capturing objects and features from various perspectives. |
| Orthophoto | An orthophoto is a geometrically corrected image, typically a photograph, in which the distortions caused by the camera angle and topography are removed, resulting in an accurate representation of the Earth's surface, often used in mapping and GIS applications. |
| Overlap | Overlap refers to the extent to which two or more images or scans cover the same area. In aerial photography or LiDAR scanning, overlap ensures that there are common features between images, which helps in creating accurate 3D models and maps. |
| Parametric models | Parametric models are 3D models created using parameters or variables that define the geometry and properties of the object. Changes to the parameters automatically update the model, allowing for easier adjustments and modifications. |
| Point cloud registration | Point cloud registration is the process of aligning and combining multiple point clouds from different scanning sessions or perspectives into a single unified 3D point cloud, ensuring that all points are accurately positioned relative to one another. |
| Point cloud | A point cloud is a collection of data points in a 3D space, typically generated by 3D scanners or LiDAR systems. Each point represents a specific location on the surface of an object or environment, and together they form a detailed 3D representation. |
| RAW data | Raw data refers to unprocessed or unrefined data collected directly from a source, such as a sensor, without any adjustments or analysis. It typically requires further processing to extract meaningful information. |
| RGB | RGB stands for Red, Green, Blue, which are the primary colors used in digital imaging and displays. By combining these colors in varying intensities, a wide range of colors can be created. |
| ROV | A Remote Operated Vehicle (ROV) is an unmanned, remotely controlled vehicle used for underwater exploration, inspection, and data collection, often used in oceanography, engineering, and archaeology. |

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| Side-scan sonar | Side-scan sonar is a type of sonar system used to create detailed images of the seafloor and submerged objects by emitting sound waves at an angle from the sides of the sonar device, allowing for a wider area to be scanned |
| Sensor | A sensor is a device that detects and measures physical properties such as light, temperature, pressure, or motion, and converts these measurements into electrical signals for processing or analysis. |
| Side lap | Side lap refers to the overlap between adjacent strips or passes of data collected during aerial surveys or laser scanning, ensuring continuous coverage of the area being surveyed. |
| SLAM (Simultaneous Localization and Mapping) | SLAM is a process used in robotics and autonomous vehicles where the system simultaneously creates a map of its environment while tracking its location within that map, allowing it to navigate and operate in unknown spaces |
| Solid modelis | A solid model is a 3D representation of an object in which the volume and boundaries are fully defined, providing a complete and accurate representation of its shape and structure. |
| STOP and GO scanning | STOP and GO scanning is a technique used in mobile laser scanning, where the scanner captures data while the vehicle is stationary (STOP) and continues scanning while the vehicle is moving (GO), ensuring efficient coverage of large areas. |
| Surface Appearance Characteristics | The visual properties of an object's outermost layer that can be perceived by sight and touch, including colour, gloss, texture, and translucency. |
| Electronic total station | An electronic total station is a surveying instrument that combines an electronic theodolite for measuring angles, an electronic distance measurement (EDM) device for measuring distances, and a microprocessor to record and process data for precise land measurement and mapping. |
| Distant surveying | Distant surveying, often referred to as remote sensing, involves collecting data from a distance, typically through the use of satellites, drones, or other aerial systems, to measure and monitor the Earth's surface or objects without direct physical contact. |
| Spatial planning | Spatial planning is the process of organizing and managing land use and development in a way that optimizes the use of space, resources, and infrastructure to create sustainable and functional environments. |
| Texture | Texture refers to the surface characteristics of an object, such as smoothness, roughness, patterns, or structure, that can be perceived through touch or sight. In 3D modeling or imaging, texture adds visual detail to the surface of models. |
| Translucency | The characteristic of a material to allow light to pass through without being completely clear. |
| UAV | A UAV (Unmanned Aerial Vehicle) is an aircraft that operates without a pilot onboard, controlled remotely or autonomously, and used for a variety of purposes such as surveillance, mapping, or scientific research. |
| *Site formation process* | Changes to a cultural heritage object caused by underwater processes, which form the object's biography. |
| Shipwreck | A vehicle that has sunk underwater for various reasons, which is no longer fit for use and has become part of the underwater environment. |
| xRite Colorchecker | A standardized color calibration target consisting of 24 painted squares used to test color reproduction accuracy. |
| Underwater Cultural Heritage | All cultural, historical, or archaeological evidence of human existence that has been partially or fully, periodically or continuously submerged underwater for at least 100 years (according to the 2001 UNESCO Paris Convention 'On the Protection of Underwater Cultural Heritage'). |