



# A Virtual Reconstruction of the *Batavia* Shipwreck in Its Landscape

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Accepted: 22 August 2022 / Published online: 8 June 2023  
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**Abstract** We present a digital reconstruction of a shipwreck in a landscape context, illustrating the value of combining and synthesizing spatial data from a wide variety of sources to provide new insights on a heavily studied archaeological site. The shipwreck used for this case study is *Batavia*, one of the best-known shipwrecks in the world due to its rarity as an early Dutch East Indiaman, its association with the early days of the discipline of maritime archaeology, and with the dramatic events that followed the wrecking of the ship on an isolated reef off the west coast of Australia in 1629. The digital reconstruction of this shipwreck site leverages LiDAR, ship-construction manuals, and contemporary and modern ship models with underwater photogrammetry to provide new insights on the aftermath of the wrecking, site taphonomy on the seabed, and to recreate the visual aspects of the site.

**Resumen** Presentamos una reconstrucción digital de un naufragio en un contexto de paisaje, que ilustra el valor de combinar y sintetizar datos espaciales de una amplia variedad de fuentes para proporcionar nuevos conocimientos sobre un sitio arqueológico muy estudiado. El naufragio utilizado para este estudio de caso es el del *Batavia*, uno de los naufragios

más conocidos del mundo debido a su rareza como uno de los primeros barcos de la Compañía Holandesa de las Indias Orientales, su asociación con los primeros días de la disciplina de la arqueología marítima y con los dramáticos eventos que siguió el naufragio del barco en un arrecife aislado frente a la costa oeste de Australia en 1629. La reconstrucción digital de este lugar del naufragio aprovecha el LiDAR, manuales de construcción de barcos y modelos de barcos contemporáneos y modernos con fotogrametría submarina para proporcionar nuevos conocimientos sobre las secuelas del naufragio y la tafonomía del sitio en el fondo marino, así como para recrear los aspectos visuales del sitio.

**Résumé** Nous présentons une reconstruction numérique d'une épave dans le contexte d'un paysage, illustrant la valeur d'une combinaison et d'une synthèse de données spatiales tirées d'une grande variété de sources afin d'apporter de nouveaux éclairages sur un site archéologique ayant été abondamment étudié. L'épave utilisée pour cette étude de cas est le *Batavia*, l'une des épaves les plus réputées au monde en raison de sa rareté en tant que premier Indiaman de la Compagnie néerlandaise des Indes orientales, de son association avec les prémices de la discipline de l'archéologie maritime et des événements dramatiques ayant suivi le naufrage du navire en 1629 sur un récif isolé au large des côtes ouest de l'Australie. La reconstruction numérique du site de cette épave s'appuie sur un LiDAR, des manuels de construction de bateau et des modèles

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de vaisseaux contemporains et modernes dotés d'une photogrammétrie sous-marine pour fournir des contributions nouvelles sur les suites du naufrage, une taphonomie du site sur le fond marin et pour recréer les aspects visuels du site.

**Keywords** archaeological reconstruction · underwater photogrammetry · Dutch East India Company · cannon

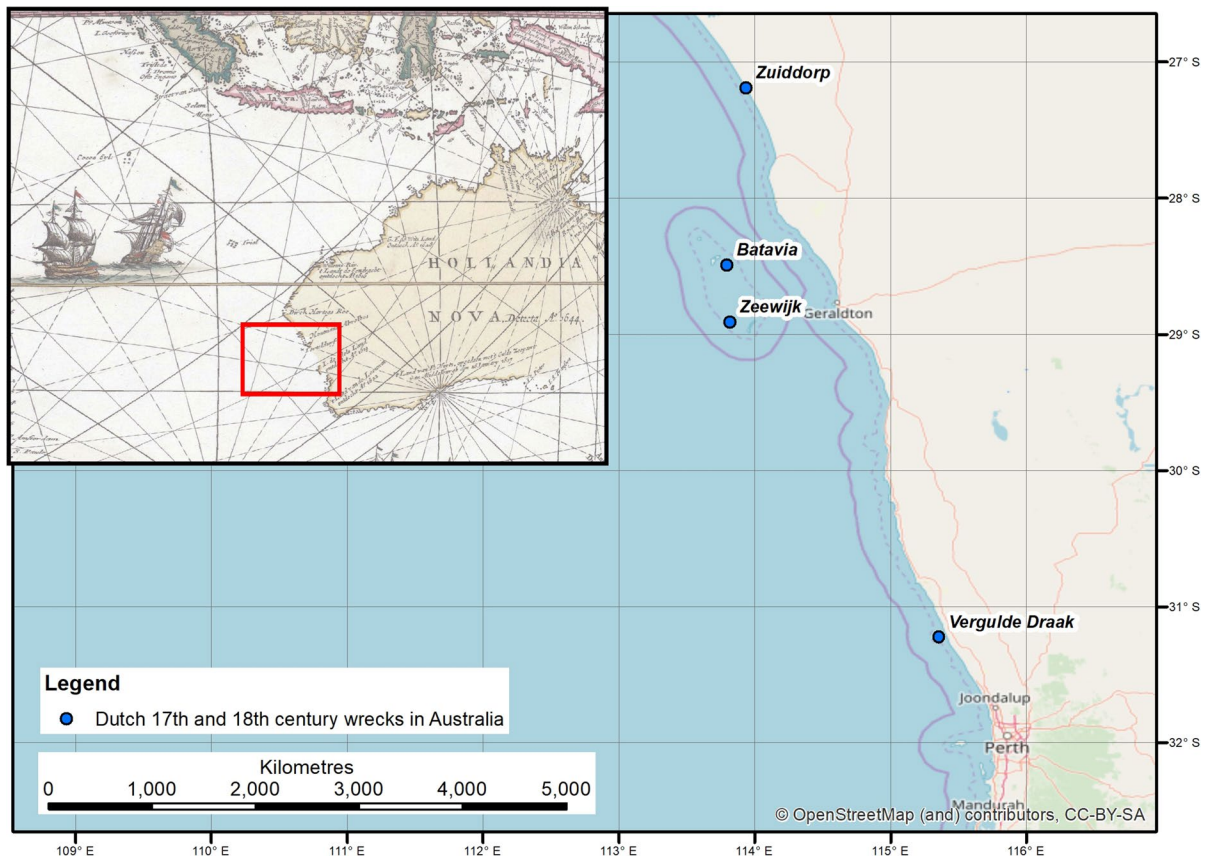
## Introduction

Since the early days of the discipline of maritime archaeology, the principal approach to shipwreck survey and analysis has relied on the creation of a series of plans and line drawings, followed in some cases by recovery and reconstruction of the original remains in a museum, in rare cases followed by the construction of a full-size working reconstruction. In recent years, underwater photogrammetry has become increasingly practical, affordable, and effective, augmenting and in some cases replacing manual survey to create a rich spatial record of underwater archaeological sites (McCarthy and Benjamin 2014; McCarthy, Benjamin et al. 2019). While this technique speeds up and improves survey, few archaeologists have exploited the potential of these surveys for more complex analyses, particularly when combined with other spatial data, such as historical evidence of ship design and landscape-scale survey data (Benjamin et al. 2019). Ships were large objects that often had complex relationships with the environment in which they were wrecked before, during, and after the wrecking event. A full spatial reconstruction can therefore offer many insights in a way similar to modern vehicular-accident reconstructions. We examine a well-known and heavily studied shipwreck site, *Batavia*. Shipwreck reconstruction is a complex and challenging endeavor, even in digital format, and a substantial interactive virtual-reality simulation focused on Beacon Island and the *Batavia* survivors' camp did not include the wreck itself (Woods et al. 2019). Here we synthesize spatial data from underwater photogrammetry, bathymetric LiDAR, ship models, and shipbuilding manuscripts to create a spatially accurate digital reconstruction of the wreck within its landscape based on the best available spatial data.

## Background

Shipwrecks of the Dutch East India Company (Verenigde Oostindische Compagnie, or VOC) are some of the most important maritime archaeological sites in Australia, collectively representing the earliest evidence of European activity on the continent (Fig. 1). Of the four located shipwrecks, *Batavia* is the oldest and best known due to the recovery of an intact section of hull as well as association with the grisly events after the wrecking, when many of the survivors were systematically murdered by a group led by the merchant Jeronimus Cornelisz. Several books have been written about the wreck (Pelsaert 1647; Drake-Brockman 1963; Edwards 1966; Roeper 1993; Dash 2003; FitzSimons 2011), and there have been several detailed archaeological studies of the wreck and the survivors' camp (Green 1989; Paterson and Franklin 2004; Van Duivenvoorde 2012, 2015a, 2015b; Green and Paterson 2020; Daly et al. 2021). This issue also includes a new study summarizing insights on the survivors' camps gained from fieldwork on the islands of the Houtman Abrohlos over the last decade (Paterson et al., this issue).

*Batavia* wrecked in 1629 in the Houtman Abrohlos, a chain of reef islands 80 km off northwestern Australia, while en route from the Netherlands to the East Indies. The hull of *Batavia* broke up slowly over nine days after it wrecked on Morning Reef, with many survivors staying onboard until the final disintegration of the hull. The *Batavia* wreck was found in 1963, and archaeologically excavated from 1972 to 1975 (Green 1975, 1989). Archaeological remains were found clustered within a large hollow dug into the reef during the original wrecking event. A substantial portion of intact stern hull was found, along with many guns, anchors, and other artifacts. The hull was recovered and, after conservation, was rebuilt for permanent public display in the Western Australia Museum in Fremantle, but most of the guns and anchors have been left in situ (Pang 1981; Green 1989; MacLeod 1990; Ghisalberti et al. 2002; Van Duivenvoorde 2015a:40–72). Published plans of the shipwreck have been schematic rather than comprehensive, and there are many details around the wrecking event and later site history that remain uncertain, such as the discrepancies between existing plans and recent photographic surveys regarding gun identifications and locations.



**Fig. 1** Locations of the known 17th- and 18th-century Dutch shipwrecks in Australian waters (Open Street Map and contributors CC-BY-SA). The inset is a 17th-century map of the Far East (Van Keulen 1689).

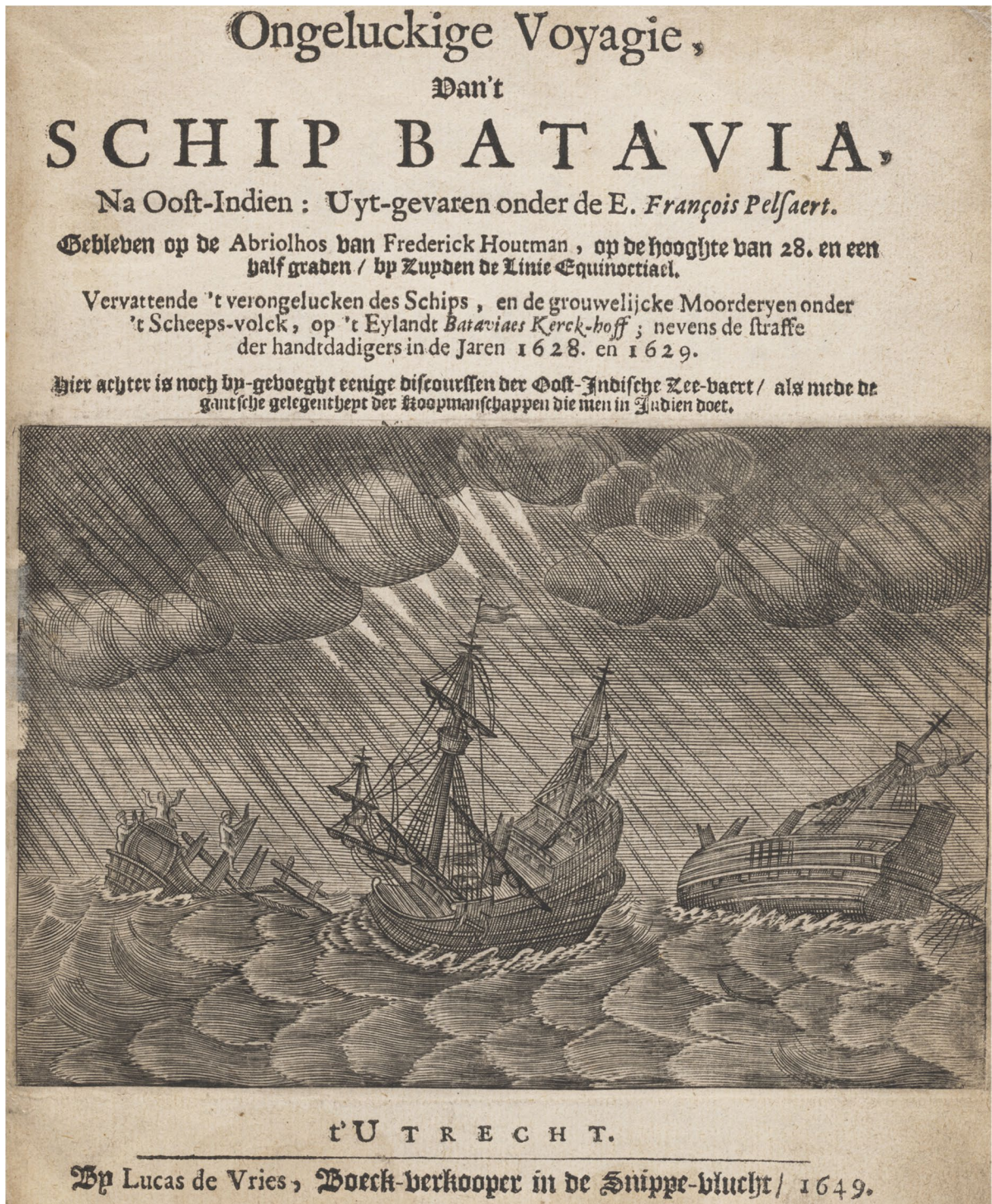
## Spatial Data Sources

There are numerous spatial data sets for *Batavia* with potential utility to create a spatially accurate reconstruction of the wrecked ship as well as the landscape (or seascape). Although some of these data sets have been considered by previous researchers, they have never been brought together.

## Iconographic Evidence

Near-contemporary iconographic representations, e.g., Figures 2 and 3, that provide artistic impressions of the breakup of *Batavia*, come from the reworked editions of Commander Pelsaert's *Ongeluckige Voyagie*, which were published for the general public (Pelsaert 1647, 1648, 1649, 1651; Van Duivenvoorde 2015a:77–78). Between 1647 and 1664, four different publishers in the Netherlands: Hartgersz.,

Jansz., Saeghman, and De Vries, printed nine different editions of this popular publication, which often varied from each other (Roepers 1993:49–52; Ariese 2012:15–16). Publisher Jansz., or Janssonius, included the most numerous and detailed engravings, of which six were copied by Hartgersz. (Pelsaert 1647, 1648, 1651; Roepers 1993:52). The engravers who made the illustrations for both publishers remain unknown. Then, publisher De Vries had the engravings from Hartgersz.'s editions copied by Hendrik Winter, while publisher Saeghman acquired and directly used the copper printing plates from Hartgersz. (Roepers 1993:52). The sequence of separate images from the first edition of 1647 by Jansz. thus seems more realistic and includes details specific to the *Batavia* story, such as the survivors' camp (Fig. 3). These images provide visual detail on the taphonomy of the wreck site, such as the cut-down main mast, and the warp anchor set out from the stern



**Fig. 2** The title page from the 1649 edition of Pelsaert's account, published by De Vries. It is sometimes suggested that it shows the three stages of the wrecking process in one image (Pelsaert 1649).

**Fig. 3** Images of the gradual breakup of the *Batavia*, from *Ongeluckige Voyagie*. The image order is changed for clarity (Pelsaert 1647).



of the ship. In contrast, the images from the 1649 title page published by De Vries, for example, have relatively inaccurate designs and proportions—the ship’s illustrations certainly do not represent *Batavia* correctly. Note that all copper plates used to illustrate the different editions of Pelsaert’s *Ongeluckige Voyagie* were made specifically for a popular print of the shipwrecking event 20 years after the actual

shipwrecking. They were all created by engravers in the Netherlands who used and interpreted primary sources that describe the wrecking and break-up of the ship, such as the original journal of Commander Pelsaert, now available in English translations (Drake-Brockman 1963; Van Huystee 1994). This journal contains information on the tides at the time of wrecking, the position of the hull on the reef, and

the progressive disintegration of the ship over nine days and its gradual abandonment by its occupants. Of the secondary literature, Dash's narrative provides a particularly useful account of the wrecking process, which, despite being semifictional, draws extensively from other primary and secondary sources to analyze the gradual demise and abandonment of the ship (Dash 2003).

### The Scale Models

A large program of analysis and 3-D scanning of contemporary Dutch oceangoing merchant ship models was undertaken between 2016 and 2020 (McCarthy 2020). A scan was made of a well-known 17th-century scale ship model held in the Rijksmuseum, named on its stern as *Prins Willim*. This model is generally considered to be an accurate representation of a real ship named *Prins Willem* built in 1651 and is a key source for the design of 17th-century Dutch ships. The model is one of the closest available parallels for *Batavia*—e.g., Vos (1991)—but while it is a VOC ship of the largest charter, it is from the Middelburg chamber rather than Amsterdam and was at least 10 ft. longer and just over 20 years later in date (“feet” in this article refers in all cases to the Amsterdam foot, equivalent to 28.3133 cm). Although the model may have been built in a VOC shipyard (Ketting 1979), and the general shape of the hull appears realistic, contemporary scale-model hull forms must be treated with great caution. Nevertheless, this model is perhaps the most detailed 3-D representation available of this type of ship, and it is likely to have been broadly similar to *Batavia* in most respects.

Another scale model was scanned in the Maritime Museum of Rotterdam as part of the same project. This interesting unnamed model is referred to here under its accession number of N16 and depicts a large VOC East Indiaman of 1652. Little has been written about the N16 scale model, but its stern iconography features a gilded dragon or lizard, and it has been suggested in an exhibition guide that it might represent the 1653 VOC *jacht*, *Vergulde Draak*, which wrecked off the Australian coast in 1656 (Jacobs 2006:43–45). The model was scanned along with several other contemporary models held in Rotterdam, but subsequent detailed examination including endoscopy by the authors of the current study and by University of Amsterdam dendrochronologist Marta Domínguez

Delmás suggest the model dates to the early 20th century. Despite this the model remains relevant to the study of *Batavia* as it seems to be unusually well-researched by its model builder, who likely drew on the *Prins Willim* and other contemporary models as well as 17th-century iconographic sources.

Further research suggests the stern iconography of the model depicts a salamander rather than a dragon. This highlights a different connection to a real VOC ship named *Salamander*, built just over a decade after *Batavia* in 1639, a 1,000-ton ship almost certainly of the largest charter of 160 ft. (Van Duivenvoorde 2015a:79). It also belonged to the Amsterdam Chamber and sailed until 1661. It is likely that the early 20th-century model builder was inspired by Reinier Nooms's etching of this ship undergoing repair or construction, dated to ca. 1653, carrying the caption: *De Salemander een Oostindis Vaerder* (Nooms 1652–1654). If the date of the etching is approximately accurate, it must show the ship in the middle of its career, undergoing repair rather than construction. The 3-D scan data can be used to compare the model to the etching as a test of the fidelity of the model to this primary source in terms of both detail and overall shape. An ambient occlusion shader (McCarthy, Sebo et al. 2020:7–8) has been used on the 3-D scan to give it an etching-like appearance and the scene has been rendered from a similar angle (Fig. 4). This highlights strong similarities such as the layout and configuration of the guns, with the two aftmost guns being on a lower level, representing the lower deck level of the *konstapelkamer*. By overlaying the outline of the ship in Nooms's drawing on the N16 model it can also be seen that the model accurately represents key proportions, such as the height of the upper works, a design aspect not normally recorded in the historical sources.

Although not contemporary with the ship, this model is therefore a useful spatial reference as it represents a design closer in many respects to *Batavia* than the near-contemporary *Prins Willim* model, which represents an unusually large 170 ft. ship. The *Prins Willim* model is also unusual in having its fore-castle removed to allow more space for guns, representing *Prins Willem* during its requisition for naval service in the First Anglo-Dutch War (Ketting 1979). In contrast the N16 model is in a standard configuration and is also close in detail, bearing the cartouche of the Amsterdam Chamber of the VOC. The scale

**Fig. 4** Comparison of Reinier Nooms’s etching of the VOC ship *Salamander* (above) (Nooms 1652–1654) with an untextured “ambient occlusion” rendering of the 3-D scan of the N16 model (below) from the same angle. (Image by John McCarthy, 2022.)



intended by its model maker is unknown, but can be inferred from its design. It bears 10 lower mainmast shrouds, indicating a ship of at least 45.9 m long or around 160 Amsterdam ft. (Hoving and van der Vliet 2015:137–138), aligning it to the largest charter of the VOC and the known length of *Batavia*. Scaled up to the largest VOC charter size of 160 Amsterdam ft., the N16 model has a scale of 1:47 (for a detailed discussion of the scaling and measurement of Dutch ship models, see Hoving and van der Vliet [2015]). The proportions of width, length, and depth of Dutch East Indiamen are recorded in detail in historical sources for each of the three general charters as well as for individual ships including the real VOC *retourschepen* (round-trip ships) *Prins Willem*, *Ver gulde Draak*, and *Batavia*, making it possible to compare them with the scale models. This comparison (Tables 1, 2) suggests that the N16 model has realistic proportions that are closest to the 160 ft. charter.

The comparison of the scan of the N16 model and engraving above highlights one important difference between this model and *Batavia*. The model carries a row of additional gun ports on its upper deck, giving it a large number of guns, 54 in total, and also has 6 unused gun ports (2 each on the forecandle deck, the stern, and on the bow) so that it could have carried 60 at some point. This is an enormous number for a VOC merchantman of even the largest size, which would normally have borne around 32 cannon (Van Dam 1927:507). It is not clear why the model builder added these extra guns, but it is not uncommon in both contemporary and later models to exaggerate the armament.

The availability of 3-D data for both models and for the recovered section of *Batavia*'s hull opens some interesting analytical possibilities for the ship's design that will be explored in detail later in this article.

**Table 1** Main data sets assessed

| Data Set  | Source  |
|---|---|
| Two scale models <i>Prins Willim</i> (ca. 1651) and the N16 model (modern).   | Digital library (scanned in the Rijksmuseum and the Maritiem Museum Rotterdam).   |
| 3-D scans of <i>Batavia</i> 's recovered hull in the Western Australia Museum Shipwreck Galleries in Fremantle, from 2005 (Van Duivenvoorde 2005) and 2014 (Annesley 2014). | Courtesy of the Western Australia Museum and Petra Helmholtz.   |
| 3-D scan of the <i>Batavia</i> II replica (above the waterline only).   | Scanned by the first author of the current study using photogrammetry during a visit to the ship in Lelystad in 2018.                                   |
| Legacy photographic surveys of the <i>Batavia</i> wreck site (1970s) by Patrick Baker and Jeremy Green of the Western Australia Museum—Shipwreck Galleries.                 | Courtesy of the Western Australia Museum.   |
| Modern photogrammetric survey (2019) of the <i>Batavia</i> wreck site.  | David Jackson of the Website: Diving Western Australia's Shipwrecks, < <a href="https://www.divingwawrecks.com/">https://www.divingwawrecks.com/</a> >. |
| Wide area navigational bathymetric LiDAR surveys, covering the Houtman Abrolhos islands.  | Western Australian Department of Transport.   |
| Tables of VOC ship dimensions.  | Summarized in Van Duivenvoorde (2015a).   |
| Iconographic depictions of the wrecking and break up of <i>Batavia</i> .  | Two separate editions of Pelsaert's <i>Ongeluckige voyage</i> (Pelsaert 1647, 1649).  |
| Schematic plans of the wreck site.  | <i>Batavia</i> excavation report (Green 1989:26–27).  |
| Elevation outline reconstruction of <i>Batavia</i> 's port side.  | <i>Dutch East India Company Shipbuilding</i> (Van Duivenvoorde 2015a:231).  |

**Table 2** The recorded dimensions of *Batavia* (1628) compared to the charters issued by the VOC up to 1653 and to *Prins Willem*, *Vergulde Draak* as built, and with scaled-up measurements of the N16 and *Prins Willem* models

| Type   | Length | Width | Depth in hold   | Length to width | Length to depth |
|--|--------|-------|-----------------|-----------------|-----------------|
| 1603 charter: Ship <sup>a</sup>                  | 130    | 35    | 13              | 3.7             | 10              |
| 1603 charter: <i>Jacht</i> <sup>a</sup>          | 80     | 25    | 10              | 3.2             | 8               |
| 1614 charter: Ship <sup>a</sup>                  | 150    | 33    | 13              | 4.5             | 11.54           |
| 1614 charter: Ship <sup>a</sup>                  | 138    | 36    | 14              | 3.83            | 9.86            |
| 1614 charter: Ship <sup>a</sup>                  | 138    | 26    | 12              | 5.3             | 10.62           |
| 1616 charter: Ship <sup>a</sup>                  | 142    | 36    | 14              | 3.94            | 10.14           |
| 1625 charter <sup>a</sup>                        | 160    | 36    | 12.5            | 4.4             | 12.8            |
| <i>Batavia</i> 1628                              | 160    | 36    | 14 <sup>b</sup> | 4.4             | 11.43           |
| 1653 charter: Return-voyage ship <sup>a</sup>    | 160    | 38    | 13              | 4.2             | 12.3            |
| 1653 charter: War <i>jacht</i> <sup>a</sup>      | 134    | 33    | 13½             | 4.06            | 9.9             |
| 1653 charter: Merchant <i>jacht</i> <sup>a</sup> | 126    | 28    | 13              | 4.5             | 9.7             |
| <i>Vergulde Draak</i> 1653                       | 137    | 32    | 13.5            | 4.28            | 10.14           |
| N16 model 1652 (1:47)                            | 161    | 38.8  | 11.1            | 4.15            | 14.5            |
| <i>Prins Willem</i> 1649                         | 181    | 45    | 18              | 4.02            | 10              |
| <i>Prins Willim</i> 1651 model (1:50)            | 182    | 43.8  | 16.85           | 4.15            | 10.8            |

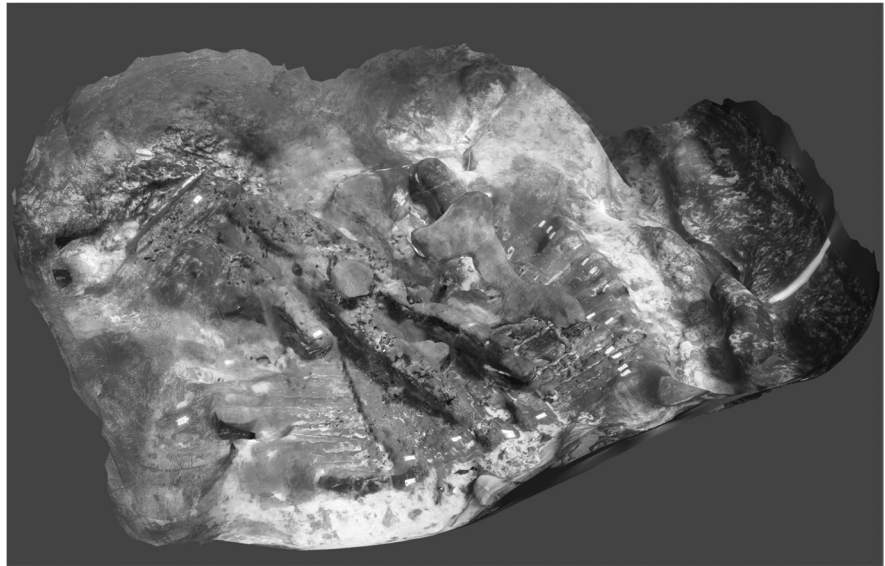
Measurements are in Amsterdam feet, 1 Amsterdam ft.=28.3133 cm.

<sup>a</sup> Van Duivenvoorde (2015a:73,241–249).

<sup>b</sup> The original instructions for *Batavia* stipulated 12.5 ft., but the shipwright chose to alter this to 14 ft. (Van Duivenvoorde 2015a:224).



**Fig. 5** Some legacy photogrammetric modeling of the in situ hull of *Batavia*, based on photos from the 1970s excavations. (Image by John McCarthy, 2022.)



### Photogrammetric Surveys of the Shipwreck Site

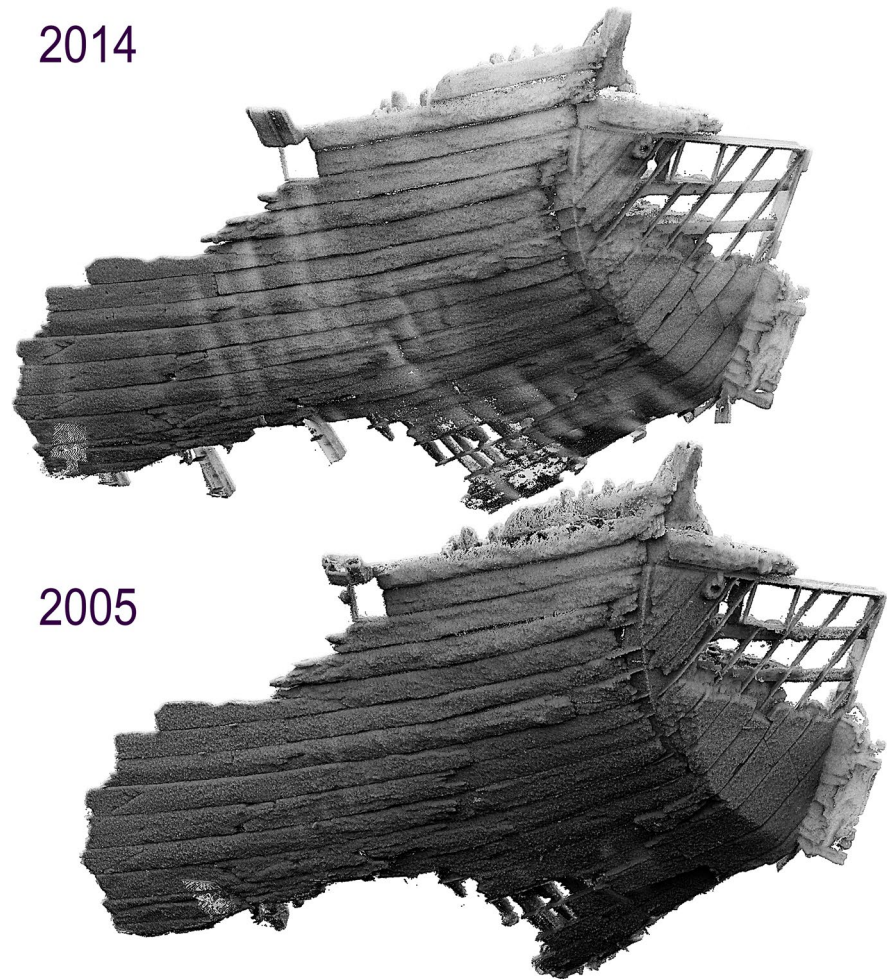
There have been three underwater photogrammetric surveys of the *Batavia* shipwreck site in recent years, all conducted long after the hull was removed from the seabed, but still clearly showing the topography of the wreck site with many of the cannon and anchors still in situ. None of the surveys have been comprehensive. The first and third photogrammetric surveys were undertaken by avocational diver David Jackson<sup>1</sup> in 2017 and 2019 (Sketchfab 2017, 2019), and the intermediate survey as part of a doctoral dissertation study (McAllister 2018:191–211). The earlier two surveys focused mainly on the sandy area around the depression made by the ship's stern, but Jackson's 2019 visit to the site, although brief, encountered excellent visibility and covered most of the site. A version of this data set has been made publicly available through the Sketchfab Website (Sketchfab 2019). This data set was captured between 7 and 10 February 2019, using a Sony RX100 IV with a wide-angle lens, and is composed of approximately 400 images. The original photographic dataset was provided to the authors directly by Dave Jackson for use in the

current study and was reprocessed in photogrammetry software to produce an enhanced 3-D model for this study in an attempt to increase coverage. The largest subset of images that could be aligned in Metashape is only 123 photos, but covers a larger area than all previous photogrammetric surveys. This result is particularly valuable as both published plans of the *Batavia* shipwreck site are simplified representations of the archaeological remains, and a detailed plan of the wreck has never been published (Green 1989:26–27).

Another potentially useful data set for photogrammetry of the shipwreck site are the underwater photographs taken by Patrick Baker, a pioneer of underwater archaeological photography, in the 1970s, as they show *Batavia*'s hull in situ (Baker and Green 1976). These photos were not taken with photogrammetry in mind, but do contain subsets of images intended for use as photo mosaics. In theory this might allow legacy photogrammetric processing (Green 2019) to both confirm the accuracy of the rebuilt hull and to accurately position the hull with respect to the surrounding seabed. Previous attempts to process these images, however, have modeled only small areas within the hull itself (Yamafune 2016:174), and further work on the images undertaken for the current study allowed alignment of more of the images than previous attempts (Fig. 5). The coverage and quality of the resulting model remained too low to be useful here. Further research into ways to maximize the area of coverage from photogrammetric processing

<sup>1</sup> David Jackson is an active member of the Maritime Archaeological Association of Western Australia (MAAWA) and operates the Website Diving Western Australia's Shipwrecks <<https://www.divingwawrecks.com>>.

**Fig. 6** Comparison of the scans of the *Batavia* hull from 2005 (Van Duivenvoorde 2005) and 2014 (Annesley 2014). (Image by authors, 2022.)



of these images is underway at Curtin University (Andrew Woods 2019, pers. comm.).

#### Hull Scans

A full-scale reconstruction of *Batavia* was built in 1992, sometimes referred to as *Batavia II*, and is currently a major tourist attraction in a permanent museum dock at Lelystad in the Netherlands (Vos 2015). This was partially scanned by the lead author of the present study using photogrammetry during a trip to the site in 2018. While this reconstruction is useful as a reference, it deviates in significant ways from the known design of the original ship (Vos 1991).

The original hull of *Batavia* is much more useful in this regard, despite only a small part of the stern quarter surviving, as this can be combined with the

known proportions to estimate the hull shape. The hull is on permanent display in the Western Australia Museum's Shipwrecks Gallery in Fremantle and has been studied in detail (Van Duivenvoorde 2015a:224–234). The reconstruction of the recovered timbers of *Batavia*'s hull was undertaken by Richard Steffy in one of the earliest examples of computer use to solve a 3-D transformation to find the most accurate fit for the timbers (Green 2009:33). Two laser scans have been made of the *Batavia* hull, the first was a laser scan (Van Duivenvoorde 2005) and the second was a comparative scan using both photogrammetry and laser scanning undertaken in 2014 (Annesley 2014). Down-sampled versions of both were available for further analysis (the earlier scan through the Western Australia Museum and the latter courtesy of Petra Helmholz of Curtin University), both in the form of point clouds (Fig. 6). The more

recent scan had been more carefully cleaned, but had been down-sampled to only 80,000 points, while the 2005 survey was available at a higher resolution of 5 million points.

A comparison of the point clouds showed negligible differences. To visualize this data in a digital reconstruction it was necessary to generate a continuous mesh surface from the point cloud. The 2005 point cloud was meshed using CloudCompare, an open-source 3-D point-cloud processing software (Girardeau-Montaut 2019). This proved difficult, due to gaps in coverage, but eventually it was possible to generate a meshed surface with complete coverage of the outside of the hull.

### Bathymetric LiDAR

One of the most useful data sets for the *Batavia* wreck site is the availability of high-resolution publicly available bathymetric light detecting and ranging (LiDAR) covering the entire landscape and seabed around the shipwreck. This aircraft-based remote-sensing survey was carried out by the Western Australian Department of Transport in 2016, principally to support navigational safety in the region. The survey covers coastal areas of the mainland north from Perth to the north of Geraldton, and includes the Houtman Abrolhos (Fugro LADS Corporation Pty Ltd. 2016).<sup>2</sup> These data were requested from the department in August 2019 and were provided as a gridded 5 m raster file in LAS format. Depths are relative to GDA94 and to the Australian Height Datum (AHD) (Landgate 2016:20). While this 5 m gridded raster LAS file is excellent for large areas, the resolution is very limited for single archaeological sites. At the scale of shipwrecks, it is much better to work with the raw survey data, which can have much higher resolution in some areas. A second request was placed for the raw survey data that were provided by the Department of Transport as a point cloud, containing every measurement taken by the airborne laser. These were provided as “bag” format files, in WGS 1984 UTM Zone 50S projection. Due to very large file sizes, data were provided only for the 1 km<sup>2</sup> areas

immediately around *Batavia*. Further processing was carried out for the *Batavia* data set in support of this case study (Fig. 7).

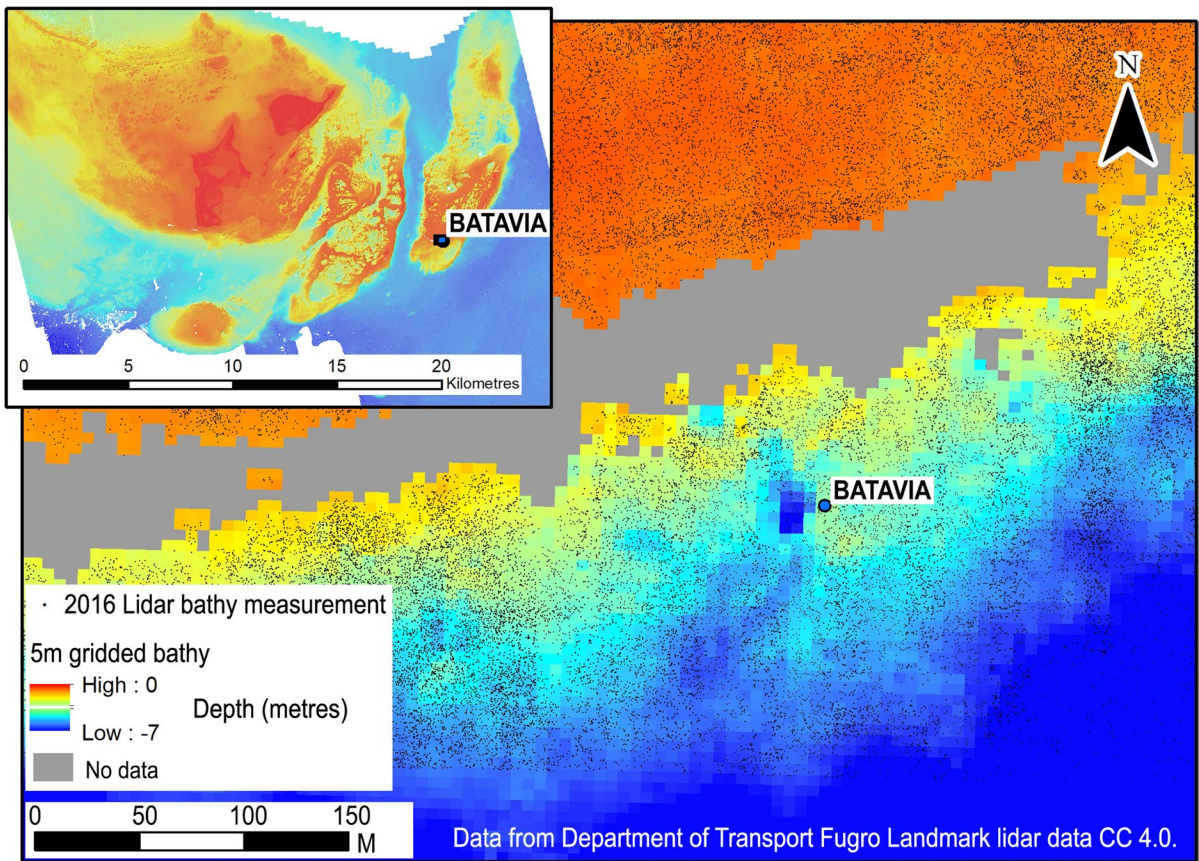
When reprocessed for archaeological use at the highest possible resolution, the quality of the LiDAR survey is sufficiently high that the shape of the hole created in Morning Reef by *Batavia*'s hull is clearly visible (Figs. 7, 8). This helps to position the wreck site more accurately than the published coordinates, but also allows the photogrammetric survey to be accurately georeferenced during the process of combining the data sets.

This data set included extraneous data, such as the sea surface and survey noise. Fortunately, the surveyors have classified all points after the survey into the categories of seabed, sea surface, noise, etc. Extraneous data was filtered using this classification in Cloud Compare using the “filter by value” command. In the case of the 1 km<sup>2</sup> tile covering *Batavia*, this operation left 2.6 million points from 5 million, giving an average density of 2.6 points per m<sup>2</sup>, a much higher resolution than the original gridded data set with 1 point per 5 m<sup>2</sup>. This density is unevenly spread, with higher densities in shallower areas and flight transect overlaps, as well as data gaps in some areas. This cleaned cloud was mapped against the rasterized 5 m grid in ArcGIS to visualize coverage in the vicinity of the shipwreck (Fig. 7). Coverage of the area around *Batavia* is almost complete, but there are some gaps. One such gap occurs approximately 20 m north of the main shipwreck site, where laser penetration was blocked by the wave breaking on the reef, generating a “bubble curtain” opaque to LiDAR (Fig. 9).

The resulting point cloud was processed into a continuous mesh surface that could be imported to a landscape visualization using a “Poisson surface reconstruction.” By using an octree level 12, a mesh is produced that uses all the LiDAR depth measurements and gives a 3-D model with the maximum possible resolution of the LiDAR source, a far more detailed representation of the seabed than the gridded raster data set and one that is much more suitable for archaeological use.

A similar mesh surface at lower resolution was generated for the entire area of Morning Reef including Beacon Island based on the 5 m gridded data set, using the “Raster To TIN” tool in ArcMap. Both mesh data sets were then cleaned and edited to fill gaps such as those caused by wave blanking, then the

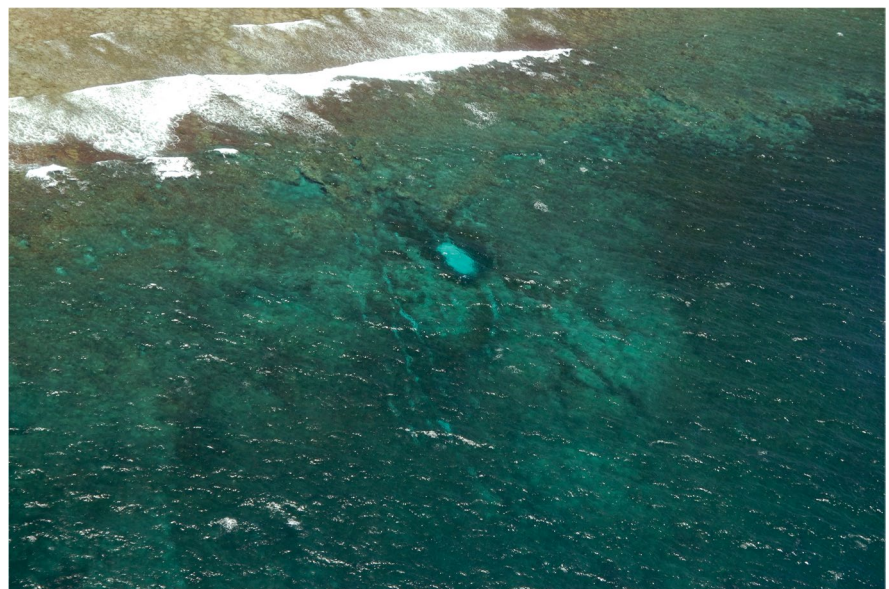
<sup>2</sup> Department of Transport, Government of Western Australia <<https://www.transport.wa.gov.au/imagery/marine-geographic-data.asp>>.



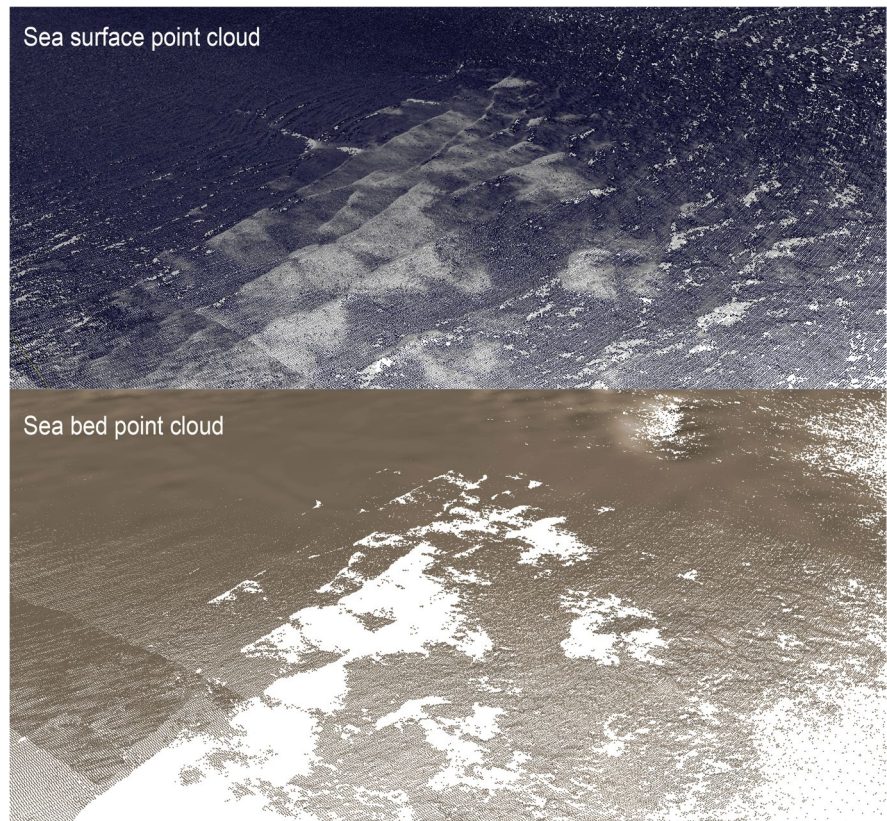
**Fig. 7** Coverage of the 2016 LiDAR bathymetry survey in the vicinity of *Batavia*, comparing the 5 m gridded bathymetry (with color ramp) with the original point measurements, shown

here as black points. (Data from Department of Transport Fugro Landmark LiDAR data CC 4.0.)

**Fig. 8** The *Batavia* shipwreck site on Morning Reef showing the sand patch in the reef where the ship’s hull pushed into the reef and created the hole visible today. (Image by Patrick Baker, Western Australia Museum, 2013.)



**Fig. 9** Waves breaking on the reef blanked out seabed survey coverage in the aerial LiDAR survey over the *Batavia* shipwreck site (data from Department of Transport Fugro Landmark LiDAR data CC 4.0). (Image by John McCarthy, 2020.)



aerial orthomosaic was projected onto them digitally and “baked” onto the 3-D model. This produced an entire textured 3-D model of the landscape and seabed that covered the wreck site in high resolution and the wider landscape, including all of Mornington Reef and its islands, in a lower resolution.

#### Combining the Spatial Data

Having collected all the data sets described above and converted them to formats suitable for use in 3-D modeling software, the data sets can be combined, firstly to give an accurate reconstruction of the ship and secondly to place that reconstruction into a spatially accurate landscape.

#### Ship Reconstruction

The first step is to estimate the true hull shape of *Batavia* from all available evidence. Despite extensive study and the construction of a full-size reconstruction, there has never been an attempt to extrapolate

the full lines of the vessel directly from the archaeological remains.

A comparison of the *Batavia* hull scan with the *Batavia* II reconstruction, the *Prins Willim* and the N16 model highlights some striking differences (Fig. 10). The surviving hull includes the wing transom, part of the sternpost and enough of the stern quarter to establish the hull form in this area. The scan can be aligned with the other digital data sets by aligning the cover at the top of the wing transom, which is present in all data sets and rotated for the best possible fit. This process shows that the *Batavia* II reconstruction is the worst fit with the original hull, with a wing transom that is too narrow and too high, as well as a hull form that is a poor fit, with the turn of the bilge being too sharp in the stern quarter. The wing transom of the *Prins Willim* model is both higher and wider than *Batavia*, not surprising as it represents a larger ship.

Closest of the three is the N16 model, which at a scale of 1:47, matches closely the width and height of the wing transom, as well as the position and

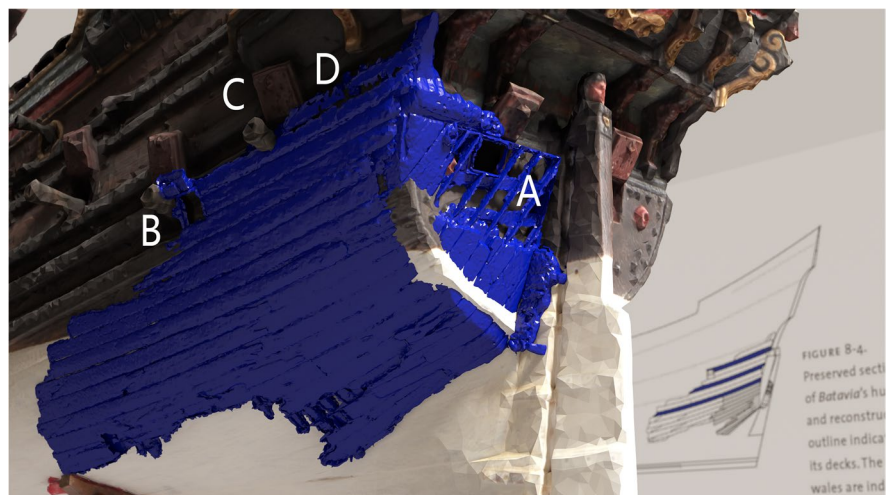


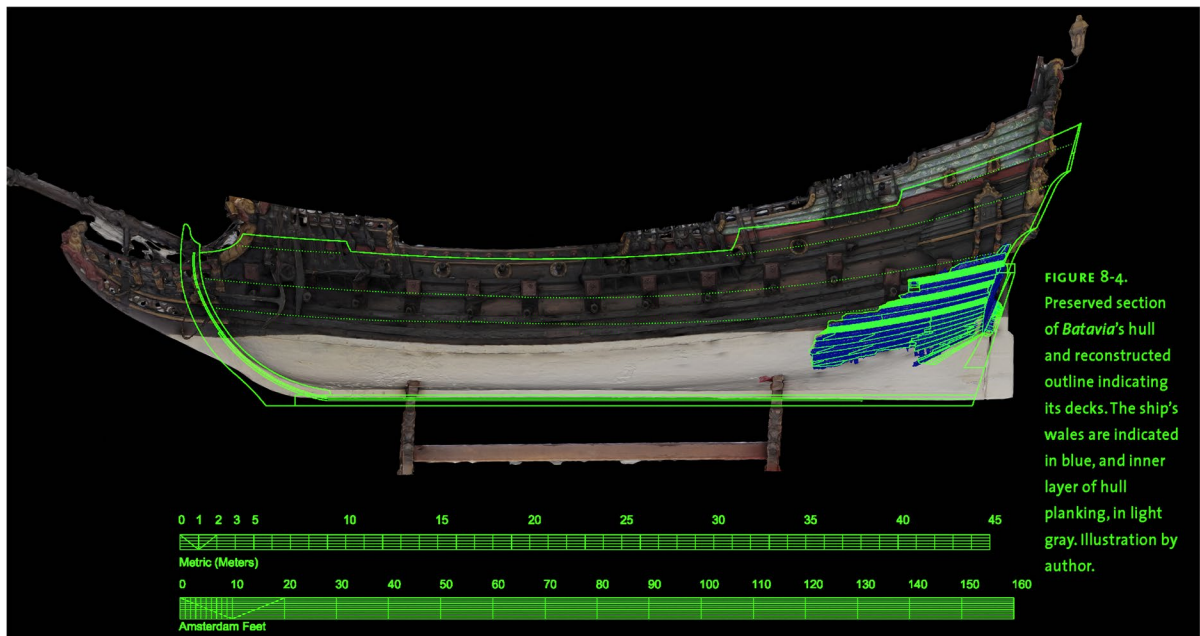
**Fig. 10** Comparison of the scans of the archaeological remains of *Batavia* (in blue) with the full-size *Batavia II* reconstruction and the scaled-up models of *Prins Willim* and the N16 model. (Image by John McCarthy, 2022.)

orientation of the rudder. When the wing transoms of both scans are aligned, the hull shapes also align well, although the *Batavia* hull appears to be slightly deeper than the N16 hull. Alternatively, as the angle of the surviving section of hull with respect to the waterline is unknown, this slight divergence might reflect a small difference in the rake of the stern, or a combination of both factors. The outer edge of the wing transom of the N16 model is sharper than that of *Batavia*'s hull fragment, but this is due to the abrasion of

*Batavia*'s hull against the coral reef during wrecking, which created a pronounced bevel along this edge (Van Duivenvoorde 2015a:49). Figure 11 shows that the position and size of the gun port on the wing transom is also a close match (A), much more so than that on the *Prins Willim* model and the gun port on the starboard quarter of the hull also matches closely in size and position (B). Another gun port on the starboard quarter of the model almost falls within the area preserved in *Batavia*'s hull, but not enough of

**Fig. 11** The close correspondence in shape between the scan of *Batavia* and the N16 East Indiaman model, including shape, size, and gun port positions. (Image by John McCarthy, 2022.)





**FIGURE 8-4.** Preserved section of *Batavia*'s hull and reconstructed outline indicating its decks. The ship's wales are indicated in blue, and inner layer of hull planking, in light gray. Illustration by author.

**Fig. 12** An overlay of a previously published outline for *Batavia* in green (Van Duivenvoorde 2015a:231) on the N16 model and scan of *Batavia*'s hull (dark blue) shows some differences. (Image by authors, 2022.)

the hull is preserved here (C). The former presence of a gun port at this point on *Batavia* might, however, explain why the uppermost strake (strake 21) has broken off at this point (D). Given N16's close spatial correspondence with Nooms's illustration (Fig. 4), the recorded proportions of contemporary sources and the 3-D shape of the surviving part of *Batavia*'s hull, suggests that either by design or by chance, the model provides an accurate proxy for the shape of a 160 ft. East Indiaman in the period between the charters of 1618 and the new charters of 1653, at least in the VOC shipyard of Amsterdam. This also suggests minimal changes in design and hull form between the construction of *Batavia* (1628), *Salamander* (1639) and *Prins Willem* (1649).

Although no ship lines have been estimated directly from *Batavia*'s hull, an outline elevation has been published, overlaid with the surviving elements of *Batavia* (Van Duivenvoorde 2015a:231). Placing the N16 model scan and the scan of the surviving fragment of *Batavia* in place, shows some small but important differences between the model and outline. It is clear that *Batavia* had a deeper draft (Fig. 12), and, although none of the lowest part of the ship survives, van Duivenvoorde has calculated

*Batavia*'s draft from the waterline markings on the sternpost sheathing at 4.1 m below the lowest surviving part of the sternpost (Van Duivenvoorde 2015a:119,225–226), while the same distance on the scaled-up model comes only to 3.6 m. Secondly, given the apparent accuracy of the upper works on the N16 model as shown by comparison with Nooms's etching (Fig. 4), it suggests that *Batavia*'s upper works rose higher above the surviving fragment than this previous elevation outline suggested.

The photogrammetric scan of the N16 model was edited for use as the basis of the new digital reconstruction of *Batavia*, which for clarity may be referred to hereafter as *Batavia* III (Fig. 13). This process was carried out in Blender, using digital sculpting, mesh editing, and texture-painting tools. Edits include the removal of cannons on the upper decks, sealing of upper gun ports, changing of the date on the stern and the replacement of the salamander with the arms of the colony of *Batavia*, awarded to the settlement in 1620 (the version on the stern is taken directly from a painting of 1651 [Becx 1651]). Most importantly for spatial analysis, the hull has been altered to match both the recorded dimensions of *Batavia*'s hull and for best fit with the scanned archaeological remains.

**Fig. 13** Reconstructing *Batavia* III by modifying the N16 scan. Sterns are shown above with *Batavia* III (top left, including scan data) and N16 (top right) and an orthographic starboard view of N16 (middle) and *Batavia* III, with deeper hull and fewer gun ports (bottom). (Image by John McCarthy, 2020.)



This includes changing the hull to the dimensions of 160 Amsterdam ft. long over the posts, 36 ft. wide inside the hull, and 14 ft. deep in the hold ( $45.3 \times 10.19 \times 3.96$  m) as well as lowering the keel to 4.1 m below the lowest remaining fragment of sternpost. Based on a change in hull construction at the lowest strake, it was previously thought that the draft of *Batavia* was 5.66 m (Van Duivenvoorde 2015a:70,80), but if the sheer of N16 is followed, this places the gun ports amidships too close to the waterline. The *Batavia* reconstruction draft is therefore estimated at 5.4 m, following the painted waterline at the stern of N16 and this agrees with the recorded depth in the hold.

Lastly, the painted waterline on the model is uneven, perhaps due to an error in repainting at some point, and *Batavia* III has been digitally repainted to

extend horizontally. The rake of the transom is also increased slightly, and the scanned masts and sails have been digitally removed and replaced with geometric solids.

The high-resolution LiDAR meshed surface and all other relevant 3-D data sets were brought into a Blender project and aligned with each other. In doing so all data was maintained in the Cartesian space of UTM 50S, where north is the  $y$  axis, east is the  $x$  axis and elevation is on the  $z$  axis. As Blender is 3-D modelling software and is not designed to cope with data thousands of kilometers from the coordinate system origin, the georeferenced LiDAR data was transformed by  $-186000$  m on the  $x$  axis and  $-6844500$  m on the  $y$  axis. No transformation is required for the  $z$  axis. All other 3-D data were then positioned relative



to this data set. This includes the laser scan of *Batavia*'s hull, David Jackson's 2019 photogrammetric survey of the shipwreck site, published plans of the site from Green's 1977 monograph, aerial orthomosaics, and the new digital reconstruction of *Batavia III*.

### Positioning the Reconstruction

*Batavia* hit Morning Reef and grounded in the early hours of the morning of 4 June 1629, before first light. The crew initially hoped that the tide was low and that the ship would soon be lifted off the rocks. Unfortunately, it was found that the tide was dropping and by noon the ship was sitting high on the reef at low tide with no hope of escape (Dash 2003:5–10). The tidal range in the Abrolhos is 1 m (Collins et al. 2006:79), so the ship probably hit the reef at close to 0.5 m above contemporary mean sea level. Global sea level at present is approximately 20 cm higher than it would have been in the 17th century, placing the sea level at the time of wrecking at a maximum high tide 30 cm above and a minimum low tide 70 cm below current mean sea level. Depths in the LiDAR data set are corrected to Australian Height Datum, a measure of current mean sea level. Pelsaert's account records that the depth astern immediately upon wrecking was 17–18 ft. of water (assuming this is Amsterdam feet, this is about 5 m), and that the depth "an arrow's shot" astern was 7 fathoms. Roeper (1993:69) estimates an arrow shot in this case as around 300 m. In the Amsterdam measure 7 fathoms would be around 12 m depth (Parthesius 2007:178). The ship also leaned to port or leeward (Van Huystee 1994:3; Dash 2003:7) and was probably raised at the bow and low in the water astern (Dash 2003:6).

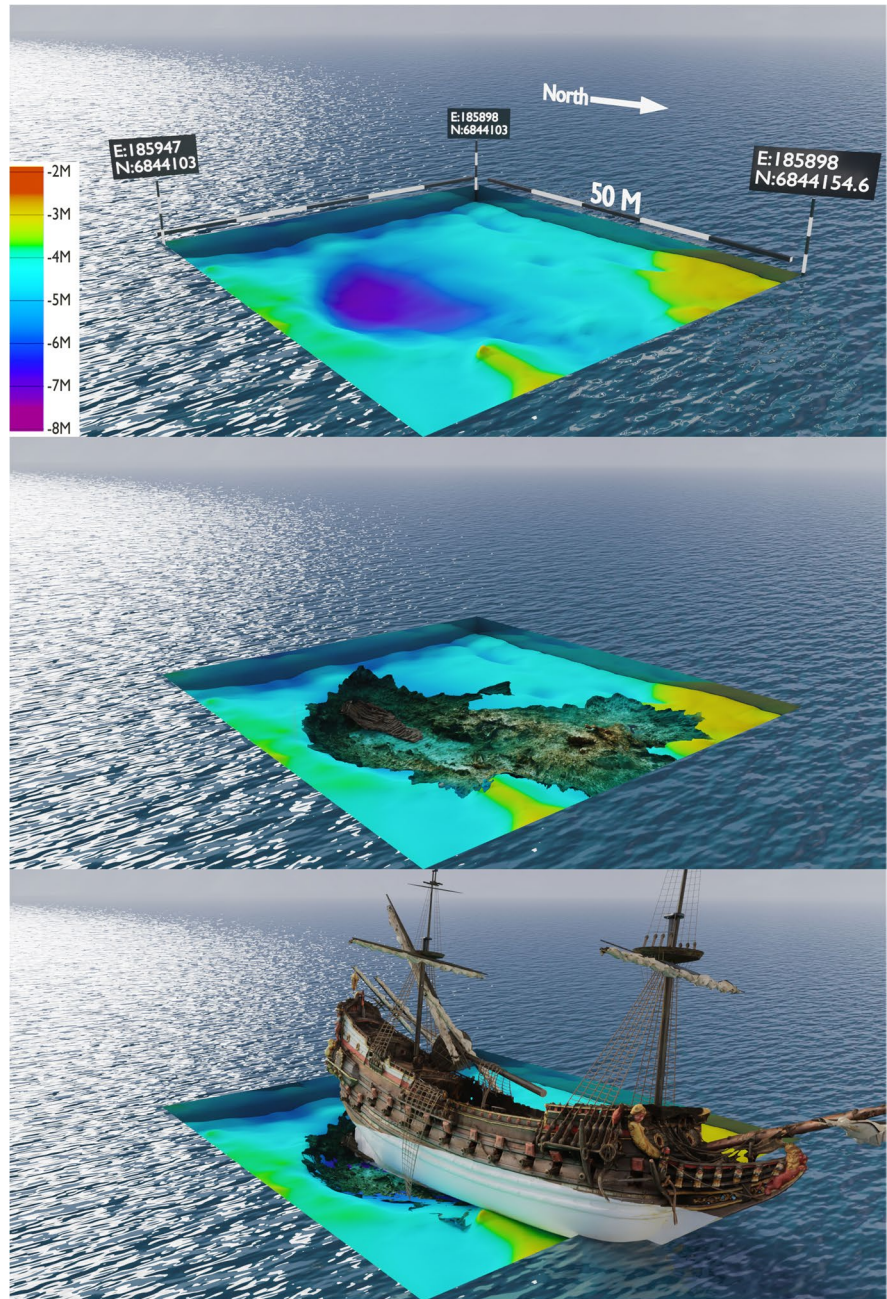
*Batavia* had a weight of 600 tons (Van Duivenvoorde 2015a:144) and attempts were made to lighten the ship so that it could be saved from breaking up on the reef and refloated by jettisoning around 30 tons in the form of cannon (Dash 2003:6) and by cutting down the mainmast. These efforts did not prevent the hull from breaking below the waterline by 10 A.M. and flooding the hold, but efforts to save the ship continued. The ship's mast was cut down shortly after dawn, but fell onto the deck causing further damage and failing to release the hull from its substantial weight. The digital reconstruction is shown with its mainmast cut down as described in the survivors' accounts. It does not lie in the water as shown in the

contemporary illustrations, but on the deck, an important distinction, as its failure to clear the ship when cut down effectively doomed the vessel. By the following night, 240 of the ship's complement had made it ashore, with many others having perished in the attempt. After nine days the hull reportedly burst open on its port side, and of 71 survivors who had chosen to remain aboard rather than risk getting ashore, only 26 were able to swim or float to safety through the surf onto the reef (Dash 2003:139).

The surviving part of the hull was discovered within a substantial hole in the reef that can be seen even in aerial photos as a bright sandy patch. This scouted depression is clearly the result of damage from the wrecking event and is much larger than the surviving hull fragment. It was most likely dug by the intact hull during the nine days before the ship broke up, while the hull had its greatest strength and weight. The discovery of the hull in this depression shows that the ship did not move far from its initial grounding position, and this is reinforced by Pelsaert's journal entry of the 18 September 1629. Encountering the ship for the first time since departing in the ship's boat to Batavia (now Jakarta) to summon help, he described it as largely broken up, such that "all above water had been washed away except a small piece of the *d'achter windtveeringh* [bulwark at the back/fashion piece] which was above water, it was almost exactly in the same place where the ship had first struck" (Van Huystee 1994:15). Although LiDAR coverage is patchy around the shipwreck, coverage of the wreck site itself is sufficiently detailed to show the shape of the hole in the reef clearly in the high resolution LiDAR mesh. This is detailed enough to georeference Jackson's 2019 photogrammetric survey based on the shape of the cut in the reef, allowing a much more accurate positioning of the site than any previously published (Fig. 14).

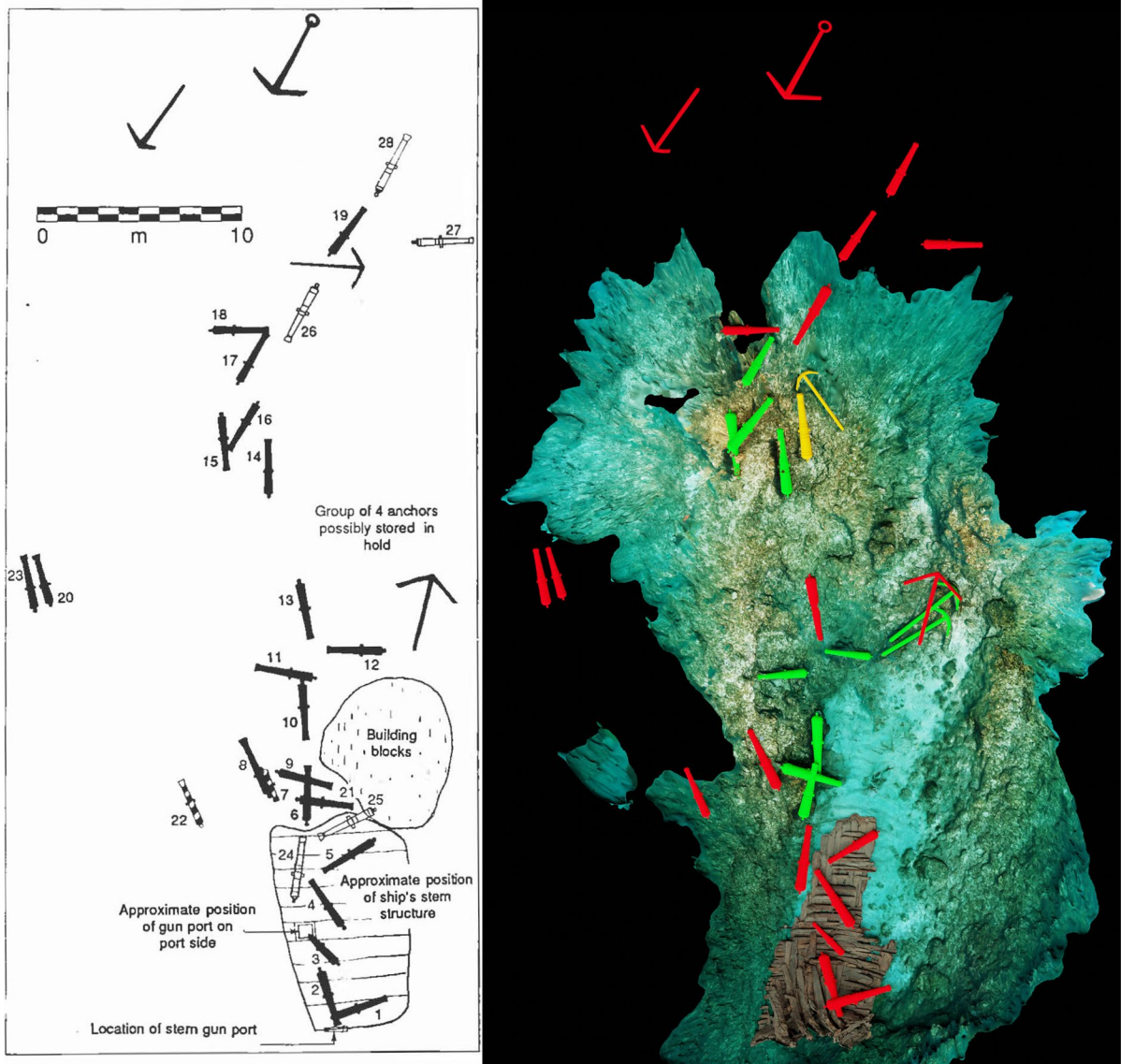
Positioning of the scanned hull within this survey is more difficult. In the absence of a usable legacy photogrammetric survey covering the area around the hull, the scan of the hull can only be positioned with reference to the schematic plan line drawings published in the 1970s (Fig. 15). Placing the 3-D hull into the position indicated by these plans makes it clear that it cannot be the same position the hull had while intact and the shape of the reef would not have allowed enough room, so that the hull must have settled and rotated as it degraded. This original position

**Fig. 14** Importing the LiDAR bathymetric mesh into Blender (*top*), positioning the photogrammetric survey and hull scan relative to it (*middle*) and finally adding the *Batavia* III reconstruction (*bottom*). Sea level is shown at mean astronomical tide. (Image by John McCarthy, 2022.)



can also be estimated using 3-D analysis. Historical accounts and iconography suggest that the ship was heeled over to port during the nine days it remained intact. The longitudinal roll of the ship at this time can be estimated by placing the aft end of the *Batavia* III keel into the deepest part of the depression and rotating it until constrained by the western edge of the hole in the reef, suggesting an angle of around  $15^\circ$ .

This positioning of the hull suggests that the illustrations in Pelsaert's 1647 account are quite accurate, and show that, even with the hull sitting in the full depth of the depression in the reef at high tide (ca. 70 cm above MAT), only the lowest portside gun ports would be submerged. Except for waves and surge, the main and upper decks would always have remained above water.



**Fig. 15** Comparison of the existing schematic surveys (Green 1989:26–27) with Dave Jackson’s photogrammetric survey of the *Batavia* wreck site (Sketchfab 2019). The photogrammetric survey includes the scanned hull from the Western Australia

Shipwreck Gallery. Guns and anchors still in position are highlighted in green, those removed or beyond the survey area are in red, while one anchor and one gun not shown on the plan are in yellow. (Image by John McCarthy, 2022.)

Secondly, the captain’s account describes the initial attempts to get off the reef by dropping cannons and this reconstruction helps to explain the distribution of guns on the wreck site. To jettison *Batavia*’s heavy guns to starboard would have been extremely difficult because of the angle of the deck, and it would have been much easier to pass even the starboard guns through the port gun ports. This is clearly reflected in

the linear pattern of guns along the western side of the hole, directly underneath the portside gun ports of the reconstructed ship (Fig. 16). Some of the guns were found on top of the surviving hull and these were probably not jettisoned, but stayed in the ship.

As well as technical insights, the spatial recreation of the environment facilitates more visual and immersive outputs. The cause of *Batavia*’s wrecking

**Fig. 16** The reconstruction explains the distribution of guns on the wreck site, almost all of which would have been jettisoned off the port side of *Batavia*. (Image by John McCarthy, 2022.)



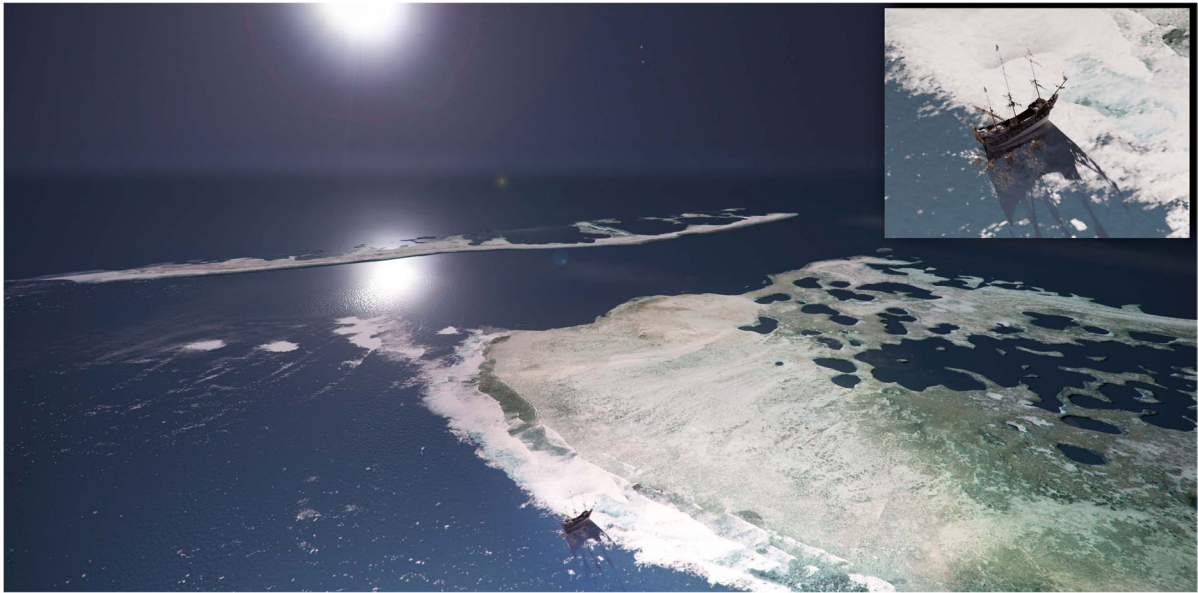
was that the sailor on watch and the skipper believed that the reef ahead of them was merely a reflection of the moon. The position and phase of the moon can be recalculated for the site using the service at <<https://www.mooncalc.org>>. This allows for an accurate recreation of the scene as it would have appeared from *Batavia* as it unwittingly approached Morning Reef. At 3 A.M. in the morning of 4 June, the moon was directly west of the ship, waxing gibbous and  $28.8^\circ$  above the horizon. At the time of wrecking it was setting and had set by 5:20 A.M., with the sun rising at 5:30 A.M. With a few modifications of the sky, tide-level, and water color, it is a simple matter to visualize the scene at the time of wrecking (Fig. 17).

## Conclusions

The comprehensive spatial survey and reconstruction of the shipwreck within its landscape allows for analysis of a type that was previously difficult or impossible. This project has demonstrated how a wide variety of sources can be synthesized into a spatial environment to build up a metrically accurate reconstruction of a shipwreck. By combing historical iconography with remote sensing data, ship models, VOC charters, builder's instructions, underwater photogrammetry,

archaeological site plans, and historical sea-level data, it has been possible to create the most accurate reconstruction of the site to date. In particular, the analysis of the stern remains of *Batavia* have been fitted into an accurate model of the stern of the reconstruction, and compared directly to existing drawings and the full-size physical reconstruction at Lelystad, showing that the original ship is likely to have been significantly different in shape.

There is insufficient room here to explore all the possible avenues of analysis that this approach opens up for *Batavia*, but we may outline some of the most important. For the ship itself, having a more accurate reconstruction provides an important data point in tracing the changes in VOC ship design over time, but there are also many further questions to ask about the construction of the ship that will be facilitated by the new reconstruction. The position of the recovered hull has been analyzed with respect to its original position, and new insights have been gained on the site taphonomy, showing that the cannons have been distributed along the port side of the ship, where it was easier to release them through the gun ports. There is clearly scope for further analysis of the distribution of artifacts on site relative to the reconstruction, particularly for reconciling the discrepancies between existing plans with the current position



**Fig. 17** *Batavia* in a landscape setting, with a high tide and the moon lighting the scene from the west as it did at the time of wrecking. This is visually appealing and provides a sense of

of guns and anchors visible in the photogrammetric survey by Jackson. There is also scope for landscape-wide analysis of the interactions between the shipwreck and the survivors, which continued long after the wreck broke up, with survivors moving through the islands of Morning Reef, but making difficult return trips to recover supplies. With this reconstruction completed, there is also significant potential for public engagement through virtual reality and other mechanisms (McCarthy and Martin 2019). Phenomenological explorations like the final example of the wrecking event also demonstrate how boundaries in current archaeological workflows can be broken down by software advances of 3-D modeling software that bring together GIS-like analytical capabilities with photorealistic visualization and rendering capabilities. This avoids the abstraction of working with line plans and allows more of a sense of the reality of the site, while maintaining metric accuracy. As background spatial data sets such as high-resolution multi-beam and bathymetric LiDAR become more widely available and archaeologists develop more skills in handling 3-D scan data and extracting spatial data from other sources, this type of digital spatial accident reconstruction is certain to become more common in the future.

the event, but is also spatially accurate in all details. (Image by John McCarthy, 2022.)

**Acknowledgments:** The authors offer thanks to David Jackson of Diving Western Australia's Shipwrecks, <<https://www.divingwawrecks.com>>; Ab Hoving; Patrick Baker; Petra Helmholz; staff of the Maritiem Museum Rotterdam and the Rijksmuseum in Amsterdam, particularly Jeroen ter Brugge and Jeroen van der Vliet; and Marta Domínguez Delmás, research associate at the University of Amsterdam. This research was generously supported by the Australian Research Council (Linkage Project LP130100137) and the Embassy of the Kingdom of the Netherlands in Canberra through the Dutch-Australian Cultural Heritage Initiatives scheme (Activity No. GCE-2017- 03), which allowed the primary author to travel to Europe for the scanning of ship models. We also thank our anonymous peer reviewers for some thoughtful feedback.

**Funding** Open Access funding enabled and organized by CAUL and its Member Institutions

#### Declarations

**Conflict of Interest** On behalf of all the authors, the corresponding author states that there is no conflict of interest.

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