



Title	Living in the clouds: conceptual reconstructions of harbour structures
Authors(s)	Shotton, Elizabeth
Publication date	2018-02
Publication information	Shotton, Elizabeth. "Living in the Clouds: Conceptual Reconstructions of Harbour Structures." Emerald, February 2018. https://doi.org/10.1108/JCHMSD-08-2017-0052 .
Publisher	Emerald
Item record/more information	http://hdl.handle.net/10197/9297
Publisher's statement	This article is © Emerald Group Publishing and permission has been granted for this version to appear here (please insert the web address here). Emerald does not grant permission for this article to be further copied/distributed or hosted elsewhere without the express permission from Emerald Group Publishing Limited.
Publisher's version (DOI)	10.1108/JCHMSD-08-2017-0052

Downloaded 2026-05-01 23:33:01

The UCD community has made this article openly available. Please share how this access benefits you. Your story matters! (@ucd_oa)



© Some rights reserved. For more information

LIVING IN THE CLOUDS: CONCEPTUAL RECONSTRUCTIONS OF HARBOUR STRUCTURES

Elizabeth Shotton^a

^a School of Architecture, Planning and Environmental Policy, University College Dublin, Ireland – elizabeth.shotton@ucd.ie

KEY WORDS: Point Clouds, History, Conjecture, Certainty, Maritime Engineering

ABSTRACT:

The harbours of Ireland, which evolved over centuries to serve local communities, are under threat from deterioration and rising sea levels. This project is documenting these structures using terrestrial LiDAR augmented by archival research to develop comprehensive histories and a comparative analysis of the evolution of maritime construction. Part of the mandate is to make the research, including timeline models illustrating the evolution of each harbour, available to future researchers and the public. The use of scanning or photogrammetry to record tangible cultural heritage is an established field and has sponsored considerable development in methods to extract legible three-dimensional models from the more amorphous point cloud data to facilitate the active management of buildings and for interpretive visualisations. Though operational formats are imperative for the management of buildings and sites, the premise of this paper is that it is accuracy that is paramount to archaeological hypotheses or architectural digital reconstructions and the need for an operational format should be reconsidered. The rationale is that these reconstructions are forms of history making where fragments of factual evidence are drawn together and upon which a conjectural reconstruction of a plausible account of events developed. The necessity to differentiate the difference between fact and conjecture is key to the intellectual transparency of the resulting representation, particularly in the case of timeline models where conjectural elements are to be modelled. The paper presents a procedure for superimposing conjectural reconstructions in point cloud format on scan data and the advantages over other forms of representations.

1. INTRODUCTION

1.1 Irish Maritime Heritage

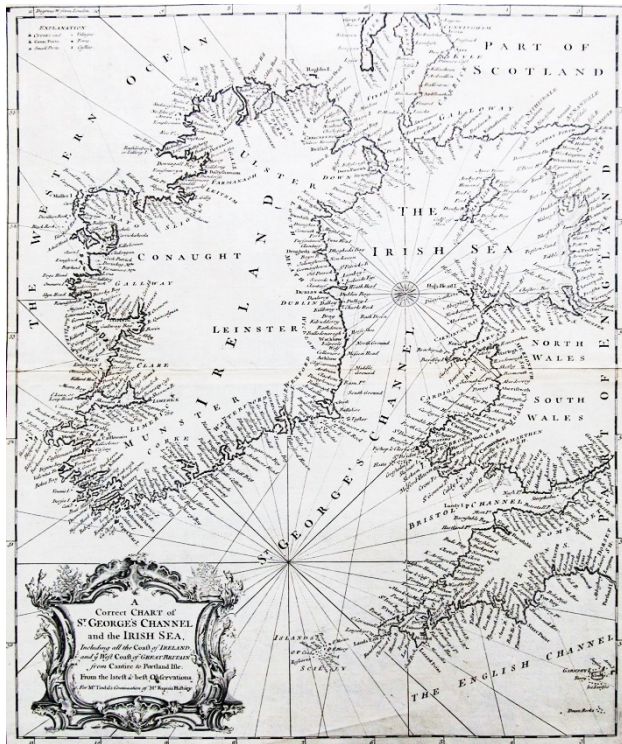


Figure 1. A Correct Chart of St. George's Channel, Richard Seale, 1742 (with permission of the Royal Geographical Society)

Although Richard Seale's sea chart of 1742 (Figure 1) is a powerful representation of the remarkable number of harbours that encrusted the shorelines of Britain and Ireland in the mid-eighteenth century, indicative of the importance of trade by sea at this time, the real boom in harbour construction was yet to come. Between the mid-eighteenth century and the start of the twentieth century the number of minor harbour structures multiplied markedly, in the first instance to support trade, particularly in coal, and more latterly to encourage local fishing communities. Thus, harbour structures along Ireland's coastline represent a significant infrastructural system that has shaped local and national Irish culture for centuries. Their early development and later modifications document the evolving nature of engineering technologies, some being peculiar to Ireland particularly in the latter half of the nineteenth century. While major harbours have been well documented (Rynne, 2006; Gilligan, 1988) there remain considerable structures that due to their small size have been overlooked. These minor harbours represent a considerable source of information, many having originated through local efforts only to be later modified through government works in the nineteenth and twentieth centuries. Of the 94 landing places, built or unbuilt, identified on the east coast by the Underwater Archaeological Unit (UAU) of the Irish National Monuments Service (2002) there are 83 for which limited documentation exists, of which 57 built structures have been identified for further study as part of the current project (Figure 2). Although some of these are recorded in the Irish National Inventory of Architectural Heritage (NIAH), it is not comprehensive and little data on the configuration, dimensions and construction are recorded.

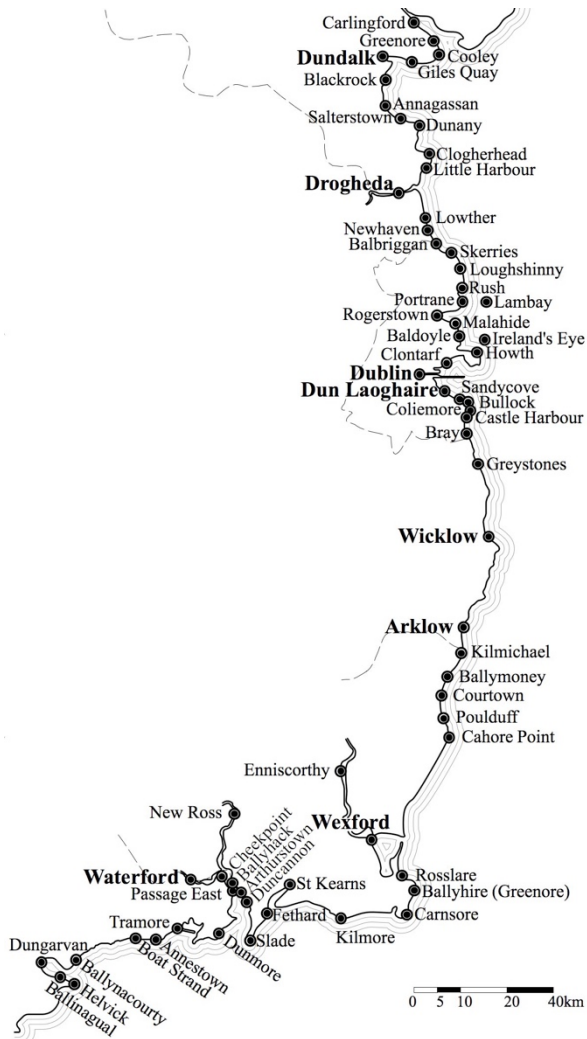


Figure 2. Harbours on Ireland's east coast with mid-sized and large harbours, excluded from the study, in bold (Shotton, 2017)

Though some knowledge on the minor harbours is found piecemeal in local history journals (O'Sullivan, 2000) or small booklets (Smyth, 1996) they tend to be examined in an isolated fashion and from a non-technological perspective, failing to understand the broader trends in technological change that influenced their building and later modifications. The danger posed to these structures from deterioration and rising sea levels is increasing and it is imperative to create accurate records to support a comprehensive analysis of the evolution of maritime engineering in Ireland, similar to the work already undertaken in Scotland by Angus Graham in the late twentieth century (Graham, 1968-69; Graham and Gordon, 1987). As clear from the work of Graham, these minor structures typically appropriate local topographical features and evolve incrementally, making their forms eccentric and difficult to capture using conventional survey methods. The use of terrestrial LiDAR to scan the harbours three-dimensionally addresses this difficulty and, when coupled with historical research, provides the information necessary for a more comprehensive comparative analysis.

1.2 Case Study: Fethard Quay

Described as Ireland's smallest harbour (Hassard, 1923), the diminutive Fethard Quay at Ingard Point east of the town of Fethard in County Wexford is one of the oldest harbours on Ireland's east coast. The harbour is approximately 30 meters in width by 60 meters in length, consisting of a quay and two piers,

one L-shaped, in addition to slipways outside the structure on each side, the eastern slipway being a more recent addition (Figure 3). Though Fethard has supported a fishing community since at least the seventeenth century (Hore, 1859), using the small creek as a haven in the first instance and later finding shelter in this small harbour, Fethard Quay had never been intended as a haven for fishing boats, but rather was purpose built to harbour a single vessel, the King's Barge.

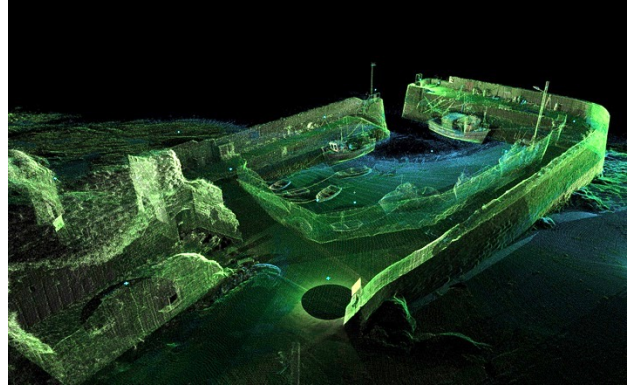


Figure 3. LiDAR scan of Fethard Quay, County Wexford (Shotton, Semar, Lennon, 2016)

The building of Fethard Quay was driven by the need for a safe haven from which a revenue cruiser could operate along the coast for the Commissioners of Customs, known locally as the Revenue Commissioners. Revenue cruisers, occasionally referred to as a King's Barge (Frizell, 1771; Moylan, 1960), were responsible for policing smuggling activities and the one planned for Fethard was but one of many operating along the coast of Ireland. Fethard Quay was commissioned and purpose built for the Commissioners in 1741 by Nicholas Loftus (c.1687-1763), then landlord of Fethard as well as much of the Hook peninsula, for which he received £200 in payment (Irish 1741-42). Built principally of partially squared, roughly coursed limestone (Stanley, 2016), which is not found in this area, in addition to some amount of old red sandstone that is local (Kinahan, 1885-89), it is probable that the limestone was shipped from the Loftus harbour in Slade, further south on the Hook peninsula where there was an abundance of limestone quarries. It is also possible that Loftus had workmen from Slade build the harbour, as traces of vertically set stone coping can still be seen in part of the west pier (Figure 4), a style used in the neighbourhood of Slade but nowhere else on the peninsula (Colfer, 2010).



Figure 4. Remnants of vertical coping on face of west pier (Shotton, 2016)

Fethard Quay remains largely intact in its original form, despite minor alterations in the twentieth century, yet there had been earlier buildings and demolitions in its history of significant consequence to its form and use. The still extant ruins of the private warehouses owned by the local Lynn family attest to part of this history, as does the remnant of the Revenue Commissioners' watch house wall and roof coping embedded in the west pier (Figure 4), while the alteration to the geometry of the quay wall is more difficult to discern. Much of the knowledge of these elements has been lost to all but the keenest of local historians, and while historic images can recapture some of these earlier moments (Figure 5), the development of a digital three-dimensional timeline model could offer the public and future researchers a more complete and accessible narrative of the complex evolution of this small harbour.



Figure 5. Lynn Warehouses, Fethard Quay, n.d. (with permission of Liam Ryan)

1.3 Digital Models and Historic Validity

“It is necessary to see the historian ... as offering merely a temporary working hypothesis which gives his readers a schema for observing the buildings discussed.”
Edward McParland, 1975.

The ambition of the survey of vernacular harbours, involving both terrestrial LiDAR scanning and historic research, was to accurately document these structures and develop coherent narratives, both written and visual, regarding their development across several centuries. Harbours, by their nature, are more akin to archaeological sites than to buildings, being irregular in form, context driven and heavily dependent on constructive detail. Thus, the development of parametric objects to define their form is problematic. Equally, and significant to this discussion, they tend to be composed of a series of accretions built over several centuries. Visualising this incremental development three-dimensionally requires the segmentation of the scan data into legible subsets, a process used by archaeologists in developing digital diachronic reconstructions of sites as discussed in Manferdini and Remondino (2012). But to create a coherent narrative many elements that are no longer extant but nevertheless critical to the history of the harbour, such as the warehouses and watch house at Fethard Quay, must be added to

the model as conjectural reconstructions, raising issues as to the legibility of fact versus hypothesis.

The use of scanning or photogrammetry to record tangible cultural heritage has sponsored considerable development in methods to extract legible three-dimensional models from the more amorphous point cloud data generated by these techniques (Manferdini and Remondino, 2012), from the generation of meshes to the use of NURBS and parametric modelling. The use of parametric modelling in tandem with the adoption of BIM, in particular, has created more coherent models to facilitate the active management of historic buildings and the capture of metadata (Fai and Rafeiro, 2014). The ambition to derive more operational forms of three-dimensional representations from the point cloud data is imperative where it is to be used for the management of historic buildings and sites. However, for use in historic research, education and dissemination, the same operational format is not imperative. Though it has been argued that ‘high modeling accuracy’ is not required in models for archaeological hypotheses or architectural digital reconstructions (Styliadis et al., 2009), the premise of this paper is that it is accuracy that is paramount in these cases and that it is the need for an operational format that should be reconsidered.

The rationale is that both archaeological hypotheses and architectural digital reconstructions are forms of history making, where fragments of factual evidence are drawn together and upon which a conjectural reconstruction of a plausible account of events developed. In this sense history is never truth, can never be fully verified and can, on occasion, be refuted and rewritten due to the introduction of new evidence or the construction of a more credible or acceptable narrative. To be of value to future researchers, histories of this kind must be explicit in distinguishing fact from the conjectural elements of the narrative. To do less than this is to obscure both the facts as well as the underlying hypothesis that is generating the conjectural reconstruction, an issue of critical importance in visualized reconstructions, where, as Favro (2006) argued, the power of the simulation can easily overwhelm any understanding of the actual ‘state of knowledge’. This principle was recognized in the earliest ICOMOS Ename Charter (2002) for the interpretation of cultural heritage sites, which recommended that, “historical interpretation ... must also indicate clearly and honestly where conjecture, hypothesis, or philosophical reflection begin” and was reiterated, though in somewhat modified terms, in Article 4.4 of the London Charter to provide what has been described as ‘intellectual transparency’ (Denard, 2012).¹ This has become increasingly important as this data is being used in web-based platforms and virtual reality simulations for education and dissemination of research on cultural heritage (Guarnieri et al., 2010) in formats that do not necessarily allow the viewer to naturally intuit fact from speculation.

The cloud of points derived from a scanner is factual, in that they record the surface of a material artefact. Nevertheless, they are difficult for architects and engineers to work with in the conservation and management of buildings or sites as they represent only momentary points on a surface and thus must be translated into a more operational format to be of service. This process of translation, regardless of the format chosen, necessarily involves approximations and averaging, resulting in surface representations that, though often remarkable in their

¹ London Charter Article 4.4: It should be made clear to users what a computer-based visualisation seeks to represent, for example the existing state, an evidence-based restoration or a hypothetical reconstruction of a cultural heritage object or site, and the extent and nature of any factual uncertainty.

apparent fidelity, are further from the truth than those fact-based points. The historian does not require an operational format because the intent is not to act on the object itself, but rather to interrogate the range of facts assembled. In this case the point cloud can be used to advantage, for instance in exploring the resonance between historic images and the dimensional reality of the point cloud (Shotton, 2016) to establish positions of earlier constructions in harbours, without the need to generate surface models.

The ambitions of the current survey of harbours is to enrich our historical understanding of their construction rather than to intervene in their fabric and, thus, the question of how the data is best formatted for both current and future research needs, in addition to dissemination to the public, is of paramount importance. Though the initial proposal had been to translate the LiDAR scan data to a mesh format, two issues became increasingly clear during this process: the inevitable approximations of the meshing process, regardless of accuracy, was sacrificing the veracity of the visualisation and; the visual certainty conveyed by meshes overlaid with photographic data served to obscure the differentiation between fact and conjecture, ultimately lending a level of authority to the model that could be misleading to both researchers and the public. It became clear that remaining in the realm of point clouds had considerable advantages, though presented new challenges.

2. MODELLING PROCESS

2.1 Digital Survey and Processing Methodology

A primary underlying ambition of the research has been to develop a more coherent history of the evolution of maritime construction technology in Ireland, which influenced the choice of LiDAR as a survey tool as it is possible to capture and preserve significant detail using this methodology. A terrestrial-based Leica P20 3D laser scanner was used to scan each harbour in the pilot study, using a point spacing of 2-6 millimeters (depending on the scan range from the object) to capture sufficient detail on the tectonic logic of the structure, in addition to a comprehensive photographic survey. The scanning operations were undertaken at low tide, to maximize the surface exposed to the scanner, and were typically completed in 1-2 days depending on the size and complexity of each structure. The resultant point clouds were loaded in Cyclone, the software supplied by Leica, for registration and analysis. Once registered the scans were unified to create a single point cloud, to be used later in web-based visualisations. The single point cloud for each harbour was further refined with point spacing reductions to 3, 5 and 8 centimeters to reduce the file sizes (in the case of Fethard, from 18GB to 2GB) for ease of modelling conjectural elements using Rhinoceros (RhinoCAD), a 3D modelling software.

Though initial trials were made using two alternative mesh engines, CloudCompare and Autodesk Recap, to develop an appropriate means to translate the point cloud data into a format compatible with CAD-based software, following discussions with UCD Digital Library regarding the point cloud visualization software a decision was taken to suspend mesh operations and investigate the potential of creating three-dimensional timeline models in point cloud format.

2.2 Visualisation of Harbour scans

An alternative protocol for the dissemination of this research is now in development using Potree, a web-based visualisation engine for large point clouds.² To date this viewer has been used to visualise the LiDAR data for each harbour (Figure 6), as part of a publically accessible digital library platform hosted by the university, due to go live in autumn 2017. With some manipulation of the underlying code supplied by one of the developers of Potree (Schütz, 2017), multiple point clouds can be input as independent layers, allowing the data to be organised into a time series to represent the incremental development of each harbour. The layers will be specific to each harbour, to include each significant rebuilding (or demolition) of the harbour elements, which can be turned off or on to interrogate the development of each harbour. The ambition is to develop a visual coding system that will allow for hypothetical reconstructions to be differentiated from the original scan data.

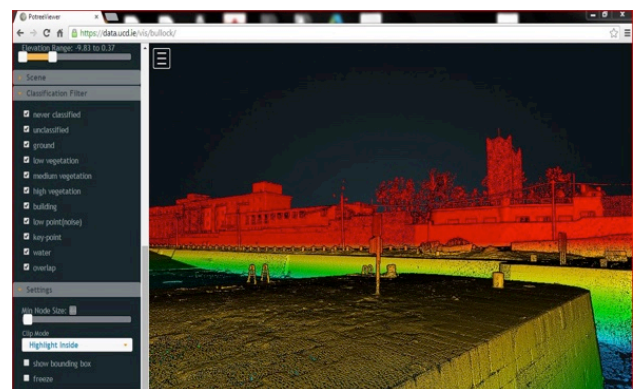


Figure 6. Bullock Harbour 2016 in Potree (Clarke, 2016)

The most straightforward form of layering would be the reconstruction of elements no longer extant, that could be overlaid on the current scan data as independent layers. In an early experiment using CloudCompare, the Revenue watch house at Fethard Quay, built in 1774 and later truncated in 1978 before finally being demolished in 2007, was developed as an independent layer to visualize a conjectural reconstruction of this building element (Figure 7). Though no longer extant, there is sufficient information from Ordnance Survey maps of 1903, photographs prior to demolition, and the remaining east wall embedded in the harbour structure to model a conjectural representation of this building in both its original and later truncated forms.

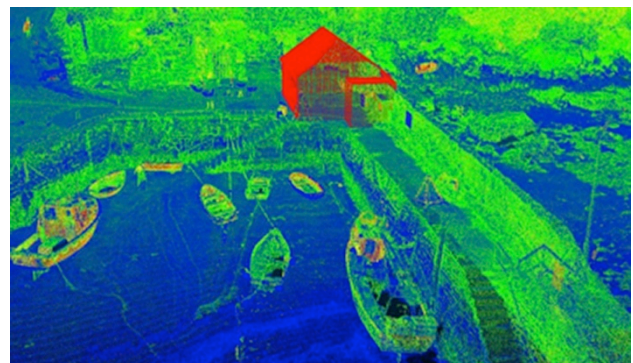


Figure 7. Demolished watch house (red) in Fethard Quay in CloudCompare (Shotton, 2017)

² Potree is a WebGL based viewer, evolved from the Scanopy desktop point cloud renderer by TU Wien, Institute of Computer Graphics and Algorithms. www.potree.org/

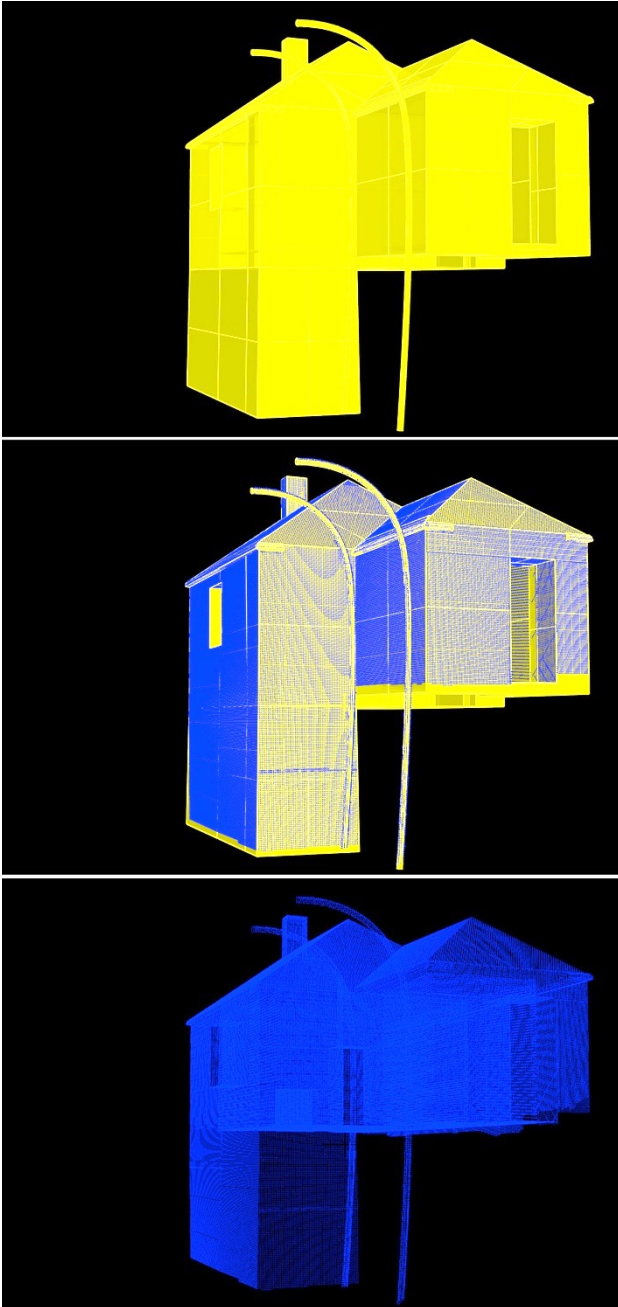


Figure 8. Watch house modelled in RhinoCAD (Shotton, 2017)

2.3 Modelling Protocols

Scan data, photographs, maps and textual evidence, in tandem with onsite investigations of the remaining stonework, were used to recreate the watch house, in its original and truncated form, as well as the warehouses, using RhinoCAD. The scan data, reduced to a point spacing of 5cm, was imported to RhinoCAD to act as a baseline for the development of the conjectural models. This was important for two reasons: that the detailed and accurate dimensional and profile data captured in the scans could be traced to inform the generation of the models; and, perhaps more critically to the outcome, that the models are spatially registered to the scan coordinates, to ensure proper registration in later point cloud visualisations.

The additional usefulness of the RhinoCAD platform is the ability to drape models in points of varying densities to mirror the nature of point clouds from scan data. Achieving the

appropriate density of points such that it registers against the density of the scan data, taken at 2-6mm to ensure information on stonework was captured, yet transparent enough to ensure that the representations were sufficiently amorphous to avoid the impression of certainty in the representation was a matter of repeated trials, ultimately leading to a density of 3-5cm spacing on average (Figure 8). As the preferred file type for loading into the Potree visualisation software is *.las, these models were exported in a drawing exchange format (*.dxf) and imported to CloudCompare to be translated to the appropriate *.las format.

However, though Fethard Quay may be the smallest and least complex of the harbours surveyed, the significant alterations to its fabric could not ultimately be successfully modelled as independent layers and simply overlaid on the scan data of 2016. The watch house, as originally built, was not wholly built on the west pier but built into the dock itself, making it apparent that the rear quay wall had been originally built further south from its current location. Review of early Ordnance Survey maps, Wexford County Council meeting minutes and close observation of the joints in the stonework confirmed that the current quay wall was an addition from 1928, built to regularize the dock wall to the watch house footprint. To adequately represent the configuration of the original watch house thus required altering the scan data from 2016, removing the stairs (added in 1978) and the quay wall of 1928 and modelling a conjectural representation of the original placement of the quay wall. In addition, the remarkable vertical stone coping of the original parapet on the west pier, present from 1741 to at least 1800, identified on the site inspection, was important to the history of the harbour, and the relationship of the watch house to the pier (Figure 9) to deserve representation in the timeline visualisation.

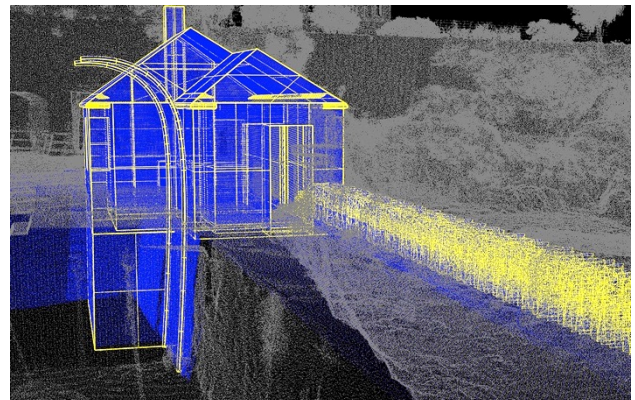


Figure 9. Watch House modelled on scan data in RhinoCAD with original quay wall (left) and parapet (right) (Shotton, 2017)

The final structure of the timeline series was based on the identification of significant moments of alteration, giving rise to a programme to develop two baseline layers; Fethard 2016, which is the original *.las scan data, and Fethard 1741, a point cloud model built from the original scan data and modified with conjectural elements to represent the harbour's original form. The latter baseline model, Fethard 1741, could then be overlaid with layers containing discrete elements, some from the original scan data and some conjectural, which represented significant changes in the physical form of the harbour since its original construction, each dated (Table 10).

No.	Title	Notes
1	Fethard 1741	modified *.las scan data
2	Revenue Watch House 1774	constructed *.las (2)
3	Lynn Warehouses c. 1790	constructed *.las (3)
4	Raised Parapet NW Pier c. 1800	partial *.las scan data
5	SE Slip c. 1900	partial *.las scan data
6	Altered Quay Wall 1928	partial *.las scan data and constructed *.las (4)
7	Utilities mid 20 th C	partial *.las scan data
8	Warehouse Ruins c. 1970	partial *.las scan data
9	Truncated Watch House 1978	Constructed *.las (5)
10	Stairs 1988	partial *.las scan data
11	Handrails and Ladders late 20 th C	partial *.las scan data
12	Fethard 2016	original *.las scan data

Table 10. Proposed Fethard Quay Timeline Series

2.4 Translation of Data to Potree

The need to alter the original point cloud of Fethard Quay into a series of modified point clouds into which conjectural representations could be placed required an alteration to the modelling process. Though the modelled point clouds from RhinoCAD could be successfully translated to *.las format in CloudCompare and uploaded to Potree, they were nevertheless not recognized as point clouds in either of these visualisation tools, as they were no more than a 3D model in point form. In order to merge these reconstructions into the modified scan data the model points were normalised in CloudCompare before being exported as *.las files and reimported to be merged into the *.las files of the modified scan data.

The original trials of visualising these conjectural elements, colour coded in red to differentiate them from the LiDAR scan data, was particularly successful as the LiDAR point cloud registered in a scalar field (SF) display (Figure 7) making the distinction clear. However, once these conjectural elements are merged with the modified LiDAR scan data maintaining this visual distinction becomes more complex. If the conjectural elements are left in RGB and merged with the scan data registered in SF, the resulting *.las file will render the harbour in SF but the conjectural elements are rendered in grey as being out of range of scale (Figure 11). A similar phenomenon occurs in the Potree web viewer. The distinction between factual points and conjectural elements remains intact, but with less visual appeal or distinction. There are two alternatives, the first to render the entire *.las file in RGB, reducing the LiDAR scan data to a single colour. This renders the detail of the harbour less easily understood though maintains the desired distinctions. Alternatively, the conjectural elements can be translated to a scalar field, before or after the merge, which will render everything in the regenerated file in the same scalar field compromising the ambition for clarity.

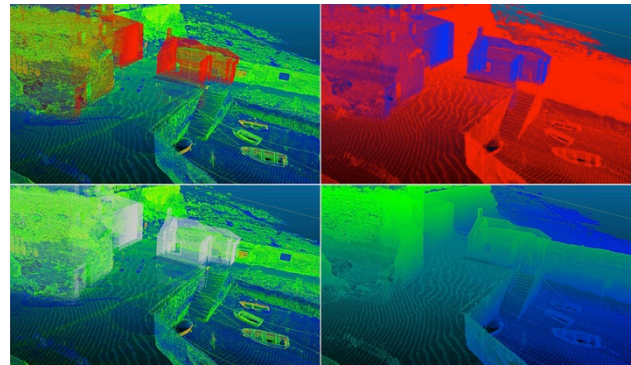


Figure 11. Unmerged *.las files (top left), Merged *.las file in SF (bottom left), Merged *.las file in RGB (top right), Merged *.las file in SF on Z normal (bottom right)

Further trials are in progress to resolve these apparent conflicts. The routine used for the normalisation of the Rhino-generated points for the conjectural elements may play a role in obtaining a satisfactory result in the final merged *.las file. The objects had been initially normalised using the standard normalisation routine provided in CloudCompare. However, a more recent trial of normal estimation for unstructured point clouds with Hough Transformation (Boulch and Marlet), provided as a plugin to CloudCompare (Mac version), though it results in a similar grey rendering for the conjectural elements, nevertheless produces a more coherent visualisation with the original harbour scan in SF (Figure 12).

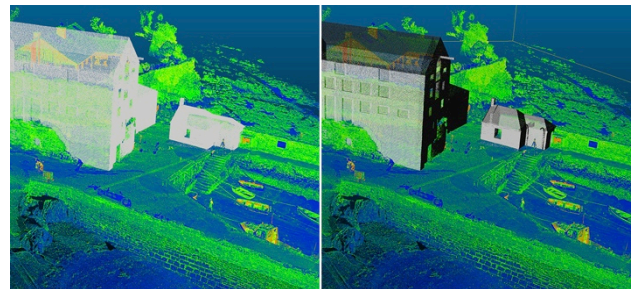


Figure 12. Merged *.las files using standard CloudCompare normalisation procedures (left) and normals estimation for unstructured point clouds using the Hough transformation

3. CONCLUSIONS

The project results are provisional, as work is still underway to develop the timeline models for the Potree visualisations. Nevertheless, the trials to date have shown promise in establishing a protocol for embellishing LiDAR scan data with conjectural elements to visualise, for both researchers and the public, the historic evolution of these harbour structures. There are a number of advantages of remaining in point cloud format for the purposes of historic research and for the public dissemination of research. The accuracy and density of the scan data allows a viewer to interrogate the harbour broadly within its context, but to also delve into the fine and often irregular detail of its stone work, a critical feature in harbours and one which could be lost, or worse generalized, if it were to be translated into a parametric model format. The ethereal quality of the scan data is also of value as, despite its accuracy, it nevertheless conveys a sense of tentativeness to the visualisations. Thus, conjectural reconstructions in point cloud format appear less resolute than when rendered as a mesh or a surface model, a quality consistent with the provisional conclusions represented by these hypothetical models. Finally, by coding these conjectural models

consistently the user of the web-viewer can easily intuit the difference between fact and historical narrative.

The use of web-based viewers for point clouds is not original, as various versions of this technology are currently being used to support dissemination of research on sites such as the noteworthy CyArk (cyark.com) or the lesser known Traditional Boats of Ireland site (tradboats.ie) to great effect. The novelty presented in this work is the potential to develop a more didactic representation in point cloud format, for both the public and future researchers, that could successfully capture a provisional thesis regarding each harbour's evolution in an explicit and intellectually transparent manner, thus enabling further enquiry.

ACKNOWLEDGEMENTS

The Irish Research Council funded the initial pilot study, with subsequent grants from University College Dublin and the Fullbright Commission to enlarge the scope of the work. Donal Lennon of UCD Earth Institute has undertaken scans and post-processing of the data with assistance from Aoife Semar, Research Assistant on the funded project. Work on archival research and drawings have been undertaken by Aoife Semar with the author. Potree modelling has been undertaken by Peter Clarke, UCD Library, for use on the UCD Digital Library site due to be online in 2018.

REFERENCES

- Colfer, Niall. 2010. Between the Sea and the Land: Coastal Limestone Quarries on the Hook Peninsula, Co. Wexford. *The Journal of Irish Archaeology* 19, pp. 113-30.
- Denard, Hugh. 2012. A New Introduction to the London Charter. In A. Bentkowska-Kafel, D. Baker & H. Denard (eds.) *Paradata and Transparency in Virtual Heritage*, Digital Research in the Arts and Humanities Series. Ashgate. pp. 57-71. <http://www.londoncharter.org/introduction.html>
- Fai, S., Rafeiro, J. 2014. Establishing an Appropriate Level of Detail (LoD) for a Building Information Model (BIM)-West Block, Parliament Hill, Ottawa, Canada. *ISPRS Annals of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, II-5, 123-130.
- Favro, Diane. 2006. In the eyes of the beholder: virtual reality recreations and academia. *Journal of Roman Archaeology*, Supplementary Series Number 61, pp. 321-334.
- Frizell, Richard. 1771. Maps of the Lordships and Manors of Loftus Hall, Fethard and Templetown in the County of Wexford the Estate of The Right Honourable Henry Lord Viscount Loftus of Ely August 1st 1771. MS 4153 (020). National Library Ireland.
- Gilligan, H.A. 1988. *A History of the Port of Dublin*. Dublin: Gill and Macmillan.
- Guarnieri, Alberto, Francesco Pirotti, and Antonio Vettore. 2010. Cultural heritage interactive 3D models on the web: An approach using open source and free software. *Journal of Cultural Heritage*. 11(3), pp. 350-353.
- Graham, Angus. 1968-69. Archaeological Notes on some Harbours in Eastern Scotland. *Proceedings of the Society of Antiquaries of Scotland*, 101, pp. 200-285 plus plates.
- Graham, Angus and Joanna Gordon. 1987. Old Harbours in Northern and Western Scotland. *Proceedings of the Society of Antiquaries of Scotland*. 117, pp. 265-352.
- Hassard, Arthur. 1923. Notes on the dredging of fishery and other small harbours on the east coast of Ireland. *Transactions of the Institution of Civil Engineers of Ireland*, 48, pp. 203-278.
- Hore, Herbert F. 1859. A Chorographic Account of the Southern Part of the County of Wexford, Written Anno 1684: By Robert Leigh, Esq., of Rosegarland, in That County. (Concluded). *The Journal of the Kilkenny and South-East of Ireland Archaeological Society*, 2(2), pp. 451-467.
- ICOMOS. 2002. THE ENAME CHARTER: International Guidelines for Authenticity, Intellectual Integrity, and Sustainable Development in the Public Presentation of Archaeological and Historical Sites and Landscapes (Draft). www.enamecharter.org.
- Irish Revenue. 1741-42. *Irish Revenue Board and Irish Board of Customs*. Minute Books CUST 1/33. National Archive UK.
- Kinahan, G. H. 1885-89. Economic Geology of Ireland. *Journal of the Royal Geological Society of Ireland*, Vol. XVIII (Vol. VIII New Series). Special Issue.
- The London Charter for the Computer-Based Visualisation of Cultural Heritage Draft 2.1*. 2009. Edited by Hugh Denard. www.londoncharter.org.
- Manferdini, A.M., Remondino, F. 2012. A Review of Reality-Based 3D Model Generation, Segmentation and Web-Based Visualization Methods. *International Journal of Heritage in the Digital Era*, 1(1), pp. 104-123.
- McParland, Edward. 1975. Contribution of History I. In *Architectural Conservation: An Irish Viewpoint*. Ed. Brian O'Connell. Dublin: Architectural Association of Ireland. pp. 21 - 31.
- Moylan, Thomas King. 1960. The Peninsula of Portrane: Part I. *Dublin Historical Record*, 16(1), pp. 22-33.
- O'Sullivan, Harold. 2000. Dundalk Harbour Improvements in the Nineteenth Century. *Journal of the County Louth Archaeological and Historical Society*, 24(4), pp. 504-530.
- Rynne, Colin. 2006. *Industrial Ireland 1750 - 1930*. Cork: The Collins Press.
- Shotton, Elizabeth. 2016. Augmented Maritime Histories: Text Point Line. In Frederic Migatrou, Laura Allen and Luke Pearson (eds) *Drawing Futures*. London: University College London.
- Shütz, Markus. 2017. *Potree Code for Layers*. Personal Correspondence.
- Smyth, Charles. 1996. *Dalkey: Society and Economy in a Small Medieval Irish Town*. Maynooth: Irish Academic Press.
- Stanley, G., Geological Survey Ireland. 2016. *Fethard Quay Site Inspection*.
- Styliadis, Athanasios D., Ipek I. Akbaylar, Despoina A. Papadopoulou, Nikolaos D. Hasanagas, Sotiria A. Roussa, and Lazaros A. Sexidis. 2009. Metadata-based heritage sites modeling with e-learning functionality. *Journal of Cultural Heritage*, 10(2), pp. 296-312.

Underwater Archaeology Unit. 2002. *Piers, Ports and Harbours: Draft Inventory*. 2 Volumes. Dublin: National Monument Service of Ireland.