

Digitally Reconstructing the Newport Medieval Ship: 3D Designs and Dynamic Visualisations for Recreating the Original Hull Form, Loading Factors, Displacement, and Sailing Characteristics

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Since its discovery in 2002, the remains of the mid 15th-century clinker built Newport Medieval Ship have been excavated, cleaned, documented, modelled, and are now midway through conservation treatment. Digital documentation methods, including laser scanning and contact digitising, were used extensively to record the hull timbers. The manufacture and assembly of a 1:10 scale physical model of the vessel remains has provided both construction sequence information and a suitable foundation from which to reconstruct the missing or damaged areas. The physical model was then digitised and a set of lines extracted and faired using Rhinoceros3D software. The lines were turned into a digital model representing the original hull form and analysed in a related modelling software plug-in called Orca3D, which has been used to determine the hydrostatic and hydrodynamic characteristics of the modelled hull form. The use of the abovementioned advanced digital modelling software has allowed archaeologists to accurately characterise the capabilities, capacity, and seaworthiness of the original vessel.

Introduction

The following paper outlines the process for creating a definitive digital and physical reconstruction of the Newport Medieval Ship using advanced modelling software coupled with detailed archaeological evidence, traditional shipbuilding knowledge and historical research. The Newport Ship hull timbers have been comprehensively digitally documented using three dimensional contact digitisers and laser scanners (Jones 2009a, 2009b, Nayling and Jones 2012). The resulting data, captured as 3D wire frame drawings of each timber, was then converted to digital solid models and finally physically manufactured using an additive manufacturing process called selective laser sintering (Jones and Nayling 2011: 54-60, Soe *et. al.* 2012, 443 – 450). The resulting individual model parts strong, light and flexible, and, when fastened together, formed a 1:10 scale model representing the recovered structural hull remains (Figure 1).

Recording the Physical Scale Model

The reconstructed 1:10 scale physical scale model of the hull remains was laser scanned using a Faro Platinum Arm and Laser-line Probe to capture a three dimensional point cloud. The scanning was carried out in three stages, the exterior scan consisting of 112.8 million points, the interior scan consisting of 15.6 million points, and the disarticulated bow portion consisting of 3 million

points, giving a combined total of 131.4 million points recorded at an accuracy of ± 0.08 mm. These point clouds were individually processed and aligned using a best fit algorithm with Geomagic Studio software. A polygon mesh surface was then fitted to the scanned point cloud and deviations checked to maintain the desired ± 0.08 mm accuracy, actual deviation achieved was ± 0.054 mm (Tanner this vol.).

The reconstructed physical scale model was assembled in the perceived order of construction using only recovered material with the emphasis on allowing the hull planking to determine the original hull form. No attempt was made to flatten distorted timbers. This process created a unique object or shape state, that is neither the original as-built vessel nor the vessel shape at time of sinking but a "post-deposition" shape state.

Reconstructing the Hull Shape

Once the scanned model has been processed and the polygon mesh surface fitted it was exported to Rhinoceros3D and the required lines plan, main and additional dimensions, hydrostatic data, and form coefficients could be extracted. This methodology was similar to the one used in reconstructing the Drogheda boat original hull form (Tanner, this vol.).

It quickly became apparent that this reconstructed physical scale model had significant amounts of twist and distortion due to incomplete framing and the asymmetric quantity of materials recovered, as well as



FIGURE 1. THE PHYSICAL SCALE MODEL TWISTED TO MATCH THE FAIRED DIGITAL HULL SHAPE WITH FAIRING RIBBANDS FITTED AT EVERY 4TH STRAKE RUN.

the uneven nature of the ground the vessel came to rest on, coupled with the compressive forces of the 5 to 7m of overburden. A longitudinal symmetry plane was fitted along the vessel centre line, with the scanned mesh orientated to suit. A substantial amount of distortion or twist towards the starboard was readily visible, measuring 8.4° in the bow and 4.2° in the stern.

A series of curves were projected onto the oriented polygon mesh to coincide with every fifth frame station and, using data from each solid model/wireframe from the recording phase, the actual strake cross sections (as recorded) was best fit to these curves.

A second series of curves was projected onto the scanned mesh to create longitudinal fairing ribbands coinciding with every fourth strake run. Site sections and photogrammetric records were then examined to reveal any localised distortion which may have resulted from post-deposition distortion of individual elements at these frame stations.

As the recovered materials included the bottom edge of a 35th strake on the starboard side, a decision was made to attempt a "minimum reconstruction" as defined by Crumlin-Pedersen and McGrail (2006:57), to at least this level. The first step in the reconstruction process was to determine a preliminary hull form, including stem and stern shape and sheer line. For the hull form shape, this sheer line was exclusive of any bow or stern castles. In order to determine a sheer line, each framing station was examined and the height extended using faired curves to coincide with 35 strakes.

In order to determine the sheer height at each of these framing stations, an average strake width at each station was required. Initially the strake widths were measured

at the visible external widths, that is from the bottom edge of a strake to the bottom edge of the strake above. However these widths varied to such an extent that it proved impossible to determine accurate average widths. The internal visible widths (the upper inboard edge of a strake to the upper inboard edge of the strake above) were examined and this produced a more consistent average width (Table 1 column 2). This observation would also indicate the plank widths were not overworked until the complete strake was hung and the upper edge was then trimmed to a fair run.

A faired curve was then created at each of these frame stations, with a curve length set to the relevant average strake widths. It should be noted that all "faired curves" used from this point onwards are degree three curves, degree one curves were used in the recording phase, but as the intended output is to represent a faired hull shape, degree three curves are required. A degree one curve comprises a succession of straight lines from control point to control point, whereas higher degree curves comprise continuous curves influenced by, but not necessarily passing through, their control points. A curve was then created passing fore and aft through the top of these extended frame stations. This three dimensional curve represents a preliminary sheer line, and was analysed using the curvature graph feature in Rhinoceros3D. The preliminary sheer line was then faired, and the corresponding station curves modified to suit. The station curves were then subdivided to fit 35 strakes giving a corrected average strake width (Table 1 column 4). The fairing ribbands were then checked longitudinally and transversely to repair any global distortion.

Once the sheer line has been created, the next stage was to determine the form of the two ends of the vessel. The recovered portions of the stem revealed that from the garboard strake up to strake eight, the planks had hood ends which terminated into a stepped rebate. From strake nine upwards, there was a change to a continuous smooth curved rebate along the stem. The recovered stem fragments also indicated a curved stem post, which was recreated using Rhinoceros3D and extended to meet the sheer line (Figure 2).

As no part of the stern was recovered, the model needed to be examined in more detail in order to extrapolate

Frame Station	Avg. internal strake width, measured	No. of strakes recovered	Corrected avg. strake widths from fairing
1	146.8 mm	4 strakes	142.5 mm
5	149.8 mm	20 strakes	144.5 mm
10	155.2 mm	24 strakes	149.0 mm
15	160.6 mm	26 strakes	157.3 mm
20	167.9 mm	31 strakes	165.6 mm
25	172.6 mm	34 strakes / partial 35th	172.9 mm
30	176.1 mm	32 strakes	175.7 mm
35	171.9 mm	32 strakes	174.0 mm
40	167.4 mm	28 strakes	169.5 mm
45	159.5 mm	25 strakes	164.7 mm
50	153.3 mm	19 strakes	159.6 mm
55	149.9 mm	16 strakes	156.5 mm
60	147.3 mm	8 strakes	152.6 mm

TABLE 1. AVERAGE INTERNAL VISIBLE STRAKE WIDTHS. THESE STRAKE WIDTHS ARE A STATISTICAL CONSTRUCT AS OPPOSED TO REPRESENTING ACTUAL STRAKE WIDTHS.

Visible Length [†]	Port Side	Starboard Side	Total Number
< 1m	0	1	1
1 - 1.5 m	3	8	11
1.5 - 2 m	12	19	31
2 - 2.5 m	28	37	65
2.5 - 3 m	28	50	78
3 - 3.5 m	23	42	65
3.5 - 4 m	1	15	16
> 4 m	0	3	3

TABLE 2. VISIBLE PLANK LENGTHS. [†]VISIBLE LENGTH IS FROM AFT END OF FORWARD SCARF TO AFT END OF PLANK, ALL DIMENSIONS ARE IN MM. INCOMPLETE, DAMAGED OR FRAGMENTED PLANKS HAVE NOT BEEN INCLUDED.

the structure of the aft end. Firstly the plank lengths making up each strake were examined to determine both shortest and longest lengths used in the building of the vessel (Table 2). These lengths were then overlaid on the existing strake from the preceding complete scarf end. Taking a maximum and minimum plank length created a probability box inside which the final plank hood end should lay (Figure 2). When this procedure was repeated for each strake run an overlapping region within these probability areas would indicate a probable location for the aft hood ends. A stern post angle (taken from archaeological and historical parallels) was then created to fit within this probability box. With all of these curves faired a preliminary faired surface was generated to represent the outer hull form of the vessel corrected for global distortion. The scanned polygon mesh was then rectified to match this repaired hull shape.

The project then returned to the physical world, where a combination of screws, braces, and cable ties were used to "force" the physical scale model into a more faired shape, closely matching the digital model. The locations of the fairing ribbands on the digital model were measured and then physically fitted as plastic ribbands to the scale model (Figure 1).

At this stage the digital model still did not represent a complete vessel so the missing parts would need to be extrapolated and recreated. For the purposes of this reconstruction it is assumed that the hull is generally symmetrical.

Establishing a Floatation Condition

In order to establish a floatation condition for the vessel, three key facts are required:

1. Vessel hull shape in order to establish the centre of buoyancy 'B'.
2. Vessel centre of gravity 'G' to establish floatation trim.
3. Vessel weight in order to establish displacement.

The Newport Ship hull shape had been established based on the reconstruction methods already employed, but a vessel weight and centre of gravity had not yet been established.

The most accurate method of determining the weight of a vessel is to weigh it in air and then carry out an inclining test to establish the position of centre of gravity (McKee 1974:11–13). In order to weigh the vessel and perform an inclining test, a complete, rebuilt vessel would be required. As this was not practical, and the fact that various hypothetical reconstructions are still being examined, an alternative approach was used (Institute for Archaeologists 2008, 8-9). Every constituent part of the vessel was accurately modelled using Rhinoceros3D solid modelling techniques and, using the Orca3D plugin for Rhinoceros3D, a material is assigned to each part and Orca3D used to calculate the weight, as well as the longitudinal, transverse and vertical centres of gravity (Tanner, this vol.).

As the flotation plane is calculated from the total weight, it is important to reconstruct as much of the overall vessel as possible by solid modelling each of the constituent parts and mirroring where necessary. The reconstructed physical scale model used as the basis for the digital reconstruction consisted of the keel, hull planking, framing, keelson, braces and stringers as recovered, but excluded items such as ceilings and the

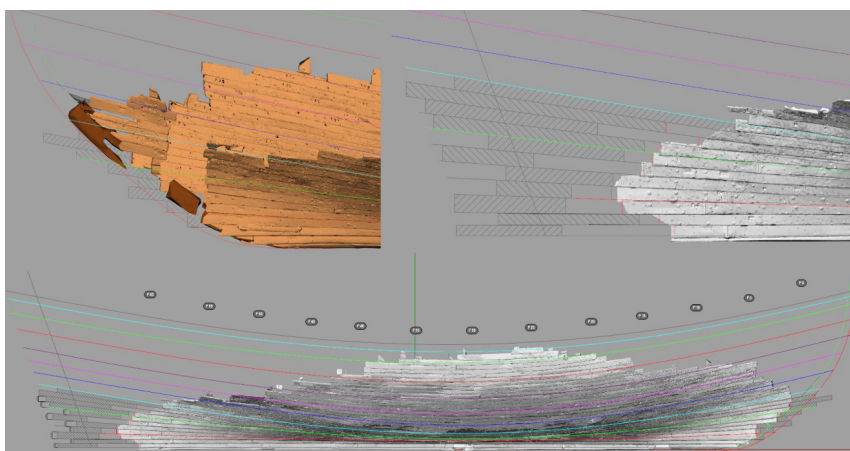


FIGURE 2. PLANK LENGTHS EXTRAPOLATED TO FIND STEM AND STERN POSTS.

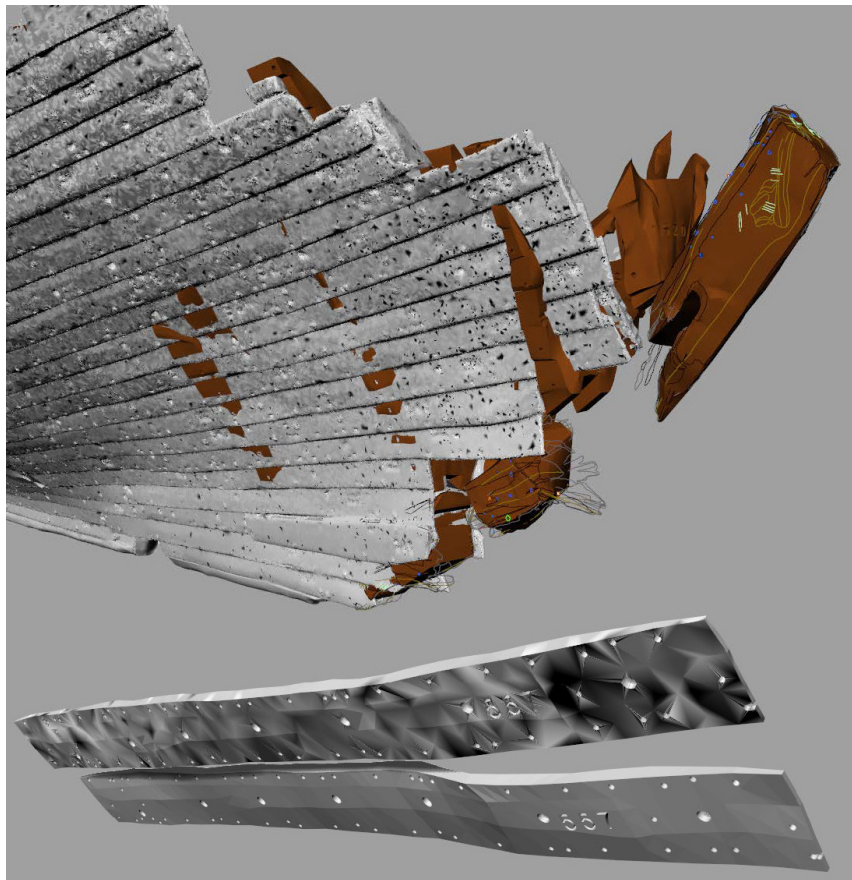


FIGURE 3: DIGITAL SOLID FRAMES AND STEM ADDED TO THE LASER SCANNED DATA SHOWING THAT THE SHAPE IS STILL INCORRECT AS RECORDED FROM THE PHYSICAL SCALE MODEL, IN THE FOREGROUND THE "REPAIRED" PLANK (TOP) AND ORIGINAL AS RECORDED STRAKE (BOTTOM). THE ORIGINAL STRAKE HAS A VOLUME OF 0.017163 m^3 . THE REPAIRED STRAKE (BENT TO REMOVE LOCALISED DISTORTION) HAS A VOLUME OF 0.017166 m^3 , A CHANGE OF LESS THAN 0.02%.

many disarticulated timbers that were recovered during the excavation. In order to recreate a more complete vessel, including items which could not be fitted to the physical scale model, the next stage was to import and align the individual recorded components into the digital reconstruction. This information was used as the basis for positioning disarticulated timbers and recreating missing components. Initial attempts at this procedure proved difficult, due to the distorted nature of the individual recorded components.

Colleagues from across Europe, using similar digital recording and modelling methods, and collectively known as the Faro Rhino Archaeology Users Group (FRAUG), have been cautious to use the powerful transform tools in the Rhinoceros 3D software. The common transform tools such as rotate and move are well understood and frequently used, however two other transform commands, which are part of the daily language of every

shipwright: twist and bend, have not been widely used.

One approach has been to flatten the digital data prior to printing on cardboard and then re-bending to create a physical scale model (Ravn 2012:316). Ravn has also suggested that the deformed and broken parts should be digitally repaired to their original design state prior to manufacturing solid components. This process could prove problematic when dealing with a component part in isolation as opposed to that component being a constituent part of the entire vessel.

Preliminary investigations using the bend and twist commands to "transform" the recorded shape state back to a shape approximating its original design have proved promising. To assess and quantify the effects of these powerful transformation tools, a number of typical planks were firstly measured in their original recorded shape state using the Analyze/Mass Properties/Volume feature in Rhinoceros3D. Then the digital solid was twisted to conform to the emerging hull shape, as a ship-builder would the actual plank when building the vessel, and the resulting

"repaired" plank again measured with the Analyze/Mass Properties/Volume command. Results to date indicate changes in the repaired component's volume of 0.02% or less when compared to the original volume (Figure 3).

Advances in computing power, and the relatively low cost of hardware and software have enabled the combining of the vast quantities of digitally recorded data into single files which can be modified in unison rather than working on isolated elements or sections of the vessel. As a result, when an individual component is twisted or reshaped, the associated original wireframe can be grouped or linked to the digital solid component and modified in tandem, thereby repositioning recorded items, such as fastening locations, tool marks, intentional marks, and any other relevant data which would be beneficial in the reconstruction process (Figure 4).

The end result of this methodology is the delivery, through an iterative process alternating between digital

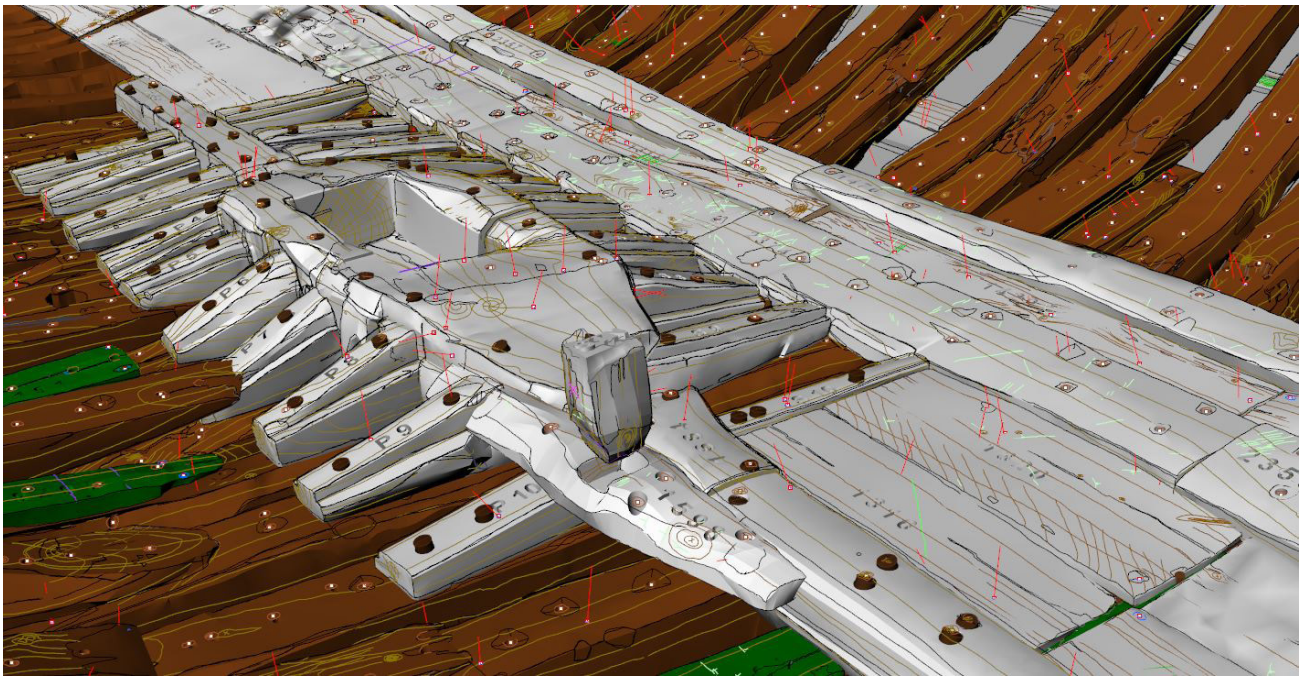


FIGURE 4: EACH INDIVIDUAL DIGITAL SOLID AND ITS ASSOCIATED WIREFRAME IS FITTED TO THE RECONSTRUCTED SHAPE.

and physical environments, of a more definitive, synthetic reconstruction bringing together many data sets (including site records of the *in situ* ship, individual timber wireframe records and their subsequent digital solid models; scans of scaled physical models from assembled, rapid-prototype manufactured 'timbers'; repaired digital timbers where localised deformation has been removed; computer generated faired surface models). The ability to include the original recorded data, including items such as additional nail holes, intentional marks, or unexplained features in the synthetic reconstruction leads to the production of a research tool which can provide insight into a wide range of potential analyses beyond original hull form and ship performance such as construction sequence and design intent.

The oft quoted archaeological truism "absence of evidence is not evidence of absence" can be reversed to read "presence of evidence, (such as a seemingly unexplained fastening or feature) is evidence of absence". This can be applied to seemingly unexplained fastenings or features present in the reconstruction, encouraging further investigation. This may lead to the identification of missing elements in the ship, leading to an "as complete as possible" reconstruction. This will aid in the analysis of the reconstructed vessel for seaworthiness, performance, propulsion and cargo capacity (Tanner, this vol.).

Conclusion

The methods of documentation and subsequent analysis of the Newport Ship have been unashamedly experimental, combining well-established methods with new approaches, while taking advantage of developments in digital technologies and relatively accessible computing power. Such methodological development is not without its risks and the efficacy of new procedures in meeting the rigorous requirements of ship reconstruction will need to be critically assessed by the wider nautical archaeology community. The purpose of the digital approaches in nautical archaeology session at the 2013 Society of Historical Archaeology conference was to encourage exchange of ideas between projects working, at least in part, in a digital environment. While the research objectives of these projects are likely to be closely aligned, focusing on reconstruction of original hull form and examination of ship performance, the specifics of the methods employed will necessarily be optimised to meet the circumstances of individual ship finds addressing specific characteristics of shipbuilding tradition and the nature and extent of archaeological survival.

As experience with the use of digital approaches grows, methods may become more formalised. In the present developmental stage, the philosophy of research networks such as FRAUG, and of the SHA session has been to exchange experience without seeking primacy for any particular method. Constructive criticism within

a supportive environment offers the opportunity to pool the hard won experience of nautical archaeologists optimising development of credible alternatives to traditional techniques. In a digital media age, other gains beyond academic research outcomes should also be considered in research designs. At the Newport Ship, the aim is to use its digital reconstructions to help guide the reassembly and reshaping of the conserved hull, as well as providing versatile content for the final publication, interim articles and future interactive museum displays, including games and animations. It is envisioned that the digital hull form will be used in complex visualisations depicting the ship in dynamic medieval settings, allowing the public the gain insight and understanding of many aspects of life in the medieval period. When successfully realised, the digital models will enable increased public access to a unique archaeological find.

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