3D scanning the 'New Jerusalem'

and other ancient monuments

The Zamani Project uses lidar to document heritage sites in Africa and further afield.

The spectacular Biet Ghiorgis, or House of St George, is one of 11 churches carved or constructed from the soft volcanic rock at Lalibela, in the mountainous heart of Ethiopia. Legend has it that King Lalibela, emperor of Ethiopia in the 12th century AD, ordered the churches to be built as a 'New Jerusalem' for Christian pilgrimage, after the holy city of Jerusalem in the Middle East was captured by Muslims. Today their true history is debated, but the Lalibela rock-hewn churches were among the first dozen World Heritage Sites to be designated by UNESCO in 1978.

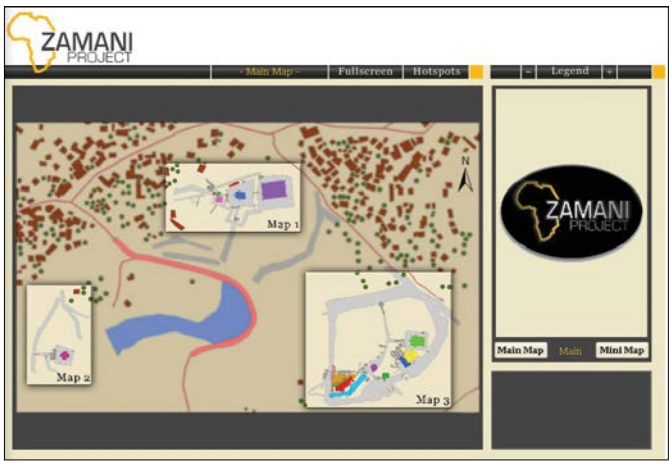
Now one of Ethiopia's main tourist attractions, the site is still used for daily worship and special ceremonies during Christian festivals, including Christmas and Easter. But there have long been concerns about the deteriorating state of the churches, and a variety of interventions have been implemented over the years. In 2006 the World Monuments Fund (WMF) and UNESCO funded research into the decay processes affecting the Lalibela rock in order to define a long-term conservation strategy, and three years later the WMF partnered with the Zamani Project to 'digitally preserve' the entire site with lidar scanning. The team returned in 2017 for a follow-up survey of two of the churches, during which they were invited to scan an inner sanctum – off-limits to all but a few priests – where King Lalibela was buried.

The Zamani Project is a research group in the geomatics division of the University of Cape Town's Faculty of Engineering and the Built Environment. It was conceptualised in 2001 by (now Emeritus) Professor Heinz Rüther – still the project's principal investigator – but the first expedition only took place three years later. Since then, the Zamani team has documented more than 250 structures and features at some 65 sites in 18 countries of Africa, the Middle East and South East Asia.

The work is important because the ravages of time naturally take their toll on these ancient architectural treasures and heritage sites. Some of those surveyed by the team had also been damaged during wars or natural disasters, such as earthquakes and floods, or – even more sadly – had been subject to theft and vandalism. Looking forward, the threat of climate change, with the predicted rise in sea level and increase in extreme weather events, puts coastal and floodplain sites at particular risk.

The Zamani Project doesn't only digitally preserve the sites for posterity though – it also transforms the data into formats that allow armchair travellers to view the sites on their own screens at home. These include 3D models, animated and virtual 'tours', as well as photos, maps and architectural plans from various perspectives.

The process begins with terrestrial lidar, using a laser scanner on a tripod. The scanner records an object by



The Lalibela rock-hewn churches can be explored using an online panoramic tour.

The Zamani Project team with their laser scanner at the Meroë Pyramids in Sudan.

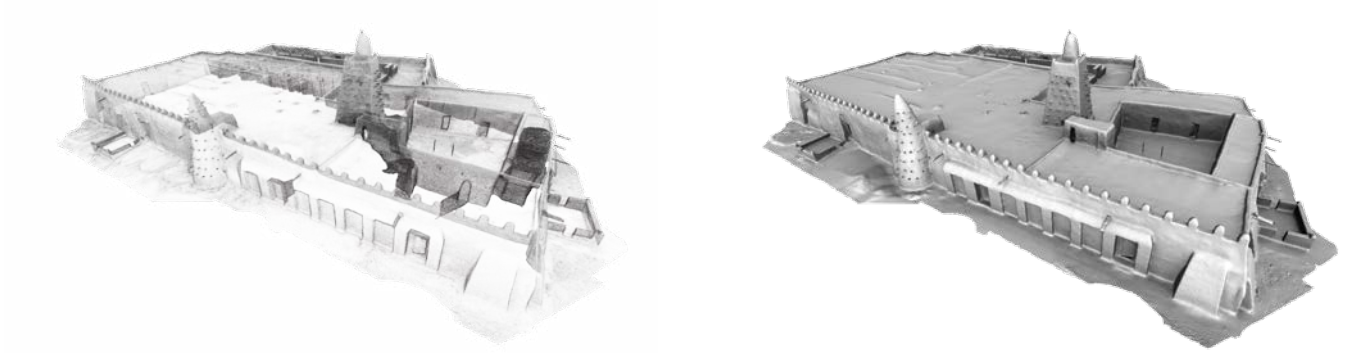
The 3D model of the Hill Complex at the Great Zimbabwe National Monument was created by the Zamani Project team in 2020. The stone structures at this World Heritage Site were built by ancestors of the Shona people in the 11th century.

determining the XYZ position of millions of points on the object surface, creating a three-dimensional 'point cloud'. To determine these XYZ coordinates, the distance, vertical angle and horizontal angle must be measured. The Zamani team's Zoller & Fröhlich phase-based scanner emits a constant laser beam – rather than short pulses as in slower pulse-based systems – and measures the phase difference between the transmitted and the return signal received by the scanner to calculate the distance between the scanner and the object. The two angles to the point are measured in the same way that a traditional theodolite measures angles.

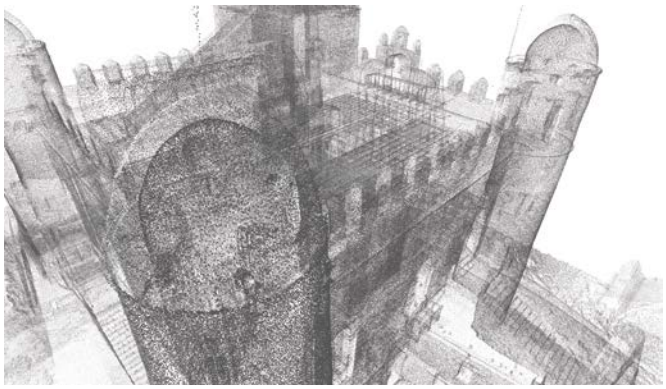
Scans are taken from numerous positions to cover as much of the object, be it a building or physical feature, as possible. Then, to fill in any data gaps in areas where the laser scanner cannot reach, photographs are taken with handheld and drone-borne cameras. Photogrammetry is used to generate additional point clouds for these gaps, and all the individual point clouds are combined and processed. Subsequently, a mesh representing the object surface is created, and photographic texture is 'draped' over the surface to give the 3D model a realistic appearance. Surfaces of models created during the early years of laser scanning have a somewhat metallic appearance – almost like they're tiny physical models made by a metal 3D printer – because software for the creation of coloured meshes was not then sufficiently advanced.

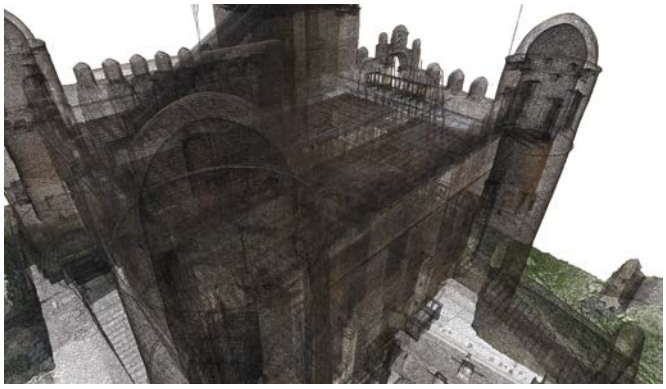
The end result is a metrically correct, mathematical representation of the object that can be viewed, navigated and even explored in virtual reality by those who have the necessary VR equipment. Accurate dimensional information can also be extracted. This means that architects and conservators can accurately plan the conservation and preservation of heritage buildings, as well as identify possible deformations and structural weaknesses.

The interactive panoramic tours are undoubtedly the best digital product to get an overall impression of a site within its surroundings. These don't use lidar but are



The Zamani Project team documented the Djingareyber Mosque in Timbuktu, Mali, in 2005. Surfaces of 3D models created during the early years lacked the photorealistic appearance of recent models because the software for such rendering was not yet sufficiently advanced.





From lidar point cloud to final 3D model of Fasil's Castle, the palace of Emperor Fasilidas, in the Fasil Ghebbi fortress in Ethiopia. Once the Zamani Project team have completed the laser scanning, photography and other survey work on site, an enormous amount of post-processing is required to create the 3D models and other digital products, including plans, sections, panoramic tours and video animations.

purely photographic depictions. Wide-angle photos are stitched together to create 360-degree images, which are in turn merged into a panoramic tour. Viewers can look in all directions from one vantage point using their mouse, trackpad or touchscreen, or move through the scene by clicking on arrows or other icons, or even leapfrog to another area by clicking on a dot on the embedded map. Some of these maps use an aerial or satellite image of the site to give a better idea of the landscape.

The tour of Petra – the 2 000-year-old sandstone city in Jordan – allows viewers to feel almost like the tourists seen wandering through the 264 000 m^2 archaeological park, but putting this tour together was just one component of a mammoth task. As part of a UNESCO project, the Zamani team spatially documented Petra during eight field campaigns between 2011 and 2014, completing over 2 000 scans that yielded a point cloud of some 12 billion surface points. These were used to create 3D models of the individual monuments as well as the Siq, the access route through a narrow canyon.

In addition, the team compiled a comprehensive Geographical Information System (GIS) and database for the site. The position of the models depicted in the GIS was accurately established by surveying control points using conventional survey methods and GPS/GNNS technology – something that is done for all sites.

Some of the sites documented are not yet available online, but the information is securely stored in a digital repository, and data requests for research and education purposes can be made. Although the majority of the sites documented to date are in Africa, the team has ventured as far afield as Myanmar in South East Asia to 'capture' the Buddhist temples and pagodas of Bagan. Close to home, the South African sites that can be explored on the Zamani Project website include Wonderwerk Cave near Kuruman in the Northern Cape, the Castle of Good Hope in Cape Town, and three rock art sites on the banks of the Clanwilliam Dam. Prior to the raising of the dam wall, due to be completed by March 2023, the rock art was scanned pending its removal – with the provincial heritage agency's permission – to a safe location. It is anticipated that the Zamani Project's 3D models and other outputs for the site will form part of a permanent exhibition in Clanwilliam.

By providing opportunities for both current and future generations to view spatially accurate depictions of heritage sites that they might otherwise never get to see, the Zamani Project helps share the insights such sites provide into past cultural practices and societal developments.

- Visit the Zamani Project's website to view the 3D models, animations, interactive panoramic tours and other digital products: https://www.zamaniproject.org/

  Animations of the 3D models and additional videos are also available on the Zamani Project's YouTube channel: https://www.youtube.com/user/zamaniproject

  Follow the Zamani Project on Facebook to stay up to date with new releases.

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