WREN | 300

THE SQUARE MILE CHURCHES

TOOLKIT

3D geospatial surveys and digital technology for historic places of worship

Image caption and credit to go here

CELEBRATING WREN IN THE CITY OF LONDON'S CHURCHES

Contents

WREN 300

THE SQUARE MILE CHURCHES

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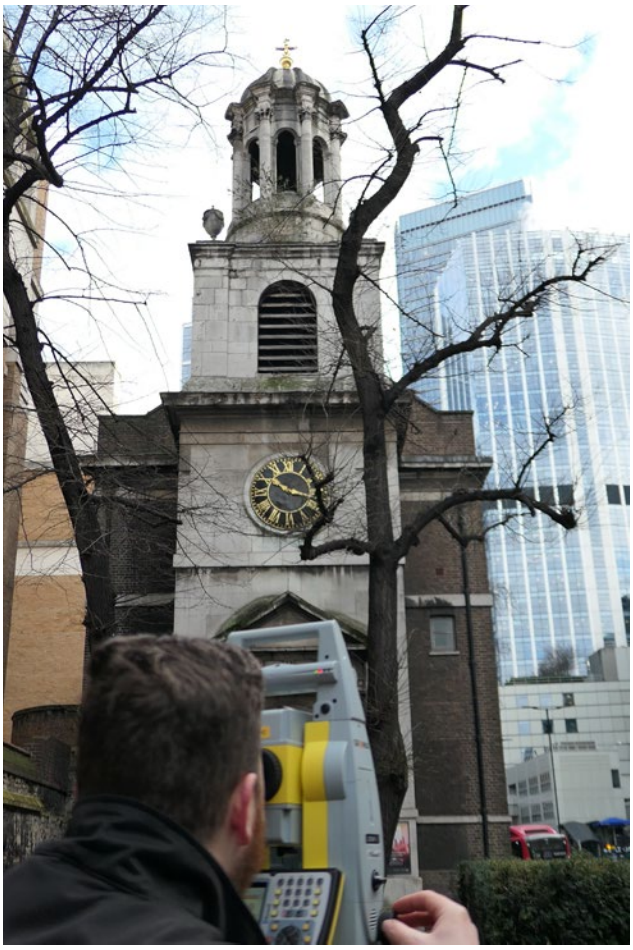
Who is the guide for?

We have written this guide to help people caring for historic places of worship to understand what 3D geospatial surveys and digital scanning technologies are, and why, when and how you might use them to understand, maintain, conserve and repair historic buildings and artefacts. Our hope is that this guide will help you navigate this area of technology and inform decision-making about the management and development of church buildings.

The inspiration for this guide was the Wren300 project, which took place during 2023, and celebrated the work of Sir Christopher Wren and the church rebuilding programme that followed the Great Fire of London in 1666.

Funded by the National Lottery Heritage Fund and the Diocese of London, the year-long celebrations included 'innovation in conservation' projects and explorations into 3D geospatial surveys and other technologies to consider different strategies for conservation.

Working with specialist firm Terra Measurement, we have explored how geospatial surveying can help us better understand and preserve the buildings we care for. Throughout this guide we have included examples from the Wren300 project and other heritage projects to show how digital scanning technologies can be used.



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A Total Station is the latest advancement in what would have been known in the past as a Theodolite. (All Hallows-on-the Wall)

What is a 3D geospatial survey?

Three-dimensional (3D) laser scanning has been around since the 1960s and since then the technology has become more and more advanced, portable and even airborne. You will no doubt have seen scanners in operation on the road, by buildings or mounted on a car roof. Today's laser scanners are accurate and fast, and, if used correctly, are quite safe.

3D geospatial surveying uses laser scanners and high-resolution cameras to record and measure the physical world, whether an outdoor space or room, historical site, landmark or even an object. It involves collecting lots of digital data using techniques to capture the appearance, surface, geometric shape and size of physical objects. Once processed, this data can then be used to create accurate digital visualisations, as well as 3D replica models. It is a field that is constantly evolving and enabling innovations in conservation for the heritage sector and beyond.

A 3D laser scanner will capture data around 360 degrees. Some scanners. work really well at 1km, while most work effectively at up to 100m with very good results. They produce high-resolution, accurate data which in heritage contexts could include anything from multiple buildings in landscapes, single features, intricate detail of surfaces, artefacts or artworks. The data can be used to document buildings and objects as they are today, monitor them over time, or share information to enable others to learn and study them. It can also be used to recreate heritage as virtual interactives, produce replica models (sometimes called facsimiles), reimagine how something might have looked when it was first built, or to communicate new uses for a building.

The 3D data can be shared in exciting ways allowing viewers to explore a building through virtual reality videos, interactive experiences and tours. It gives audiences the chance to explore places and see things that they otherwise couldn't.

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Why use these technologies?

Uses for heritage

Digitising the world around us has infinite purposes in innovation, science, medicine, industry, transport and development. But it can also play an important part in heritage, helping us understand and conserve historic places of worship and communicate their value.

The holistic nature of 3D surveying means that it has the ability to capture every visible aspect of a building, whether walls, windows, ceilings, façades, beams, or even ornamentation. Geospatial surveying technologies are non-invasive and avoid potential damage to precious and fragile objects and surfaces.

These technologies are an aid to the documentation, analysis, restoration, interpretation and accessibility of historic places of worship and the cultural heritage that they contain. The data they produce can potentially be useful for many professionals – such as architects, structural engineers, conservation officers, planners, M&E consultants, conservation specialists, historians and local authorities – and non-professionals, particularly public audiences.

Alternative to traditional 2D measured surveys

A 'traditional' measured building survey involves taking simple linear measurements to create, for example, two-dimensional (2D) floorplans, sketches of an elevation, estimates of building height and features. Although handheld laser 'tape' measures can make the process easier (no-one needs to hold the other end of the tape) and more accurate over long distances, the approach and results have essentially not changed a lot over the years.

3D geospatial surveys are the next evolutionary step as new technology has allowed 2D surveys to become 3D. 3D survey data provides a significant level of detail that can be converted into the measurements needed for accurate drawings and plans at different scales, such as floor, roof and ceiling plans, internal and external elevations and cross-sections. Should a building project need to change or adapt for any reason, then there is a bank of raw data that can be returned to time and again, and new plans and information extracted via a computer desktop process.

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3D surveys capture the Bell Tower and Crawl spaces at St Mary Abchurch in full 360-degree detail

Creating 3D visualisations of buildings can help those not used to reading an elevation or section of a building to understand what is being proposed. These visuals can be used during public consultations, in support of planning and the development of buildings, to inform listed building consents, repair planning, structural investigation, as well as architectural design.

Before embarking on a full geospatial survey, however, it is important to carefully consider your actual project; other solutions may be more appropriate for your needs and budget. See **Is it right for my project?**

Documentation

3D scanning builds a picture from millions, or even billions, of data points known as a 'point cloud'. The 3D imaging allows us to break down a building into parts to be able to look closer into certain spaces and document the detail – from architectural features to cracks in surfaces. For heritage and conservation professionals, a 3D virtual model (most often using CAD, Revit or SolidWorks software) can provide a tool to investigate a space, detect issues, consider conservation needs and plan repair programmes.

It can also provide a comprehensive and highly detailed visual representation of an artefact, capturing its form, texture, and structure in a way that words and 2D images cannot fully achieve. Traditional methods of documenting artefacts often involve written descriptions, photographs, and sketches. While these methods have their value, they can be limited in conveying the true intricacies and details of an object.

EXAMPLE:
St Bride's wall survey

The walls of St Bride's church have accumulated years of environmental impact, due to exposure to pollution and weathering in London. Historic walls can also suffer damage, such as vandalism and graffiti, as well as through the use of incorrect mortars, concrete pointing or paint.

Before different cleaning and repair treatments were tested on St Bride's north wall by Cliveden Conservation (specialists in stone conservation), Terra Measurement produced a series of overlapping high-definition photographs to create a detailed condition record of the wall.

Photogrammetry can aid conservators in their planning and strategies to repair and conserve heritage. It also allows before and after comparisons to be made.

See how when 'meshed' together, the photographs create a 3D model able to be viewed virtually.

https://www.youtube.com/watch?v=gglYsLRUsZE

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Monitoring and making comparisons

Increasingly, 3D surveys are being used for benchmarking and comparative purposes, helping to inform decisions linked to monitoring decay and change over time. They are particularly useful as a means of providing detailed information of heritage that is fragile or not easily accessed. Also, the more buildings and objects are recorded in this way, the more potential there is to share knowledge and compare information between heritage sites.

Visual inspections will still have a role in tracking ongoing decay, however, if you think that you will need to repeat the same level of detail that a laser scan provides, remember to consider this when you cost your project.

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Scanning in the City – All Hallows-on-the Wall

Building preservation and disaster recovery

In the worst-case scenario of a major natural disaster or devastating event such as a fire, an accurate colour 3D dataset that records a historic building and its features can aid in rebuilding and restoration. The information can be studied and used to create templates for replicating and restoring damaged or destroyed features and to create strategies to preserve what remains of original features. Similarly, data can be processed to support making 3D replicas of whole objects, or portions of them, as well as reverse engineering an element of a building so that it can be restored and missing parts recreated. In some projects, the data collected can be used to plan how to display and protect heritage. For example, replacing a historic plinth, frame or mount in order to minimise damage to heritage.

These two projects illustrate how 3D technology is helping safeguard heritage:

3D Data Collection underway for Safeguarding the House of Wonders in the Stone Town of Zanzibar World Heritage site | UNESCO World Heritage Centre

https://whc.unesco.org/en/news/2247

Ukraine is racing to 3D scan its monuments in case they're bombed in the war and need restoration | Euronews

https://www.euronews.com/next/2023/01/22/ukraine-is-racing-to-3d-scan-its-monuments-in-case-theyre-bombed-in-the-war-and-need-resto

Object conservation and restoration

Smaller-scale, 'macro' scanning allows for historic artefacts to be captured in 3D digital formats. By studying the precise details of the original object, conservators can plan and execute restoration efforts more accurately. They can simulate different treatments and evaluate their potential impact on the artefact, allowing for informed decision-making to preserve the object's integrity. These digital replicas can serve as backups in case the original items are lost or damaged due to natural disasters, accidents, or ageing. By creating accurate 3D models, the artefacts can be virtually preserved and shared with future generations.

EXAMPLE:

When objects go bust: bringing conservation and technology together

When a plaster bust of Sir Christopher Wren (a cast of a marble portrait bust sculpted by Edward Pierce in 1673) was smashed into many pieces, this catastrophic accident became an opportunity to recreate it as a 'Digital Artefact'.

The Wren bust was first painstakingly restored piece by piece by Cliveden Conservation. 'Macro' photogrammetry undertaken by Terra Measurement captured this depiction of Wren in incredible detail, including the sculpture's form, texture, and structure.

Now Wren's bust can be explored digitally, and there is a permanent record for the future that can be used should a disaster ever happen again. Or taking technology to another level, Wren could even be 3D-printed or recast in any size or form.

See Wren in 3D

https://www.youtube.com/watch?v=4_nBn6-o_MU

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GAUTIER Stephane / Alamy Stock Photo

Notre Dame Cathedral, Paris, engulfed by flames and smoke, 15 April 2019

Research and analysis

Digital capture enables researchers and scholars to study artefacts remotely without needing physical access to the original objects. High-accuracy 3D digital models allow for detailed examination and analysis, facilitating in-depth research and the discovery of new insights. Scholars can zoom in, measure, and analyse datasets, enabling closer examination than which may be possible with the physical artefact.

Notre Dame Cathedral was famously scanned in 2015 by an American academic, Professor Andrew Tallon, using a 3D laser scanner. The devastating fire, which occurred in 2019, destroyed the wooden roof and spire, while smoke damaged numerous paintings and artefacts. The data captured by Tallon has been used both to inform its restoration as well as provide new knowledge of its original construction.

See more about his work at Notre Dame and how this has become his lasting legacy.

https://www.vassar.edu/stories/2019/190417-notre-dame-andrew-tallon.html

Accessibility, communication and education

Data from 3D scans becomes a lively communication tool when transformed into 3D digital experiences, animations and other computer visualisations. For audiences, the technology can be viewed from the comfort of their own homes, on mobile devices or through on-site interactive screens. The technology is allowing heritage professionals to open up spaces within buildings not normally available to visitors, as well as giving audiences the opportunity to explore places and objects in any way and from any angle they choose. It also allows us to break the rules of normal tours; we can go through walls, peel back time, look down from the ceiling, magnify and interact with heritage in ever more creative ways.

3D digital capture of artefacts can be utilised as educational tools in schools, universities, and other learning environments. It also offers opportunities to see things that would be too fragile to move or expose to light. Digital replicas of historic artefacts can be shared online, allowing people from all over the world to access and experience these objects virtually. Replica models can allow untouchable objects to be touched and handled by professionals and the public. They can even be scaled up for exhibition as well as research.

The implications for improving access in its broadest sense are compelling, enabling people to touch, look through surfaces and bringing heritage to people at home, in schools, universities and care homes, or to clubs and societies. Museums and cultural institutions can create virtual exhibitions, providing an immersive experience for visitors who may not have the opportunity to visit the physical location. This enhances accessibility, enables cultural exchange, and promotes a wider understanding and appreciation of diverse heritage.

EXAMPLE:
Peeling back the layers

Visualising and understanding all the complex spaces of a historic building and how they fit together is a challenge. See how a 3D model peels back the layers of St Mary Abchurch to reveal the building from the outside in, including its tower which is not open to the public. This visualisation helps users see the church in new ways, wherever they are in the world.

See how a 3D model peels back the layers of St Mary Abchurch to reveal the building from the outside in, including its tower which is not open to the public.

https://www.youtube.com/watch?v=rf6jlxvhxr8

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Challenges and limitations

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While this technology continues to develop, there are some limitations to consider alongside the considerable benefits.

The first of these is cost. 3D surveying is a more involved process; operating scanners and processing the data requires professionals trained to use the specialist equipment and the cost of their time. Be aware that this technology can cost more than a 2D survey produced using a tape or laser measure. It is important to consider what you are trying to achieve, what level of detail or accuracy you need, and if this solution is right for your project.

The second is the accessibility of an object or space. Scanners need a direct line of sight as well as good, constant light levels, otherwise these factors will interfere with readings. A laser cannot record hidden features or inside solid structures such as walls, and despite the multiple angles used to create images, there may be some spaces in a building that prove problematic. For an airborne survey, permission from the local authority and other bodies responsible for security and transport will also be needed to use a drone.

The third challenge is the nature and size of the digital survey files that are created. The scanning processes (combining 3D laser scans, photogrammetry, total station measurements, 360-degree photographs) create vast amounts of raw data, potentially too large and specialised to be held and accessed on normal office computers. The unprocessed survey data of your historic place of worship will need specialist software to be interpreted and turned into plans and other forms of output. Additional desktop processing of the data will likely require the ongoing involvement of the scanning company and potentially incur further costs. It is important to know these costs at the outset and to factor them in. The data may also not be easily transferable and be linked to the software of one company. However, a competent professional company will provide you with easy ways of viewing your survey and should provide the data on a portable hard drive for you to archive. See section on **Commissioning** for more information.

Lastly, a potential challenge is finding scanning professionals that are both specialists in using the technology and processing the data, as well as having an understanding of working in a historic environment. It is important to take the time to find a reputable company with the necessary credentials and experience for your project.

How is it done?

Once you have appointed a company to deliver your project, they will take you through the practicalities of having a scan on site as well as the type of scanner that best fits your needs. It can take anything from a day to two weeks to complete the scans and then additional time to process the data. The time really depends on the scale and complexity of the site and what you need to be created from the data.

The company you appoint will make sure all the right permissions are in place for them to carry out their work, and all health and safety and other legalities are complied with. Your job is to make sure that on scanning days the schedule is clear (i.e. no services, meetings or maintenance tasks), and that the programme is clearly communicated to your team, including volunteers. Laser scanning will pick up everything in a space, including people, chairs and general clutter, as well as cars parked in front of the building.

Systems of 3D surveying

Professionals refer to the different methods for capturing the 3D data required as 'systems', whether that is a single or multiple type of scanning technology, to arrive at the 3D data required. Some are best suited to spaces, buildings and even landscapes, others to objects and specific architectural features – or both.

These systems can achieve a very high level of accuracy when precision equipment is combined with best practice methodologies. They are capable of producing results within just +/- 1mm of accuracy, a level that is unlikely to change for the foreseeable future. Nevertheless, technologies continue to advance, largely resulting in a speedier process. These efficiencies in turn keep improving the affordability of surveying.

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A terrestrial scanner attached to a telescopic mast helps capture every level of St Mary Abchurch including its tower.

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A terrestrial laser scanner in use at All Hallows-on-the Wall

Terrestrial 3D Laser Scanning

Terrestrial laser scanning is the most accurate 3D system for capturing buildings. There are two types of terrestrial laser scanner – Pulse (time of flight) and Phase-comparison.

Pulse scanners send a pulse of laser light towards something and measure the time it takes for the return flight. These scanners can have a range of up to 1km and are particularly useful for the historic environment when capturing data across greater distances.

Phase comparison scanners, also called continuous wave scanners, have a shorter operating range. While they can achieve results at up to 350m, under 100m is the optimum. They use a slightly different calculation to the pulse scanners and have higher rates of data capture.

Both types of terrestrial laser scanners are typically mounted onto sturdy tripods. They are positioned around a building, taking account of any unusual shapes or obstacles, so that multiple scans can be taken from every possible line of sight. Some areas may still not be visible and these will either have to remain missing from the final survey or can be supplemented with data from other surveying methods.

SLAM 3D Laser Scanning

SLAM stands for 'Simultaneous Location and Mapping'. SLAM scanners are made to be mobile and are either handheld or a wearable device. They can also be attached to a mobile robotic device. The scanner is moved slowly around the survey area to maximise coverage and the overlap of data. As it does so, the scanner head rotates, continuously capturing data while an onboard computer uses an algorithm to build the 3D world around it – think of it as simultaneously recording both where you are going and where you have been.

In heritage situations SLAM can be employed to reach awkward and inaccessible areas such as small gaps, crawl spaces and hidden crypts. While the technology has been around for a few decades now, it is constantly improving and has become a very important asset in 3D surveying. Its simplicity of operation means it can also be used to complete a lower budget survey. However, the system is prone to drift and errors, and therefore the results are not as accurate as terrestrial scanning. It is important that regular survey control checks and more time spent in post-processing are factored in to improve its accuracy.

EXAMPLE:

Revealing the Charnel House at St Mary Abchurch

Beneath St Mary Abchurch lies both a small, rib-vaulted crypt and an adjacent Charnel House, where human skeletal remains are stored. This bricked up vault and its contents has remained unseen for many years. SLAM scanning equipment, accessed through a small gap in the wall, has allowed this remarkable space to be uncovered, revealing the many bones of adults and children and lead coffins interred within.

Explore this hidden space.

https://www.youtube.com/watch?v=fnzY3MF3bH0

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3D Digital Photogrammetry

Photogrammetry is the process of using a high-definition 'full frame' digital camera to create a 3D model. Multiple 2D photographs are taken from overlapping angles which are then processed and fused together through specialised software to produce a 3D point cloud. It is a relatively quick process and is useful for capturing accurate colour data.

It can be used for both large spaces and smaller-scale objects. Cameras can be handheld or mounted on a tripod. Uses include quick recording of vulnerable or inaccessible sites. A surveyor may use it to enhance a 3D survey with 'fill in' coverage and extra fine detail. Photogrammetry is very good for recording translucent surfaces like alabaster and marble. Examples of uses also include surveying sculptures, monuments, architectural features, hard-to-reach places through the use of drones, high and low reliefs. For artefacts, the additional benefit is that a 'mobile studio' can be set up so that they may not need to be moved. The data can then be used for screen-based applications, sharing with researchers and creating replicas.

Photogrammetry relies on high-quality resolution and light exposure and can therefore be compromised if there are particularly dark areas. As with SLAM scanning, it is also prone to drift and error if not controlled properly. Photogrammetry as a methodology is not new, but the advent of digital photography and the more recent increase in computer memory capacity and processing power has transformed it into a cutting-edge and accessible survey method.

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Airborne systems – Drone-mounted Photogrammetry

With this method, a camera is mounted on a drone. The larger the camera, the larger the drone needs to be to carry the weight. It is most commonly used for reaching high areas – whether outside or inside a building – not visible with terrestrial 3D laser scanning. It is extremely important that drones are flown by licensed professionals with the correct permissions and risk assessments – particularly around and within listed buildings and scheduled monuments.

Uses include documenting hard-to-reach indoor and outdoor areas of buildings such as roof areas, towers and spires, complex internal spaces in historic places of worship, monuments as well as archaeological sites. This system of scanning has the potential to reduce or avoid the costs of expensive scaffolding and working at height.

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Drones fitted with photogrammetric cameras at Gwrych Castle, Conwy

EXAMPLE:

St Mary Abchurch surveyed by drone – making the inaccessible accessible

Surveying the upper levels of St Mary Abchurch's four-storey, 51-foot-high tower with a leaded spire and inaccessible roof areas would normally present major challenges. Instead, a photogrammetry camera attached to a drone allowed a bird's-eye view of these hard-to-reach spaces, and for the church to be captured digitally in its entirety.

Before beginning, however, permission from the Civil Aviation Authority, Met Police and London Heliport, along with a NOTAMS (Notices to Air Mission) investigation and flight risk assessment were needed.

[Explore St Mary Abchurch from above](https://www.youtube.com/watch?v=StDhTGj0KQE)

https://www.youtube.com/watch?v=StDhTGj0KQE

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Structured light scanning

This type of scanning uses a single light projector in concert with multiple cameras. It works by projecting a pattern or grid over a surface and basing its calculation on the deformations of the pattern or grid lines. This method is sometimes used to fill in fine detail that cannot be picked up adequately by terrestrial 3D laser scanning or photogrammetry.

It is particularly helpful if a location doesn't have access to a natural or artificial light source, but equally fluctuations in light levels can prove challenging if not controlled.

Uses include scanning sculptures, objects, reliefs, and facades, and the data can then be used for screen-based applications, 3D printing, creating prototypes and replicas, and reverse engineering.

Total Station

This is used for 'survey control' which is the way that surveyors can calculate precise distances for each survey subject in relation to the equipment used for the scan. It uses electronic distance measurement (EDM) combined with laser technology and robotic movement. It is an important piece of equipment in a 3D geospatial survey and without it there is no guarantee of a survey's accuracy.

Triangulation scanners

Two or more lasers project very small points onto the surface of an object and a camera records these points. Calculations are carried out using these laser line points and the camera(s) images to achieve the 3D triangulation. This approach produces accurate, high-resolutions scans.

Scanners are typically mounted on tripods, but may also be handheld or carried in backpacks. The tripod-mounted scanners are used to scan larger objects. They are operated by a professional and scans can take up to an hour in each location.

Static scanners are used for close work. They are mobile and can be used off or on-site. They include lighting techniques that enable detailed data to be collected about objects, such as paintings, carvings or mosaics. Static scanners specifically designed to digitise books, manuscripts and photographs are also available to commission. These enable recordings to be made of delicate pages without damaging bindings.

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Processing

The data from 3D laser scanners or photogrammetry has to be processed before it can be used. Initially the data needs to be cleaned and filtered so that only the subject of the scan is saved and the dataset kept as small as possible – scanners are indiscriminate, and will pick up animals, vegetation, and buildings not included in the brief.

The different uses or applications that you ultimately want your scans to have will also dictate how the data is managed from this point forward. For example, are you going to share the processed data with your architects or conservation professionals, so that they can investigate the different features of a building or object? Alternatively, if you want to create a model or replica of a building or object, the data will need to be converted into a format known as a mesh, which consists of hundreds of triangles that accurately represent the surfaces. Meshes can also be used for image-based outputs like animations or 3D fly-throughs.

Applications

Once a space or object has been digitally captured, the data can be used to create a variety of different types of output and formats. Here are just some of those applications:

Using software such as CAD , Revit or SolidWorks, 3D survey data has practical application for producing **2D (PDF) measured survey drawings, elevations and sections**. As the 3D digital data can be reinterpreted time and again, you can return to it to extrapolate a different set of plans or details. Remember, however, that any new drawings and plans will likely need to be produced using the software of your appointed scanning company and thereby involve some additional cost. This means you will have an ongoing, potentially longer-term relationship with the company. Factor this in when selecting who you will work with.

3D laser scans of your historic place of worship can produce high-resolution 360-degree, full-colour panoramic images as well as sectional, bird’s-eye and cutaway views. It can also be converted into a ‘digital twin’ model with incredible detail and realism. Interactive models can be manipulated and investigated by the user, such as heritage professionals and conservators, to view a space or object from any perspective and at any distance. Digital Repair can even allow fragmented objects to be digitally reassembled and viewed virtually in their original form.

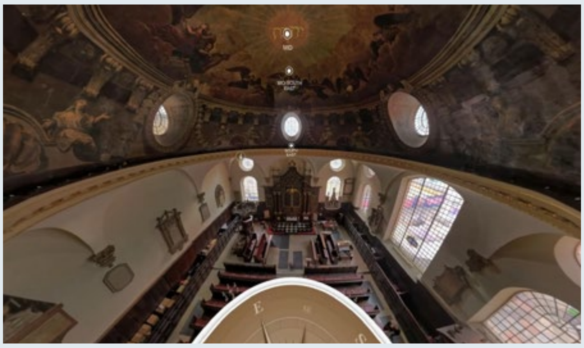
EXAMPLE:

360-degree view of St Mary Abchurch's magnificent 300-year-old painted dome

The 40-feet wide dome at St Mary Abchurch is one of its most striking architectural features. Built with no external supports, its weight is distributed between the walls of the church making it a fine example of Wren's engineering abilities. It is made from plaster on a wooden frame and is illuminated by four circular windows. Various issues impact on its condition and vulnerability today – from bomb damage during the Blitz to major subterranean building works in the vicinity – and monitoring is essential. Using photogrammetry, the dome was captured in full colour from every angle and position, giving a 360-degree view that documents its breathtaking architectural details, as well as condition – small areas of paint flaking were revealed and other conservation needs.

Explore the dome

https://www.youtube.com/watch?v=EUIGqpBdbZ8



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Laser scanning allows the dome's condition to be monitored in high definition including areas of cracking in the surface and painted decoration.

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Watch as this time lapse shows the process of 3D scanning the dome from every angle. A mast helps the scanner reach the top.

https://www.youtube.com/watch?v=sGxe2MBiCtA

Getting creative

Virtually

As we have described, scanned data can be processed for a variety of digital outputs. It is well worth looking at different museum and gallery websites to see how laser scans are being used to support fundraising efforts, to keep visitors informed about the progress of a capital project and as ways to engage people in heritage. If you are working with interpretation consultants, it will be useful to explore with them how they could use the data as part of their work with you.

These digital representations of heritage can take people on a virtual tour and invite them to interact with what they find. They improve access for people unable to visit your building, provide opportunities for schools to connect with your heritage ahead of a visit and open up spaces that the public cannot otherwise visit because of site restrictions or the fragility of your heritage.

Animations can take you into a virtual reality with a high level of realism. Full-colour **3D video tours** which 'walk' or 'fly' you through the spaces can be embedded on a website, experienced as virtual reality with goggles, or interacted with as a touch-screen exploration.

EXAMPLE:

Take a flight through All Hallows-on-the Wall

Surrounded by a busy road and modern buildings just metres away, All Hallows' plain brick exterior gives little hint of what lies inside. Flying through its front doors on a 3D virtual tour, you can experience its barrel-vaulted nave, fluted Ionic columns, half-dome apse, and contents – all in 360-degree full colour, wherever you are.

Take the tour

https://www.youtube.com/watch?v=q2AxAUWdGBI

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Models & replicas

From 3D printing to robotic carving, there are a growing number of techniques to help organisations create physical outputs for display. Visitors can explore and touch replicas that they might not otherwise be able to engage with. Replica objects can also be used by academics, conservators and other professionals to support research, conservation and education.

Replicas can also be taken into communities as part of education and learning activities, allowing more people to connect with your heritage and to respond to it.

EXAMPLE:

Recreating Grinling Gibbons' Venetian lace cravat

See how the V&A have used 3D scanning and printing technology to recreate the extraordinary limewood cravat carved by Grinling Gibbons over 300 years ago, and how this compares with the traditional tools and carving techniques of contemporary carver, Clunie Fretton.

https://www.vam.ac.uk/blog/museum-life/imaging-and-imagining-grinling-gibbons-limewood-cravat

Clunie Fretton

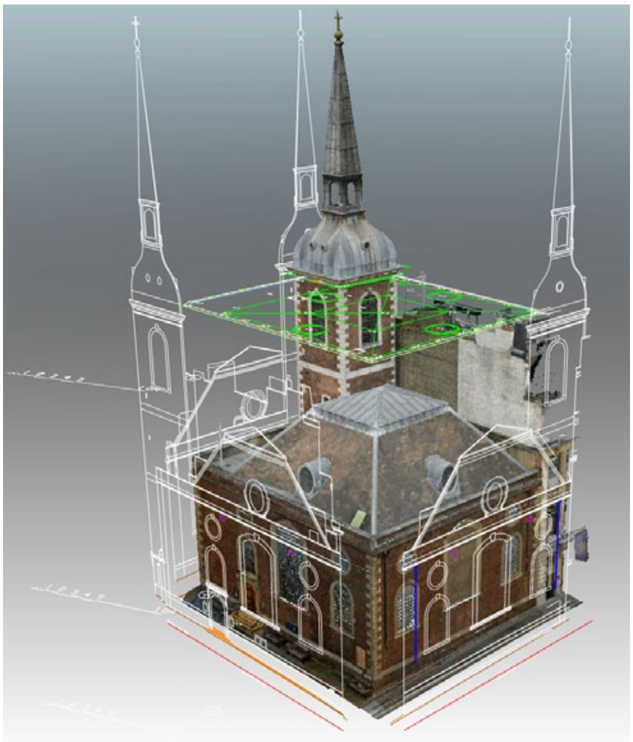
Is it right for my project?

Purpose

The detail that you can achieve through 3D geospatial surveys is compelling, but requires investment. If that investment needs to be raised from a grant-giving body or the public, then you will need to have a very clear case for support (why your heritage is important) as well as clarity of purpose (how you will use the data).

Examples of why you might want to use the technology

- To develop a more comprehensive picture of a building/artefact that cannot currently be provided through professional input (for example, an aerial view or spaces that are not currently accessible without scaffolding or machinery).
- To build a replica of an artefact to support learning and to inform modelling of the artefact as it was first crafted.
- To provide accurate templates for restoration of elements of a building, including colour matching of materials.
- To track the progress of a complex ongoing issue with your building, for example problems caused by subsidence, and to complement other monitoring techniques.
- To share colour and 3D images with FE/HE students and academics with an interest in our cultural heritage
- To create and store a digital archive of raw data that can be reinterpreted and reprocessed as technology advances, and made available to academics, architects and the public.



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3D scan data from St Mary Abchurch is used to create CAD drawings

Balancing act

While it is seductive to be able to capture the depth of data that 3D scanning can deliver, does your project need this level of detail now, and could you deliver your project without it? You will need to balance a desire for high-quality digital data and the practicalities of getting your project over the line within a fixed budget.

If your project will significantly change the look of a historic building or what remains of a historic building, you may want to use 3D geospatial scans to digitally document the building to be archived, or to help others, such as the public or planning committees, to understand your plans through a virtual experience of what the new developments will look like.

A project may require a high degree of accuracy and detail to ascertain the extent of the damage, or how it has changed over time, for example, providing baseline data to support ongoing monitoring of a crack in the surface of a historic building.

However, it might be that your project needs a much lighter approach and that a traditional photographic or measured survey will give you enough for the floor plans, elevations and sections that you need to get planning permission.

DIY with 3D scanning apps

As technology develops, various phone and tablet-based apps are becoming available that can support basic, small-scale scanning without the need for physical 3D hardware. There are various options out there for you to explore. However, while offering very handy tools to record simple 3D images, it is important to realise their limitations. These will not be able to give you the accuracy and detail of a scan using professional equipment and expertise. They will struggle with certain environments and objects. Some apps are only available on certain types of devices and operating systems.

For more information see *3D scanning – Digital Creativity: a Practical Guide* – Subject Guides at University of York

Costs

Speak to other historic places of worship or heritage organisations about the costs of their projects to give you a sense of how much it might cost to do something similar. While the costs may have changed over time, it will give you an early opportunity to refine your wishlist to fit with your fundraising plan.

Consider also what other methods could give you usable data for your project. This is something to discuss with your heritage architect or Quinquennial Inspector (QI).

Commissioning

Where to begin?

There is some excellent guidance produced by Historic England on how to commission surveys, which is regularly updated to reflect the progress of these technologies.

https://historicengland.org.uk/advice/technical-advice/recording-heritage/

A 3D survey should ideally be a useful resource for many years to come. It therefore needs to be carried out to a high standard by experienced professionals who adhere to best practice.

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It is important to be clear from the outset what you want to achieve so that you can match a surveyor to these specific needs. In most cases, the more accurate the survey, the more uses and longevity it will have. Some methods can be quick and therefore cheaper, but the data may not always be fit for purpose. Discuss not just the type of scanning methods that are used, but also what outputs you need, how the data will be stored securely, on what platforms it will be shared and who will own the data.

You will want your surveyor to be able to evidence their experience (with examples of previous commissions and references) and commitment to continuous professional development to give you confidence that they are maintaining their skills, not only in the technology, but also in best practice for processing and storing data. Remember that technology is updating all the time, and what may be innovative now, may down the track be out of date and obsolete.

As part of the procurement process, it might also be worth asking them about which professional standards they will work to (for example, following Historic England's guidelines) and how they plan to collaborate with other professionals over the duration of your project.

Below we have listed some of the things that you might find useful to consider ahead of commissioning 3D geospatial surveys.

Some considerations

Site visits

Invite prospective contractors to review the site so that they can see your heritage, discuss options for the methods of scanning and review any risks or challenges there might be to access your heritage (for example, land ownership and security).

Risk assessments

Discuss and present any risks and hazards that you need the contractor to consider in the tendering process.

Planning and preparation

Professionals who work with these technologies should carefully plan their approach to ensure that an accurate and comprehensive survey is achieved and that there is minimal disruption to the church's daily functions. There may also be logistical and ethical considerations as well as permissions to factor in, all of which should be worked through before scanning starts.

Repeatability

In the future, it might be important to repeat the survey (for example, to record subsidence or the impact of climate change). If you think that you will need to repeat the survey, either as part of your current project or for a project in the future, then this will need to be specified and costed in the contract.

Survey control

Survey control is the backbone of every professional geospatial survey. It is the process that enables consistent accuracy, position and orientation of a survey.

Survey control points will be installed around the outside of a church and can be temporary or permanent. Temporary control points are brought into a church for the duration of a survey but removed after with no trace. During the site visit discuss any permissions that might be necessary (for example, on a scheduled monument) and the permanence of these markers (for example, using approved adhesives). Experienced professionals will avoid damage to historic fabric during this process.

The coordinates and position of the permanent survey control points should be presented to you as a document which explains the accuracy and methods used and can be shared with other professionals and referred to in the future.

Remember, 3D scanning can achieve different levels of accuracies. It is important to know what level your project needs – Historic England's *Geospatial Survey Specifications for Cultural Heritage* guidance explores the options.

Deliverables

Deliverables are the outputs that you expect to be provided by the end of a survey. Think about what you want delivered and list these things as part of your brief to commission a surveying team. It is a good idea to request a survey report that gives diagrams of scan positions, targets, details of the overall accuracy as well as colour information. You should also specify how you want the data to be provided and the file formats such as:

- CAD survey drawings (floor plans, elevations, sections)
- PDF versions of the CAD drawings
- An online 3D Data viewing platform
- The archive of the 3D data on a portable hard drive.

RAW data

The RAW data from scanning results in very large files that need to be processed into files that other professionals can use (for example, CAD for your architects, PDF images to a particular size for design teams). Give some thought to the access you will expect to have to the data for the purposes of your project, what needs to be processed into other digital formats for use by other professionals and how you will want access over time. This will help avoid unexpected costs for data processing arising.

Data ownership

As custodian of a building and its contents, the data recorded should be retained by you, in order to make future decisions on how the data can be used and to receive the benefits from any commercial uses of that data. However, you may decide that you want conservation professionals and the academic community to have free access to the data for the study and monitoring of your heritage. If this is the case, then the 'Creative Commons Model' is a route you may wish to explore. Creative Commons is a legal structure that means that anyone can see the data and use it for research and analysis, but anyone wishing to use the data for commercial purposes will need to approach the custodian for permission to use the information. This will ensure that the custodian can benefit, should a commercial use become clear.

EXAMPLE:

See how a 3D model allows a user to manipulate and move around a 3D space

https://www.youtube.com/watch?v=vyOjbZ4_oPE

A 3D geospatial survey can be a useful tool in making decisions about physical restoration, planning maintenance or informing inspection reports. Inspection reports generated from 3D scanning may, for example, look at surface condition, deviation or movement of a structure (subsidence, sloping, bending or leaning), and floor flatness for drainage purposes.

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Jargon busting

Airborne surveying
Survey equipment is attached to an unmanned airborne platform (sometimes referred to as a drone).

CAD
Computer Aided Design describes graphics software primarily used in engineering and design.

Custodian
Owners or guardians of heritage assets that have primary responsibility for decision-making and the protection of the fabric of that building.

Creative Commons
Legal structure that means that anyone can see the data and use it for research and analysis (not commercial purposes).

Digital Twin
A virtual representation or computational model replicating a physical object or even a process. It gives a true-to-reality simulation of physics and materials and virtually mirrors behaviours, characteristics and performance. In architectural terms, it can range from a virtual copy of a single structure, such as a bridge, to more complicated infrastructure, such as an entire city.

3D Laser Scanner
Devices that collect 3D coordinates of given objects, buildings or places. The scanners emit and receive their own laser light and don't rely on light sources (natural or artificial) as in ordinary photography.

LiDAR
Light Detection and Ranging measures the distance to an object by sending a light pulse, bouncing it off the object back to the sensor, and recording the Time of Flight (ToF).

Mesh
A method of digitally representing a surface using points connected by lines (usually triangles).

Photogrammetry
A process that takes multiple photographs to create 3D data. It can help to take images of moving objects by using multiple cameras to capture an instant array of images. A macro lens can also be used to capture very small, highly detailed objects.

Point clouds
A set of data points (or dataset) that represents an object or space. Data points are captured using a 3D scanner, LiDAR, or photogrammetry software. Each point represents a single spatial measurement on an object's surface. If you're scanning a building, for example, each virtual point would represent a real point on walls, windows, ceilings, floors, or any surface the laser beam hits, including fixtures and fittings. When data points are brought together, they form a point cloud representing the entire external surface of an object. A point cloud can be made up of millions or even billions of data points. Each point can even be recorded with a colour (RGB) value creating a full-colour point cloud.

Reverse engineering

Reverse engineering is a process that involves measuring a physical object and reconstructing it as a 3D model. The main principle is to understand how a product works or an object or building has been constructed. ‘Deconstructing’ architectural structures and objects enables design information to be extracted and highly accurate CAD models to be created for various applications.

Scan position

The location from which scanning is performed.

SLAM

Simultaneous Location and Mapping (SLAM) is a process that enables robotics to navigate autonomously through new environments and generate maps during their movements.

Structured Light Scanning

A type of 3D scanning that projects light patterns onto an object to help us to calculate its shape and size.

Survey control

The survey control ensures the correct position and accuracy of every survey method used.

Time of flight

Measurement of how long it takes for a laser beam to reflect back to a sensor.

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SLAM allowed the bricked-up Charnel House at St Mary Abchurch to be scanned and now explored virtually.

Resources and further reading

Publications and websites

Historic England
Geospatial Survey Specifications for Cultural Heritage January 2024

https://historicengland.org.uk/images-books/publications/geospatial-survey-specifications-cultural-heritage/

The website includes three documents:

- Geospatial Survey Specifications for Cultural Heritage
- Geospatial Survey Specifications for Cultural Heritage – project brief
- High Resolution Illustrations

ICOMOS
Study on quality in 3D digitisation of tangible cultural heritage: mapping parameters, formats, standards, benchmarks, methodologies, and guidelines

https://www.icomos.org/images/DOCUMENTS/Study_on_3D_Quality_Digitisation_Final_Study_Report.pdf

European Commission
Quality control in 3D scanning

https://digital-strategy.ec.europa.eu/en/library/study-quality-3D-digitisation-tangible-cultural-heritage

University of York
3D scanning – Digital Creativity: a Practical Guide

https://subjectguides.york.ac.uk/digital-creativity/3D-scanning

National Lottery Heritage Fund
Doing digitisation on a budget: a guide to low-cost digital projects

https://www.heritagefund.org.uk/funding/good-practice-guidance/doing-digitisation-on-budget

Culture Hive
3D scanning, implications and opportunities

https://www.culturehive.co.uk/digital-heritage-hub/resource/planning/what-implications-and-opportunities-should-we-consider-when-using-3D-scanning-or-printing/

Disaster recovery

Big Think
3D scanning in preserving world heritage sites

https://bigthink.com/culture-religion/3D-scanning-save-heritage-archaeology/

Nottingham Trent University
3D scanning for post-earthquake recovery

https://irep.ntu.ac.uk/ideprint/47306/1/10.17631-rd-2022-0005-dprac_v2.pdf

CNN
3D technology, preservation and Ukraine

https://edition.cnn.com/style/article/ukraine-uses-3D-technology-to-preserve-cultural-heritage/index.html

Inspiration from other projects

Grinling Gibbons cravat

https://www.vam.ac.uk/articles/how-was-it-made-grinling-gibbons-carved-cravat/

This 'Venetian lace' cravat was carved from limewood over 300 years ago. A 3D laser scan and print was made and is shown in a film with contemporary carver, Clunie Fretton, as she recreates a part of the cravat in her studio using traditional tools – Victoria and Albert Museum.

Limewood cravat carved by Grinling Gibbons alongside its 3D printed nylon replica

Historical graffiti

https://www.nationaltrust.org.uk/our-cause/history-heritage/archaeology/mysteries-of-historical-graffiti

The National Trust has been laser scanning historical graffiti to create an accurate record and help to explore the meaning of these marks and inscriptions – whether they were made in protest, invested with symbolic meaning or simply used to identify the maker. Some graffiti dates back centuries, other examples to WWII.

Natural history – 300 years of insect life

https://www.nhm.ac.uk/discover/news/2021/july/high-resolution-3D-scanning-understand-insect-evolution.html

The Natural History Museum has been using high-resolution 3D scanning to record its collection of 35 million insect specimens dating back over 300 years, ranging from the smallest flea to the biggest butterflies. A new dataset, to complement the 2D digital record, will allow researchers to peer back in time and understand how insects have evolved.

Your scans, your stories, your heritage

https://www.storyfutures.com/resources/immersive-fellowships-your-scans-your-stories-your-heritage

A 3D scanner was sent to British Overseas Territories to capture portraits of young people and record them describing their everyday lives, stories and heritage.

National Churchyard mapping project

https://www.churchofengland.org/media/press-releases/nationwide-digital-churchyard-mapping-project-begins

As part of a five-year project from 2022, the Church of England has been laser scanning Anglican churchyards across England. There are around 19,000 burial grounds in total.

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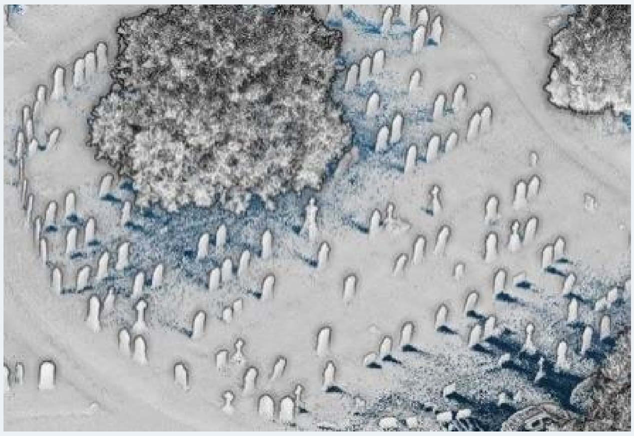

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The ancient church of St Bega on the shores of Bassenthwaite Lake in the Diocese of Carlisle is the first churchyard to be scanned

Our Shared Future: Reckoning with our Racial Past

https://3D.si.edu/our-shared-future

Educational films to show how 3D laser scanning can be used to explain and examine racism within collections and to share information and stories about objects for a modern audience. There are six films that describe how the scanning was undertaken, as well as providing audiences with an exploration of objects that are connected with America's complicated history of race and racism.

Tracing the past: medieval vaults

https://www.tracingthepast.org.uk/

A research project into the design and construction of medieval vaults through the use of contemporary laser scanning and 3D modelling to investigate and share learning. The project is based at the University of Liverpool.

Testing the role of digital technologies in recording values of human settlements in Asia and the Pacific

https://whc.unesco.org/en/canopy/digital-APA/

For four years, a team at the University of Queensland tested new and old technologies, such as photogrammetry, laser scanning and community mapping, to record the interaction between tangible and intangible layers of traditional human settlements in China and India.

Conservation & mount-making

https://www.getty.edu/projects/3D-scanning/#about

Since 2010, conservation departments at the J. Paul Getty Museum have been using 3D scanning to help them to research, restore and make mounts for artefacts. An example of a project was the replacement of wooden tripods with a veneer of intricate ivory carvings unearthed at the Villa dei Papiri in Herculaneum, near Naples.

The scans were used to help cut away material from the existing, damaged wooden mount and then create a new mount.

J. Paul Getty Trust

Museum conservation staff use scanning to acquire accurate, non-invasive three-dimensional data about a bronze sculpture (left), and after processing produce a digital 3D model (right).

Pompeii using VR

https://www.pompejiprojektet.se/

https://news.artnet.com/art-world/pompeii-virtual-reality-2089517

A digital model of Pompeii was created by academics from Lund University using data compiled from 3D laser scanners which mapped an entire neighbourhood from 2000 onwards. A VR version of a home was then imported in a video game engine (Unity which is used for gaming such as Pokémon Go). As well as providing visitors to the site with an experience of what the home would have looked like 2,000 years ago before it was destroyed by the eruption of Mount Vesuvius, researchers are using it to track eye movements to understand better why statues, murals or artefacts were positioned.

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