Chapter

Digital Technology to Preserve Heritage Structures

Steve Hold

Abstract

Heritage masonry structures such as castles, ancient sea walls, breakwaters and lighthouses have existed for centuries but more than ever in this current era need to be preserved and quite often strengthened to be able to survive natural and manmade destructive forces. This chapter uses examples of digital technology to not only strengthen and preserve such structures but by advocating the use of the internet offers archive access to what these structures are, what has caused their deterioration and what has been done to strengthen them for future generations to see. By also using archive research into their construction in a combination with digital models of the structures the examples in this chapter show others how the use of LiDAR, drones and GPR have been able to secretly and sensitively strengthen and preserve these structures. The examples in this chapter range from a Neolithical tomb to castles and breakwaters dating from the middle ages and unique engineering examples from the UK's Victorian age of engineers. Now that these worked examples of preservation and strengthening have been stored and become available visually through the internet to those interested and working in this field by using such modern digital tools, they are now able to enter a new paradigm of Heritage preservation.

Keywords: Preserving, Digital, Record, Heritage, Monuments

1. Introduction

In the recent years, particularly since about 2010, I have been capturing and recording the significant projects that I have worked upon and been involved in either restoring, strengthening and preserving in the field of Heritage buildings and Heritage sea defence masonry structures. This usually involves repairing or strengthening these structures 'in place', often with invisible strengthening methods that minimise adding or altering the fabric of the Heritage structure as little as practically possible.

The forces at work attacking these masonry structures, particularly the sea and sometimes man-made development around the areas in which they sit, means that there has usually only been a transient focus on what was done to preserve them in the current era .. This quite often means that what was recorded for the long-term posterity is limited and minimal records being kept during the projects. The detailed information of how, why, and where the structure was repaired and strengthened is quite frequently not recorded sufficiently and the useful and critical data is often lost.

2. Digital technology to preserve knowledge of heritage structure conservation and the virtual storage of data

Since the 1990s, major projects that I have been involved with as project manager or repair works engineering designer and specifier have been recorded by progress photographs and video notes. In this way a visual and 3D record of what was done and how it was achieved has been archived. This work has now accumulated a significant archive of different types of Heritage structures and how they were investigated, repaired, or strengthened for both teaching and sharing the more innovative ideas of such sensitive repairs. The objective is then to make this recorded visual detailed information available to the current, or present-day generation of engineers or conservationists who are interested in the preservation of these types of Heritage monuments. The method of doing this in the past has been by passing this knowledge on and includes 'papers' and 'presentations' at conferences for Civil Engineering, Forensic Engineering and Heritage bodies [1]. This after many years has built up a 'legacy store' of digital data used for such presentations. In recent years the progression of technology has meant transferring all of this type of standard information usually from VHS video for projects in the 1990s to CDs and then more recently having the CD information available on hard drives in the current era. This type of data storage not only condenses a large amount of practical knowledge down into a very small space for archiving but can transfer information through the internet as required to interested parties anywhere in the world. Currently even less space for storage will be needed when storing is transferred to the next stage of archiving development in the 'Cloud' and as a by-product of 'file sharing' and 'transfer links' data sent worldwide (**Figure 1**).

Figure 1.
1. Level – Normal hard copy files of projects, investigations, and solutions. 2. Level – Information from files and VHS video takes. on to CDs. 3. Level – Information stored on files on hard drives. 4. Level – Information available from 'cloud'.

3. Digital examples of recording

For digital examples it is important to note and record what was learnt from the archive searches, how we arrived at a solution and then how it was made to work successfully on site. In this electronic archive way the methods used can be made available to various bodies of engineers and conservation societies that need such data examples and who would find it useful in the future because having worked visual examples is both very informative as well as helpful and reassuring. In the United Kingdom these worked examples and papers have been for the Institute of Civil Engineers 'Structural Faults' and 'Concrete Solutions' conferences in the main. A list of references for these is in the Citing Sources section of the Appendices, as are the selection of video material referred to in the text [2].

Most Heritage monuments are subjected to the destructive forces of nature and in particular old sea walls and breakwaters to an increase of storm duration and intensity, due to sea level rise through climate change. Also, many land-based Heritage masonry walls are subject to chemical attack from pollutants in the atmosphere, floods, and heavy rainfall. More direct human intervention forces, quite often from developers changing the surrounding environment of the building or wall is another frequent source of destructive intervention. Usually unrecognised, manmade influence is often the lack of finance leading to greatly reduced or even zero maintenance for the structure and its environment. Another more recent threat to the structures is when the personnel or custodians of such monuments change from different departments, or different governments take over responsibility and they do not provide an effective 'hand over' of knowledge for preserving the Heritage monument. Therefore, it is important to ensure that the organisation or society responsible for the upkeep of the asset has a 'virtual' record of what is currently in existence in case some future disaster should happen i.e. earthquakes, wars etc. The new custodians need an understanding of the behaviour of the structure and the strengths and weaknesses of it as well as having access to the store of archive data.

This chapter gives practical examples of using digital capture of Heritage masonry structures that can be used by those responsible for the future conversation of similar types of asset. This philosophy of digital access will also enable those who have to take over responsibility for the various, sometimes iconic, structures to be able to see what was done and where it was done in a previous similar example which was invariably under great pressures to expend a minimal cost for the maximum advantage gained for the preservation i.e. the constraints of most custodian's budgets. There are several examples where the use of digital models have helped to procure the funding for major and significant civil and marine engineering repairs such as St. Aubins breakwater, Gorey Pierhead and St. St. Catherine's Breakwater in the UK Channel Island of Jersey which has an aggressive 11 m tidal range and faces the storms from the Western Atlantic Ocean.

4. LiDAR examples of recording

This chapter therefore provides examples of how digitally capturing the whole external shape, surface and geometry of the structure was applied to examples at St. Aubins Harbour piers and Gorey Pier in Jersey where LiDAR (Light Detection and Ranging) was used to great effect. The use of LiDAR again, together with drone surveys and photo model enhancement, was used at St. Catherine's breakwater at a different part of the coast of the island of Jersey. The use of this data proved essential in illustrating to the Government funding bodies of the Island that emergency finance was essential to save these assets for the Island of Jersey's Heritage.

From the archives search the failure of the inner face of the breakwater wall (**Figure 2**), Ref. [3] was seen to be the result of wave impact on the outside face of the breakwater causing, through 'stress propagation', the wall on the inner face of the breakwater to be forced outwards resulting in a partial collapse. The inner wall had also settled because it was originally built on the beach sand using large, loose blocks of granite stones with no foundations in 1640 by a young king Charles II. The solution shown in the model, in **Figure 3** (Ref. [3] Vid [1]), was for 'mini-piles' and 'secret fix ties' across the two granite walls of the structure which are designed to arrest any further movement.

The North Pier of the harbour at St. Aubins was also suffering from the same defects common to these old marine structures of inner wall settlement on no existing foundations that was resulting in a significant rotation inwards of the inner wall of the structure getting worse and more vertical towards the end of the breakwater [5–8]. The LiDAR survey produced the accurate model of the loose stone structure that was able to be assessed (**Figure 4**, Ref. [3] Vid [1]).

Of particular interest here was that the model moved graphically with the blue curser moving along the wall in plan with an imbedded graphic which showed the verticality of the inside loose stone wall becoming more vertical as the curser approached the end of the breakwater (**Figure 5**, Ref. [3], Vid Ref. [1]). As the original loose granite stone breakwater slopes inwards (called a 'batter'), the graphic was able to show dramatically that the further along the breakwater the inner face of the loose stones had reached vertical towards its end and was about to fail in a similar manner to the St. Aubins Fort breakwater seen in **Figure 2**. This demonstrated to everybody concerned with the maintenance of the structure that there was an urgent need to 'pin' and 'support' the inner stone wall at the end of the breakwater and tie the two masonry walls together with a 'secret fix'.

Figure 2.
St Aubin's fort breakwater failure 1972 (archives).

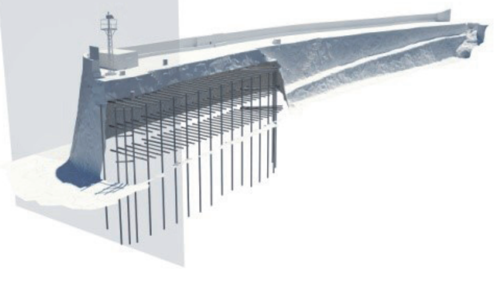

Figure 3.
St. Aubins N. pier LiDAR 3D model. (video Fly through and model Ref. [4]). (Link to video materials is available at the end of the chapter).

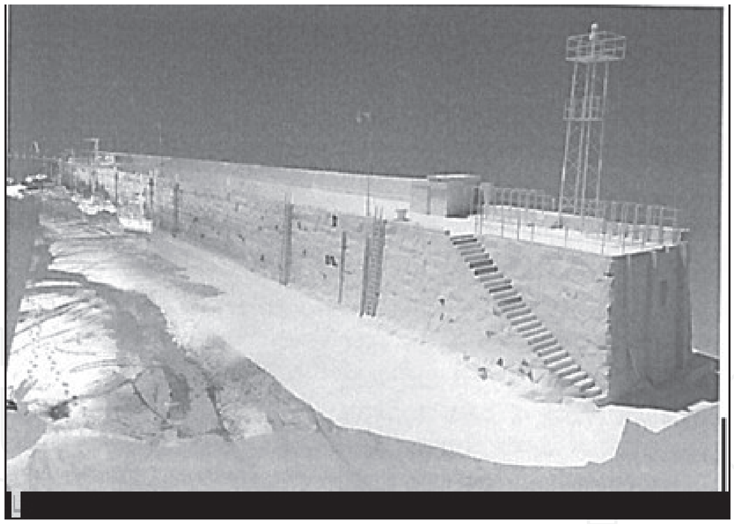

Figure 4.
North pier St. Aubins harbour LiDAR screenshot.

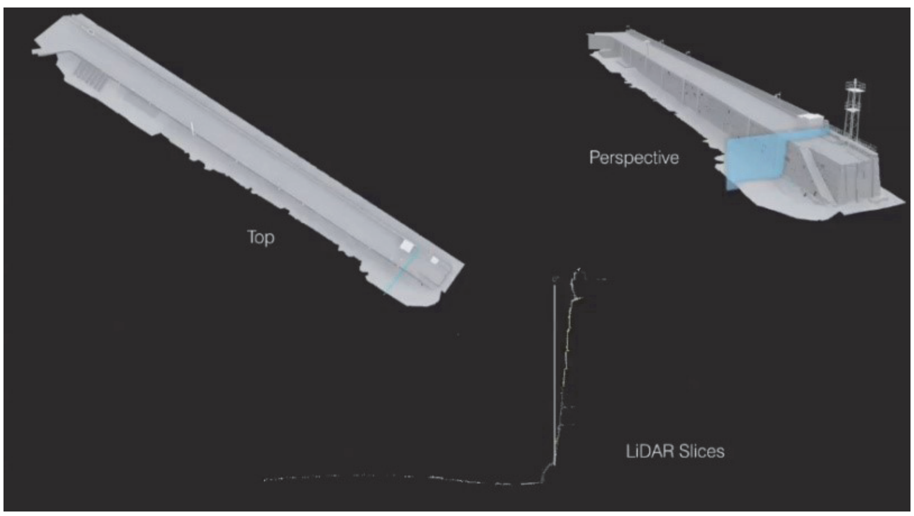

Figure 5.
Model used to demonstrate inner wall rotation of north pier. (Video of curser in moving blue cross section, Ref. [4]).

5. Digital graphical demonstrations

Similarly, Gorey Pierhead in Jersey was also saved from destruction (it also had failed in 1964, **Figure 6**, Ref. [10], Vid [1]) using LiDAR techniques to make the digital models that helped to demonstrate the need for intervention and to secure funds to enable the preservation of the pierhead of the breakwater and jetty.

Photographic merges and videos of the pierhead at low tide (with Gorey Castle in the background) showed the size of the loose granite masonry structure and where'bulging' of masonry and loss of concrete foundations were exposed (**Figure 7**). The pierhead itself show in **Figure 8** had to be rebuilt in 1964 after a major storm failure shown from the archives in **Figure 6**. To understand the evolution of the structure from the original pre-1620 pier, a LiDAR survey accurately captured the geometry of the whole of the pier in 2009. There was another major storm event in 2011 and a second LiDAR survey was taken, and the Point Cloud data overlaid on the GPS referenced coordinates of the original 2009 survey. **Figure 7** shows graphically the super imposed LiDAR scans to show where there was a "bulge" outwards of the masonry and a loss of concrete at the base.

Figure 6.
Collapse of Pierhead in 1965 (archives), Ref. [9].

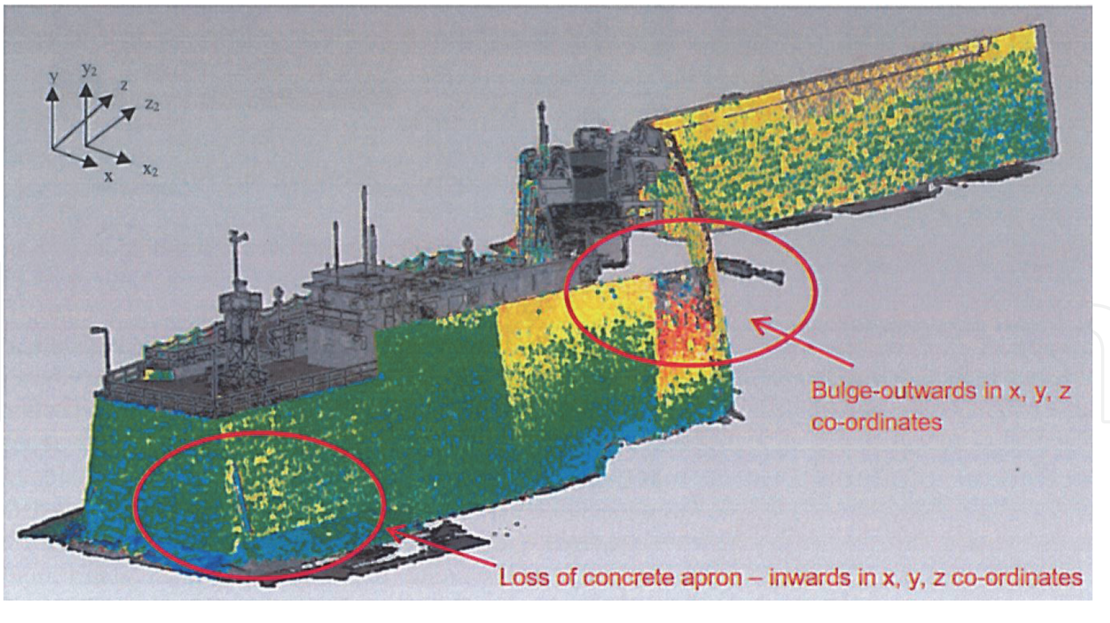

Figure 7.
Digital models overlaid 2 years apart. Localised masonry movements highlighted. Screen shot graphic colour. Ref. [9]. (Link to video materials is available at the end of the chapter).

I have used this image widely in several engineering papers and conferences because the overlay of LiDAR models (with an accuracy of ±2 mm) superimposed upon one another two years apart is self-explanatory. The second survey was directly after a severe storm and significant concerns by the structures' custodians were raised as some areas of visible physical movement had taken place. The model

Figure 8.
Gorey Pierhead and breakwater at low tide. Gorey Castle in background (digital photo merge), Ref. [10].

was able to demonstrate that one small area was 'bulging' out of the page (red in x, y, z coordinates indicates out of the page movement) and at the base concrete had been lost from the foundation apron (blue in x, y, z coordinates indicate in to the page movement). Just as importantly, the model graphic was able to clearly demonstrate that the damage was in two areas only because most of the pierhead and breakwater had remained in place after the storm (green overlay of the two sets of x, y, z coordinates have no distance). This meant that for the custodians (the Ports of Jersey) no very high costs were involved for the whole breakwater and only localised strengthening was requiring funding.

6. Photograph and digital models secure repair funds

Another very large breakwater on the island of Jersey (Jersey projects are particularly challenging because of the 11 m tidal range and adverse sea state conditions) was St. Catherine's Breakwater which stretches some 600 m out to sea (**Figure 9**, Ref. [11]). In a time of urgent crisis for the end of the structure in 2008, the breakwater roundhead was surveyed with GPR (ground penetrating radar) and found to have a very large hidden void under the concrete slab covering the roundhead at the end. If not repaired before the coming winter, then there was likely to be a failure and collapse. As soon as this occurred a section of the breakwater would have been likely

Figure 9.
St. Catherine's breakwater and roundhead 600 m out to sea.

Figure 10.
Photographic manipulation used to obtain emergency repair and protection funding, Ref. [11].

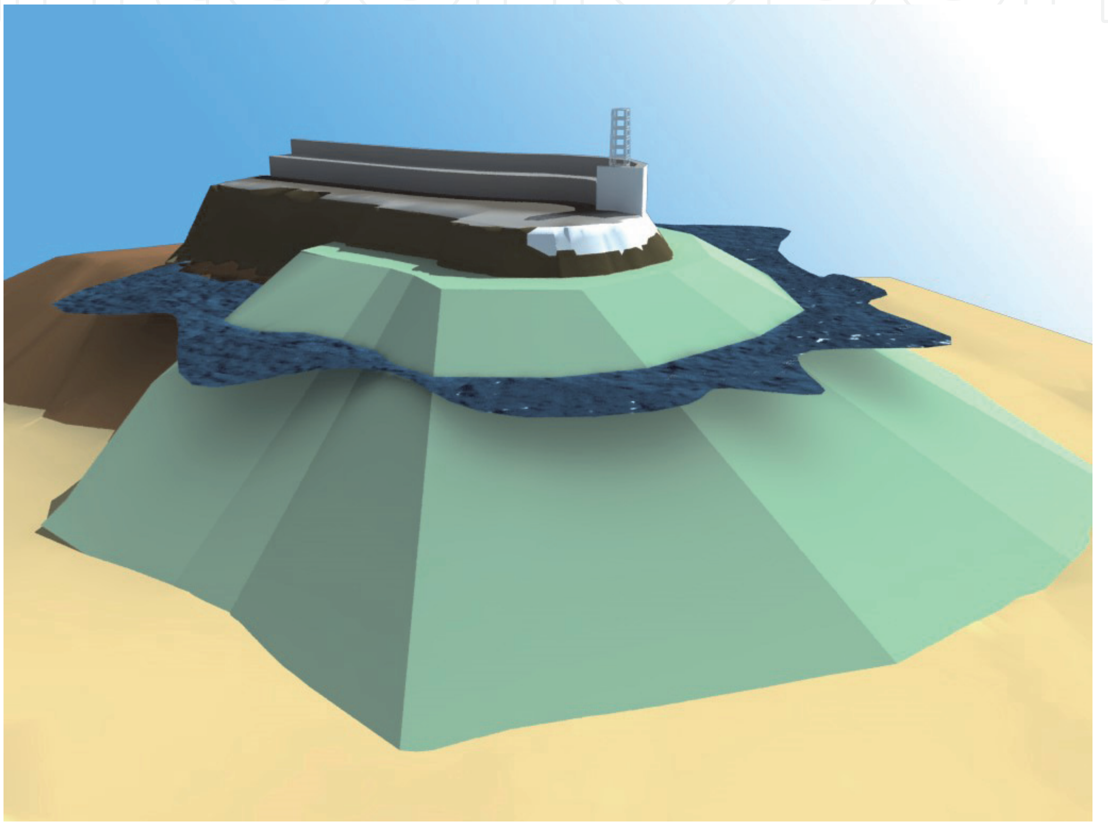

Figure 11.
Early digital model illustrating rebuild with rock Armour protection, Ref. [11].

to unravel during the type of fierce winter storms that occur around the coast of the Island. Digital models, drawing models using photoshopping images (**Figure 10**, Ref. [9]) of a likely collapse and unravelling mechanism helped to convince the governments treasury to release emergency funds. Drone surveys were then used to capture visual images of the whole structure that is particularly difficult and dangerous to survey conventionally and this also contributed to obtaining the urgent Government funding to repair and preserve this heritage marine monument as well as to be able to monitor it in the following years. (An early graphical model of the rock armour protection needed following the roundhead repairs is shown in **Figure 11**).

7. Manmade destructive influences

The deterioration of Heritage monuments due to manmade problems, for example at La Hougue Bie which is a Neolithic burial mound and tomb on the island

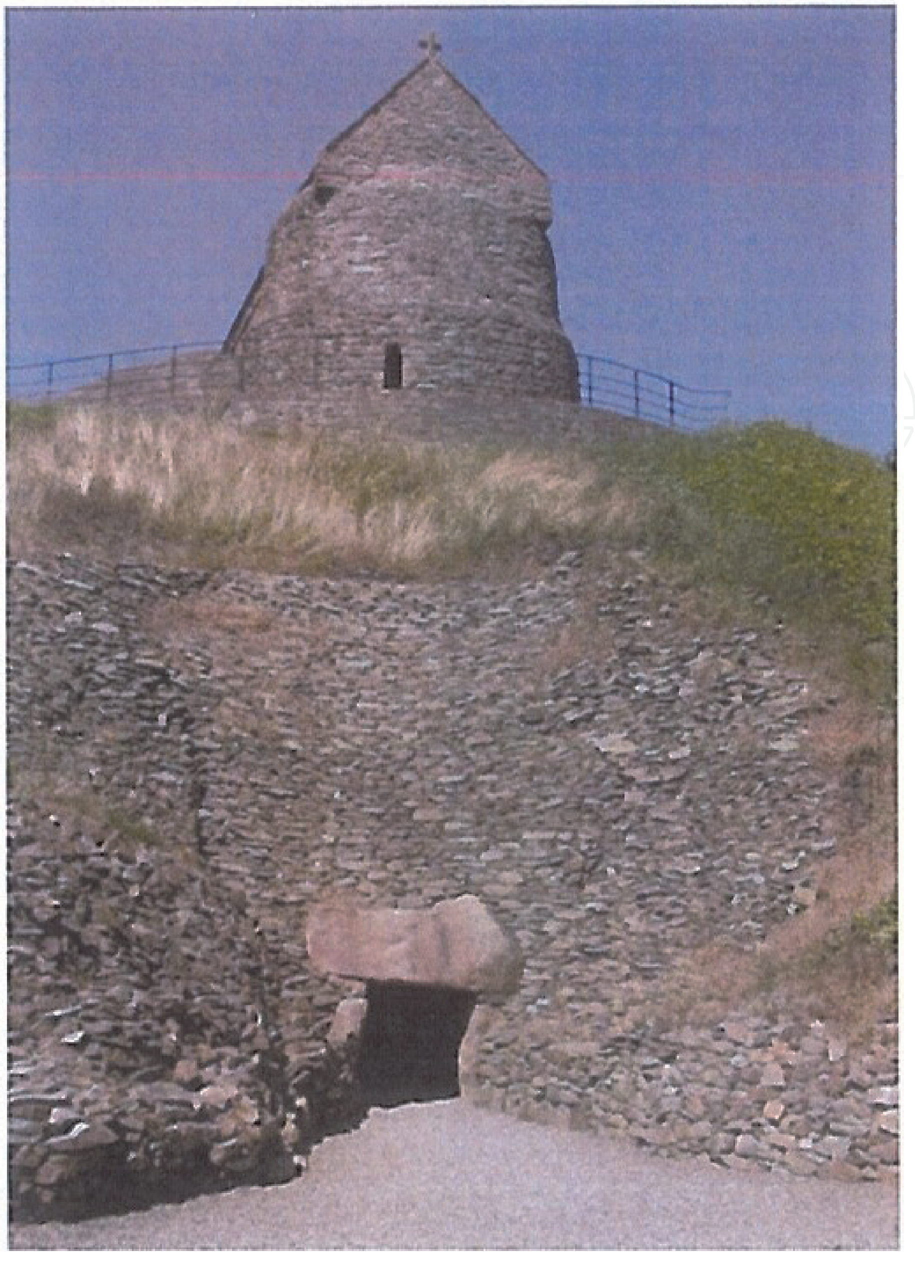

Figure 12.
LiDAR scan of burial mound entrance. Screen shot of mound entrance and film. Ref [12]. (Link to video materials is available at the end of the chapter).

of Jersey (**Figure 12**, Ref. [12], Vid Ref. [3]), also prompted a LiDAR scan and model of the whole site. In the course of recent history, trees had been planted on to the burial mound and there was great concern that the mound was slowly being destroyed by tree roots growing ever larger and into the mound. So its digital preservation for the current and future generations was recorded and the finished model has a fly-through and around the mound, as well as recording the 12th century chapel on the top of the mound (**Figure 13**, Ref. [12], Vide Ref. [3]) and even into and around the burial mound itself (**Figure 14**, Ref. [12], Vid Ref. [3]).

8. Man-made mistakes

The nearby Gorey Castle East Gate area was also damaged by manmade interventions because to accommodate tourist parking to visit the Gorey harbour and

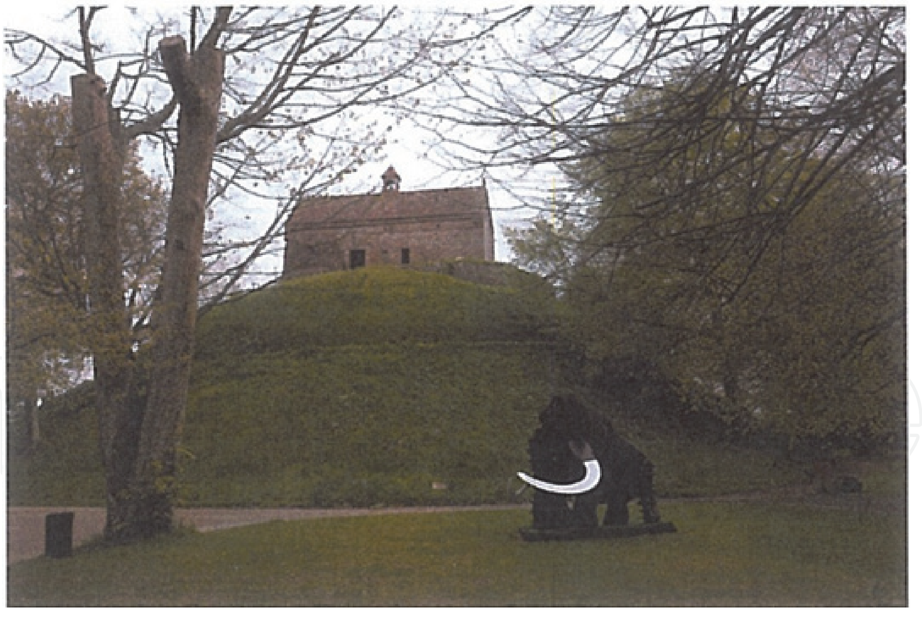

Figure 13.
Photograph of burial mound with trees (and not a real mammoth!), Ref. [12], Vid Ref. [3].

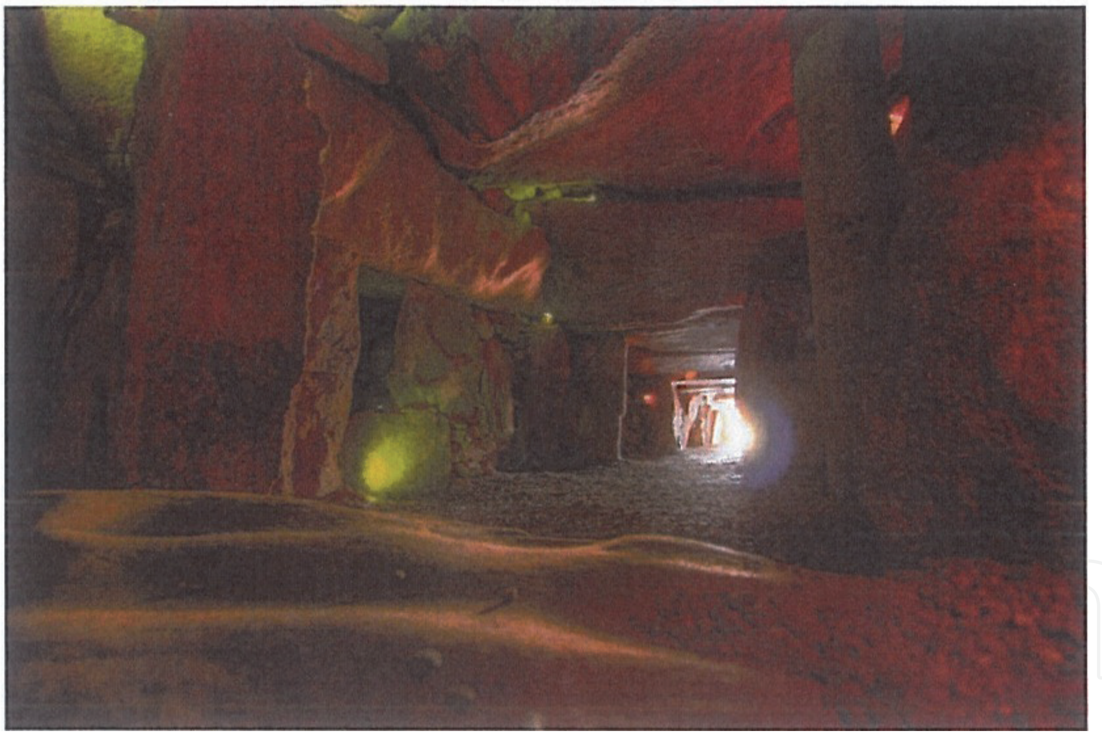

Figure 14.
Spectacular LiDAR fly through into chamber. Screen shot and film, Ref. [12], Vid Ref. [3].

Castle, excavations were carried out to create more car parking space adjacent to the Castle entrance (**Figure 15**, Ref. [10], Vid Ref. [2]). However, the works were excavated too close to the East Gate of the Castle and undermined the wall close to, and beneath this gate. The resulting movement and cracking in the masonry was significant but was also difficult to assess and map conventionally but with the use of the LiDAR model the engineering team was able to design repairs (**Figure 16** Ref. [10], Vid Ref. [2]).

LiDAR was used to accurately record the surface of the structure's masonry shape and to map the cracks so as to identify what parts of the masonry had moved

Figure 15.
LiDAR area of high density focus for accuracy. Show red line cracks.

Figure 16.
Drone survey of castle. Target area for LiDAR. Screen shots and survey video of castle, Ref. [10], Vid Ref. [2].

and by how much. This type of heritage masonry is very difficult to draw conventionally but the high intensity LiDAR scans produce accurate drawings that not only provide an archive but also very good visual records of this type of historic masonry structure and when and where it was repaired.

9. Man-made maintenance forethought

A slightly more academic exercise was carried out for the Elizabeth Castle in St. Helier because the custodians of the Castle, Jersey Heritage, required a 'resilience study' of the major elements of the Castle complex (**Figure 17**, Ref. [9], Vid Ref. [4]). In addition to a full photographic record, drone surveys were used to visually access the very high inaccessible castle walls on the rock outcrop to examine the masonry and to have a full record of the large number and variety of different era structures that make up Elizabeth Castle complex (**Figure 18**, Ref. [9], Vid Ref. [4]).

Figure 17.
The area to be scanned of the St. Helier breakwater.

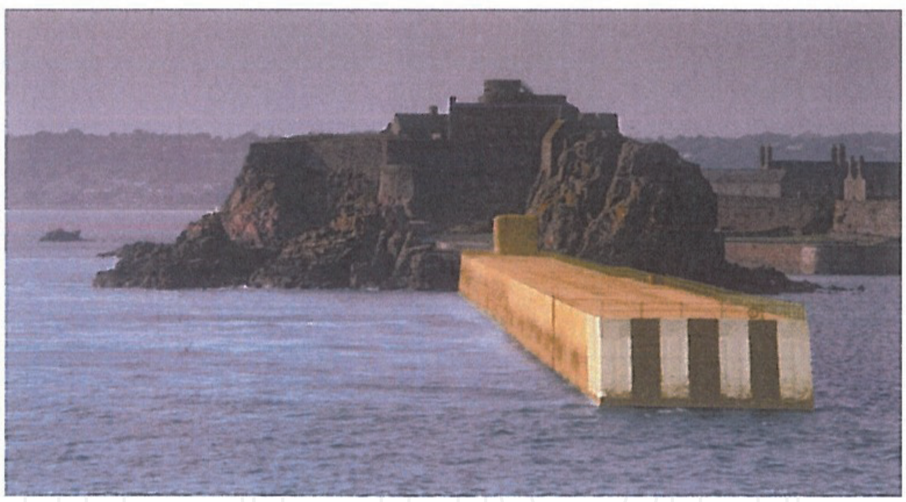

Figure 18.
Drone survey of area to be scanned by LiDAR for the Elizabeth Castle, St. Helier breakwater. (Screen shot of LiDAR castle fly over, reference video ....). (Link to video materials is available at the end of the chapter).

The Jersey Heritage Board were concerned that the annual vintage airplane display and fly past for celebrating the Battle of Britain in Jersey flew directly over the castle complex from the St. Aubins Bay in the south. The CEO of the organisation needed to know what the scale of the damage would be should any one of these ancient aircraft fall and impact on some of the priceless Heritage buildings. This included St. Helier's Chapel itself dating from 555 AD which was directly in the flight path of the display (**Figure 19**, Ref. [9], Vid Ref. [4]). The evidence from the study was then used to justify the organisers of the display in to changing the flight path away into a different direction in the Bay to safeguard the Heritage buildings (**Figures 20–22**).

Figure 19.
Helier chapel from 555 AD in the flight path.

Figure 20.
From the shore the aerial fly past display over Elizabeth Castle.

10. Safety and other practical benefits of using digital technology

This type of technology, especially the use of drones to gather large numbers of images of a difficult to access part of a structure enables the production of 'Point Cloud' models with 3 mm accuracy. This methodology also means that the safety of personnel in gathering data such as at the Castle walls and the difficult and dangerous to access breakwater walls, has increased significantly. Also, distance in using this digital technology is not limited and Heritage conservation knowledge has, or should have, no international boundaries. By using LiDAR and drones to produce digital models, I have been able to work on the strengthening and preservation of several Heritage monuments in China. Examples are the Chongching Gate and the Yongying Bridge in Shanghai and the White Pagoda in Guang'an were able to be

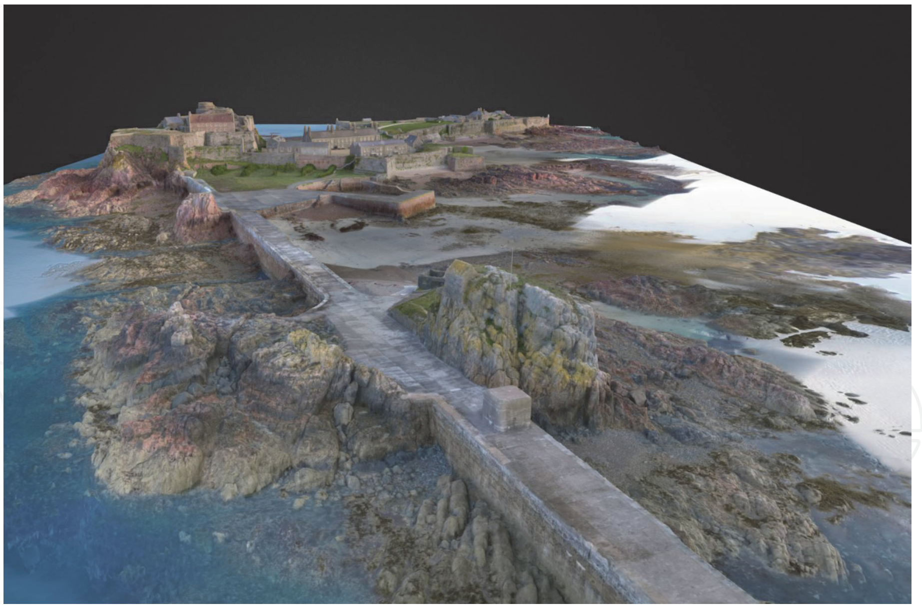

Figure 21.
The full drone Elizabeth Castle model. The fly through over the complex is along the flight path and St. Helier's Chapel is in the centre of the picture. Screen shot and fly over.

Figure 22.
The drone survey model of the higher in accessible west facing castle walls.

assessed for strengthening and preservation using the 'secret fix' Cintec anchor method developed in the UK. Through digital communications and from exchanges of data I have been able to provide assistance in these Heritage preservation schemes. Along with the progress of Chinese modernisation and development in recent decades has come the recognition and appreciation by local Government Authorities, the community value of the Heritage monuments being preserved (**Figures 23–28**, Ref. [15]).

11. 'Secret fix' versatility

In the UK historical bridges and buildings have also had their structural integrity enhanced and preserved using digital models to work with the Cintec Anchors

Figure 23.
The threatened Chongquing gate to be preserved and strengthened.

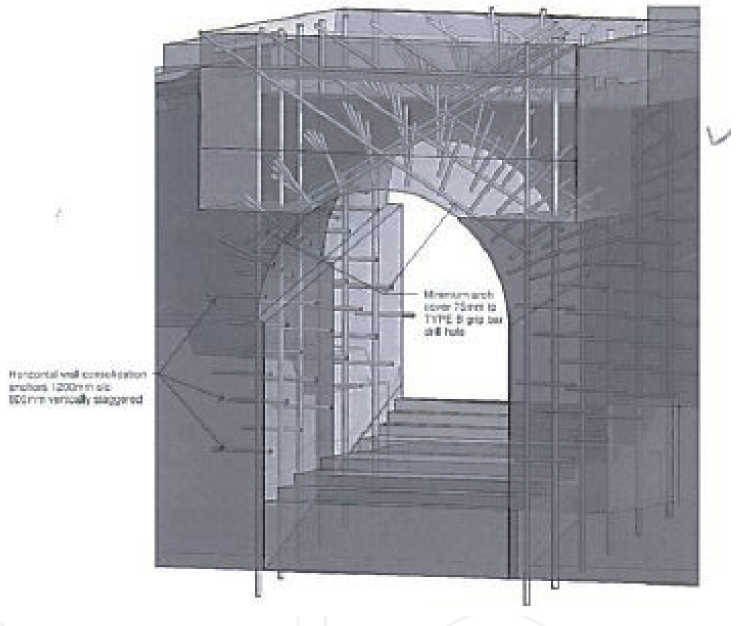

Figure 24.
The 3D model of the Cintec 'secret' anchor strengthening of the gate.

'secret fix' stitching reinforcing anchor system, as demonstrated in the St. Aubins breakwater examples in Section 4.

When modernising areas of city centers for example, façade retention has also been required in terms of Heritage and Planning to enable modern buildings to be constructed within or behind the Heritage façades. The new structure can be tied to the façade to be retained by using these methods.

12. Archive information equally important to record

An important aspect of the accumulation of the digital data work prior to commencing an investigation or study involves obtaining as much historical data from archives, drawings and records obtained from any available source. A good example recently of this whole sequential process and has been the Principal

Figure 25.
The damage to the slender Yongying bridge.

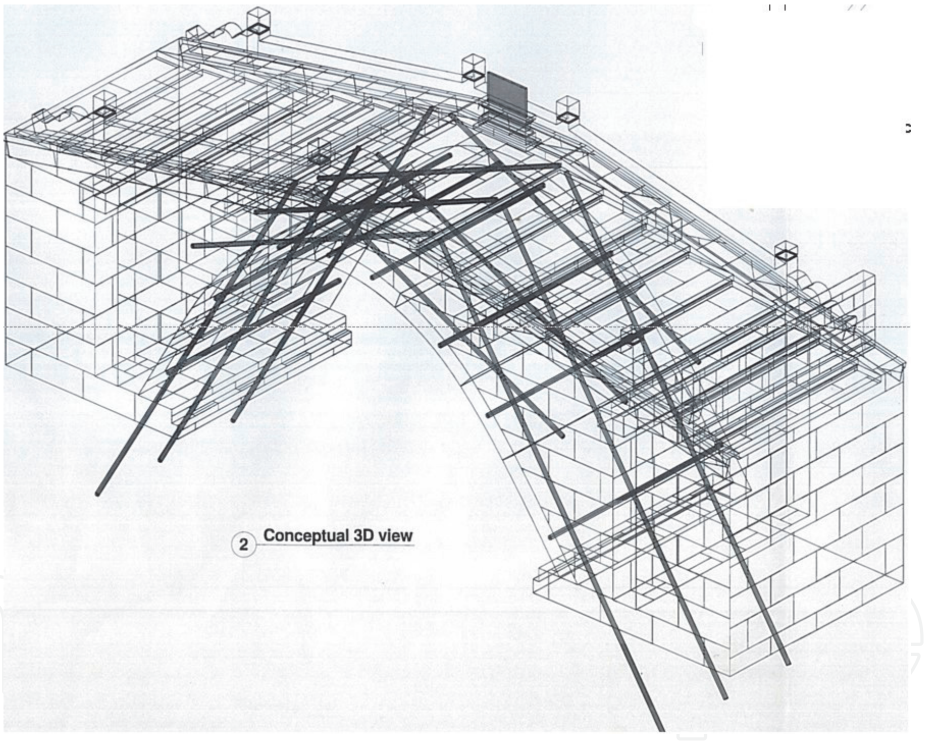

Figure 26.
3D model of the Cintec 'secret' anchor strengthening scheme.

Engineer's inspection of the Elizabeth Castle Breakwater in St. Helier, Jersey (**Figure 29**, also refer back to **Figures 17** and **18**, Ref. [9], Vid Ref. [4]).

This structure was conceived and constructed in 1860s by the English Victorian era engineer Jonathan Coode (**Figure 30**). He developed in the course of designing the breakwater a new innovative method for constructing new concrete blocks instead of using large granite stone blocks to construct the Elizabeth Castle Breakwater (**Figure 31**). It was also discovered in other archive records on the Island that at about this same time, he was able to construct the first concrete lighthouse on the island of Jersey at Corbiere (**Figures 32** and **33**).

Figure 27.
LiDAR scan of the white pagoda surface erosion.

13. A unique access and records problem and location resolved by drone survey

The work to preserve and protect the lighthouse at Corbierre in Jersey (**Figure 32**, Ref. [13], Vid Ref. [5]) has also involved LiDAR scanning common archive research and drone surveys to assess the inaccessible damaged surface coatings to the very first cast concrete lighthouse erected during the UK's Victorian era in the 1860s (**Figure 33**). Access there is only gained by a causeway at low tide and is in at a very dangerous rocky part of the Channel.

14. Another unique remote location challenge

In terms of circumventing dangerous rocks and restoring Heritage value to a site, the recent work to assess and design the repairs to a sea wall at Les Minquiers, a rock archipelago 20 km south of Jersey, between the island of Jersey and mainland of France, has relied heavily upon a drone survey (**Figure 34**, Vid Ref. [6]). This particular dangerously rocky outcrop of islands forming an archipelago of unique flora and fauna is virtually inaccessible unless by light small boat (**Figure 35**). Previously there had been no surveys or any drawings done of the main island itself or the fisherman's shelter cottages that had historically been built on the island (**Figure 36**). The ability to replay and 'pause' the drone video enabled the difficult and remote access parts of the failed

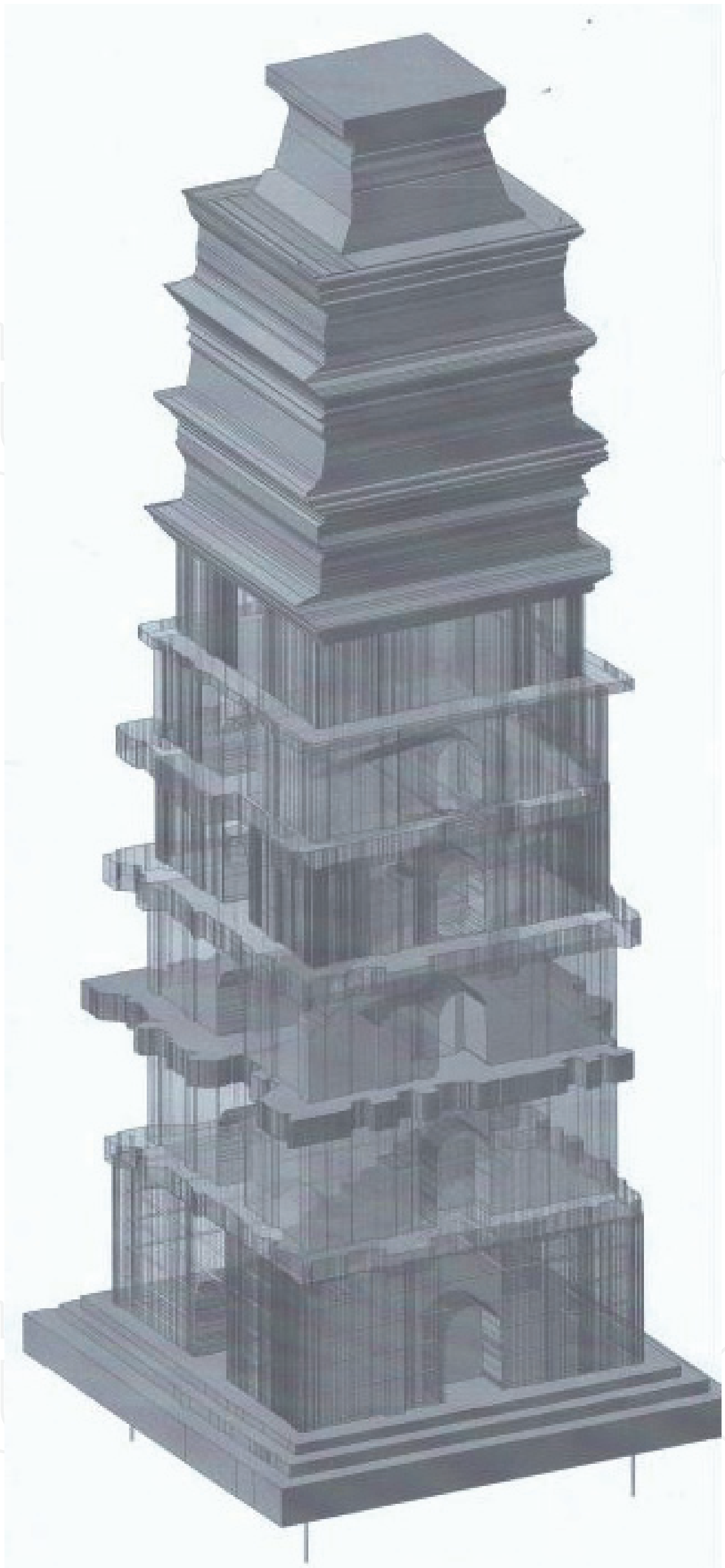

Figure 28.
Model of the structure for analysis.

sea wall to be studied and modelled so that a Heritage and environmentally sensitive repair and rebuild could be achieved.

15. Conclusion and looking forward

The issue of using digital capture has therefore come into its own in the modern era and in a practical sense to be able to 'bring back' the structure into a design

DOI: http://dx.doi.org/10.5772/intechopen.99023

Figure 29.
The damaged west side of Elizabeth Castle breakwater.

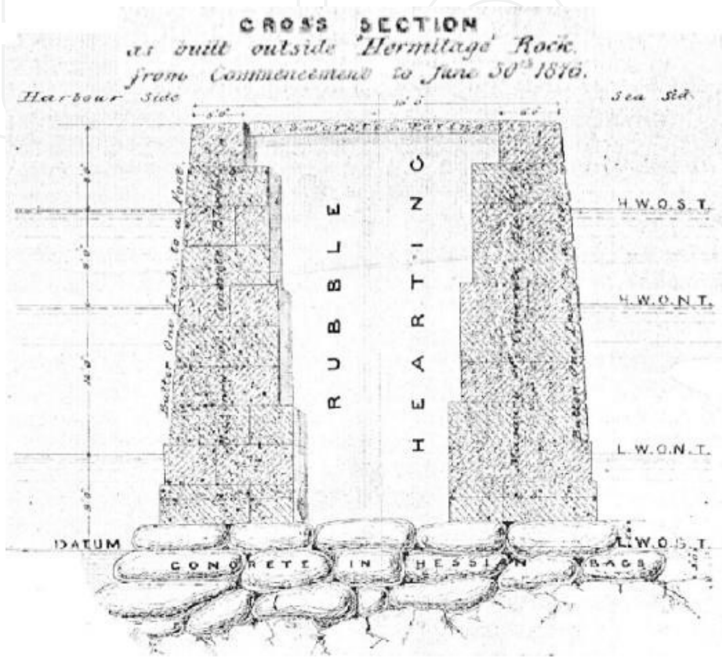

Figure 30.
Archive drawings of the breakwater's construction with concrete blocks instead of granite blocks forming the outer walls of the breakwater.

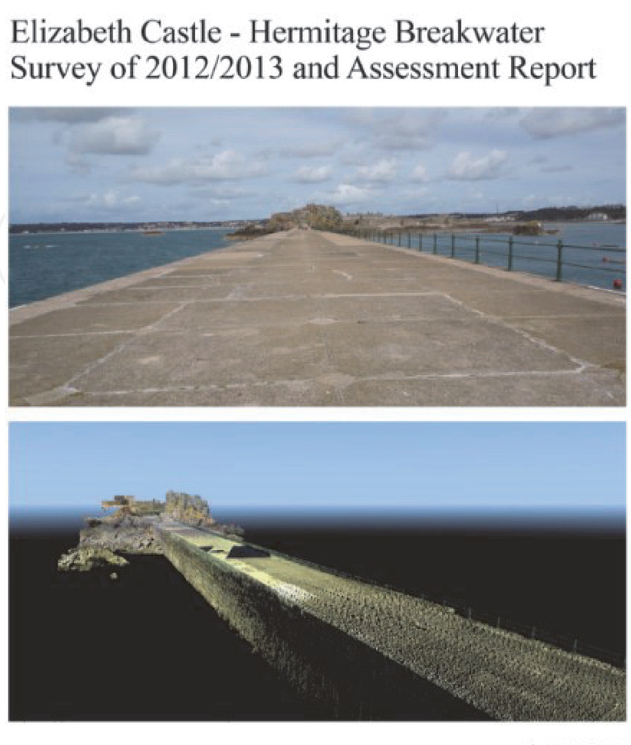

Figure 31.
Principal Engineer's report using LiDAR and drone information. Ref. [9], Vid Ref. [4].

Figure 32.
Archive search of construction of lighthouse. (Link to video materials is available at the end of the chapter).

Figure 33.
Lighthouse with raging storm.

office to be able to discuss the problems and the practical methods that can be used to strengthen and preserve the Heritage structures (**Figures 36** and **37** for the sea wall rebuild at Les Minquiers is another good example).

However, the types and format of digital information and records need to be available to all and pooled together if possible and practical so that the various bodies that can benefit from using the visual experiences which has been captured. It should then be practically possible to not only pass on the technical knowledge but also provide a 'virtual record' of what was originally constructed from the archive research together with the visual records of how the site investigation and repair work was done. The data stored then remains as a full detailed record of what was done at a particular time to preserve these magnificent heritage structures for future generations to marvel at. This concept puts forward a new way of sharing how these unique structures have been assessed, repaired and strengthened and creates a new paradigm for Heritage Structural Preservation.

DOI: http://dx.doi.org/10.5772/intechopen.99023

Figure 34.
LiDAR model of structure and later a full access drone survey of outer surface, Ref. [6]. (Link to video materials is available at the end of the chapter).

Figure 35.
Access to the island at low tide through a rock reef.

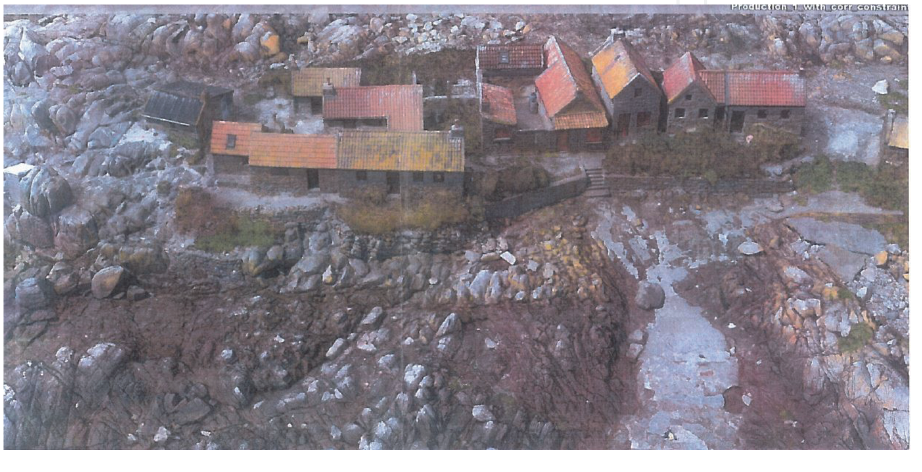

Figure 36.
Location of the damaged sea wall to be rebuilt.

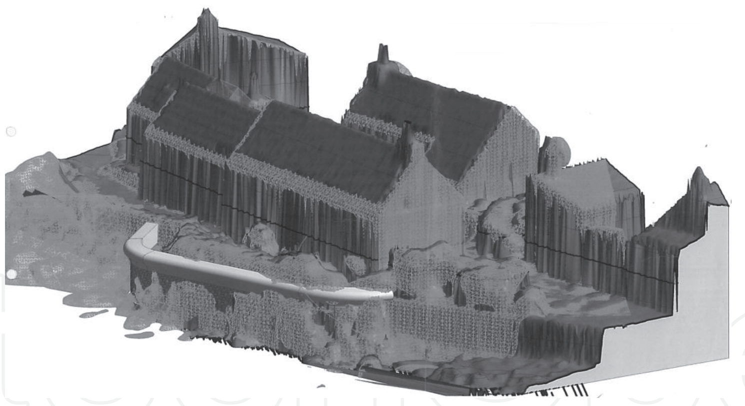

Figure 37.
Initial model helped select design geometry of sea wall repairs.

Videos

Videos are currently being edited professionally and they will be labelled and forwarded to Intech separately.

1. Jersey Fly through
2. Gorey fly through
3. La Hougue Bie
4. The Hermitage
5. Lighthouse at Corbierre
6. Les Minquiers

Video materials

Video mentioned in References [4, 9, 12] is available to download here: https://arup-my.sharepoint.com/:v:/p/bernadette_gardner/EU9S2nYdaYRDgmyaYCuGCGMBDhTI2F0LK77zEptBojrt0A?e=4gGoD8

Author details

Steve Hold
SHCCE Ltd., The Bowerhouse Studio, Cowbridge, South Wales, United Kingdom

*Address all correspondence to: steveholdconsulting@gmail.com

References

[1] Stephen Charles. 4th Internal Conference on Forensic Engineering, April 2013 ICE London, UK

[2] Stephen Charles. Structural Faults and Repairs, Edinburgh University 2012, Scotland

[3] Stephen Charles. Stitching the Past – "Strengthening of two heritage marine structures in Jersey with needling technology"

[4] Stephen Charles. Medachs 08 Marine Heritage Structure, Lisbon, January 2008, Portugal

[5] Stephen Charles. ICE Symposium, Marine Structures, Swansea, April 2008, Wales, UK

[6] Stephen Charles. ICE Conference, Coastal Management Belfast, 2011, Ireland

[7] Stephen Charles. PIANC Maritime Maintenance Seminar, Exeter March 2012, UK

[8] Stephen Charles. PIANC Maritime Conference ICE London October 2012, UK

[9] Stephen Charles. ICCRRR 2015, Leipzig, Germany

[10] Stephen Charles. An award winner paper at Structural Faults and Repairs, Imperial College London, September 2014, UK

[11] Stephen Charles. Coasts, Marine Structures and Breakwaters 2013, ICE Edinburgh, Scotland

[12] Stephen Charles. PIANC Seminar, October 2015, ICE London, UK

[13] Stephen Charles. Jersey Heritage Museum, 2013.