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WHEN NEW TECHNOLOGY JOINS OLD DOCUMENTS AND EAST MEETS WEST: VIRTUALLY RECONSTRUCTING THE FISHER ISLAND PAGODA LIGHTHOUSE (CHINA)

CUANDO LA NUEVA TECNOLOGÍA SE UNE A LOS DOCUMENTOS ANTIGUOS Y EL ORIENTE SE ENCUENTRA CON EL OESTE: LA RECONSTRUCCIÓN VIRTUAL DEL FARO PAGODA DE FISHER ISLAND (CHINA)

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Highlights:

- This paper describes a successful way of using modern computer software to reconstruct a long demolished building from a unique photograph.
- Chinese and western historical documents and scattered fragmentary remains acted as auxiliary data sources.
- It recovered dimensions, location, orientation, function and materials of Taiwan's Fisher Island pagoda lighthouse, built in 1778, and demolished in 1875.

Abstract:

Located on the route between Xiamen and Taiwan (China), the Penghu (Pescadores Islands) are an archipelago and the site of a military garrison. The second largest island, Xiyu or Fisher Island, was accordingly an obvious point to build a navigational marker to guide sailors. Records indicate that some type of a marker, in the form of a tower or pagoda, was constructed in the 17th century. However, in 1778 the original was replaced by a different sort of pagoda tower. The new structure has long been known to have been a purposefully designed lighthouse. Although today's Yuwengdao lighthouse, built in 1875, has become a famous heritage landmark, the earlier 1778 structure, it can be argued has greater heritage significance in that it was an entirely original creation preceding the introduction of western lighthouse technology in China by nearly a century. Thanks to the fortunate discovery of a hitherto unknown photograph of this earlier lighthouse backed by further research in early navigational documents, gazetteers, charts and inscriptions and The authors have been able to make a 3D virtual reconstruction using state-of-the-art Revit software and thus answer several research questions about this old lighthouse pagoda, including dimensions, location, orientation, function and materials.

Keywords: 3D reconstruction; virtual reality; epigraphy; 3D printing; documentation

Resumen:

Situado en la ruta entre Xiamen y Taiwán (China), Penghu (Islas Pescadores) es un archipiélago que históricamente tenía una guarnición militar. La segunda isla más grande, Fisher Island, era por lo tanto un punto obvio para construir una señal de navegación para guiar a marineros. Los registros muestran que un tipo de torre o pagoda sirvió también como señal de navegación, que se construyó en el siglo XVII. Sin embargo, en 1778 fue reemplazado por una pagoda conocida por haber sido diseñada principalmente como un faro. Aunque hoy en día el faro de Yuwengdao, construido en 1875, se ha convertido en un hito famoso de la herencia cultural, la estructura anterior de 1778 se puede argumentar que fue de mayor significancia patrimonial porque era una creación enteramente original, precediendo la introducción de la tecnología occidental de un faro en China casi un siglo. Gracias al afortunado descubrimiento de la fotografía hasta ahora desconocida de este antiguo faro, respaldada por investigaciones adicionales en los primeros documentos de navegación, nomenclátores, tablas e inscripciones, los autores han sido capaces de hacer una reconstrucción virtual 3D utilizando el software de última generación Revit y responder consiguientemente a varias preguntas de investigación sobre este antiguo faro pagoda, incluyendo sus dimensiones, ubicación, orientación, función y materiales.

Palabras clave: reconstrucción 3D; realidad virtual; epigrafía; impresión 3D; documentación

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1. Introduction

Digital heritage rehabilitation has recently made significant progress as a useful tool in understanding ruined or otherwise compromised heritage structures. For example, 360° panoramic images have been used to construct web-based virtual reality guided tours (Bastanlar et al., 2008; Maícas & Viñals, 2017). The aim has been to rehabilitate heritage using a set of terrestrial images of a building envelope to generate a 3D model. An obvious problem occurs, however, when there are no ruins of a past structure or known images of one. In such circumstances, there is no basis upon which to reconstruct past appearances. 3D modelling and visualization for many archaeological sites is normally not possible because either there are no significant remains or there are too few to give any sense of the form of the whole (Portalés, Alonso-Monasterio, & Viñals, 2017). Thus, the term 'virtual reconstruction', in this article, is defined as using the combination of a single but vital historic photograph, combined and interpreted with information gleaned from gazetteers and navigational guides, old inscriptions, old marine charts and maps, and modern interactive geographical data through the use of architectural modeling software to recreate the 3D 'actuality' of the original in terms of its dimensions, appearance and location.

The term "lighthouse" is dominated in the popular imagination by the iconic structures of the great age of modern lighthouse building that began in the western world in the mid-18th century. The core image is of a cylindrical, tapered tower painted white or black, or with black and white or red and white horizontal bands, topped by a glazed lantern chamber under a cupola roof, for all that actual examples exhibit a wide variety of regional features. That dominant image with its western provenance has tended to obscure the question of the extent to which other maritime cultures also had similar structures and, if they did, what they may have looked like. Beginning with the precursors of modern lighthouses in the ancient and classical European world (for example Egypt and Rome), in recent years lighthouse historians have begun looking more carefully at indigenous precursors elsewhere. In the case of China, for example, it has long been known that traditional pagodas were used as river and sea marks from as early as the 10th century (Tang Dynasty), and in the dark they showed lights. However, these were built primarily as religious structures with, at best, a secondary use as a navigational mark in the daytime (as a seamark) and only an occasional use at night. With the Xiyu Pagoda Lighthouse, however, we have a quite different structure with a primary purpose as a lighthouse, its religious function being secondary and, though there is some doubt as to this, possibly relegated to a separate building.

Many traditional pagodas with secondary uses as lighthouses still stand today, for example Shanghai's Mao Pagoda Lighthouse, built in 874 CE, Wenzhou's West and East Pagodas >10th century CE or Guangzhou's c. 12th century Huaisheng Si or Guangta Si (Lighthouse Mosque). It follows that studying their dimensions, orientations and locations is easy. But for the Xiyu Pagoda Light, China's first and, as far as the authors know, unique example with a primary function as a lighthouse, the only extant data given in gazetteers and in inscriptions was imprecise. There were thus no clear answers to questions of the pagoda's scale, dimension, orientation and location.

This article aims to answer those research issues following the discovery of:

- A photograph (Fig. 1) taken in 1875 and archived in the collection of The Royal Geographical Society Picture Library (Anonymous, before 1900).
- Data from 18th century Chinese documentary sources: The Illustrated Guide to Penghu's West Island Lighthouse, Map of Penghu's West Island Lighthouse, Diagram Showing the Reconstruction of various Structures in the Prefecture of Taiwan, in the Collection of National Palace Museum (National Palace Museum, 2017).
- A manuscript draft survey chart in the United Kingdom Hydrographic Office Archive (Collinson, 1844b).

With these foundational sources and additional data culled from transcriptions of 18th and 19th century stelea in Xiyu, it has been possible to make the 3D reconstruction and visualization of the Fisher Island Lighthouse Pagoda presented in this paper.

2. The history of the Fisher Island Pagoda Light

Xiyu Ta Deng, in English translation Fisher Island Pagoda Light, was completed in 1778 (43rd year of Emperor Qianglong), funded by donations raised by Jiang Yuanshu, Taiwan Prefectural Magistrate, and Xie Weiqi, local Penghu Magistrate. We learnt from a stele commemorating the construction of the pagoda, that there had been an earlier structure:

> At night, a lighthouse can be seen. It is on the western end of the island's ridge (in the location of) the original Tian Hou temple and was built by the Prefect Jiang Yuanshu and magistrate Xie Weiji, who (organized) donations of gold. The tower has seven levels.

That seven-level pagoda, suffering from lack of maintenance and bad management, was significantly damaged by a typhoon in 1823 (3rd year of Emperor Daoguang), though it is not known what the extent of the damage may have been. The pagoda was rebuilt and was put back into commission in 1828.

Funds for the reconstruction and upgrade were raised from officials, merchants, store- and ship owners – the record says a total of 500 silver taels by the then Penghu Magistrate Jiang Yong and the local navy commander Chén Huà Chéng. What westerners called the tael (from the Malay tahil = weight) was a customary Chinese unit, *'liǎng'*, of c. 37.5 g of 900 fine silver. It was not normally or necessarily a coin until the after the mid-19th century, when the 0.72 tael (c. 27 g) silver dollar steadily became the standard unit of currency. Until our research it was supposed Chén Huà Chéng was called Chen Yuanrong (Lin, 2000, p. 230 & 500). This appears to have been a transcription error that has become mistakenly accepted.

The detailed background and the purpose of the pagoda and its auxiliary Mazu Temple can be learned from two granite tablets, or steles, located in the forecourt of the Wenchang Wang Temple in the nearby village of Wai'an. However, the data given in the steles and on a contemporary map, which describes the pagoda as a

Figure 1: Xiyu Pagoda Lighthouse in a unique Chinese style demolished in 1875.

"Buddhist pagoda/stupa established on Xiyu (Island) by donation" are imprecise. This is particularly so because there is no mention of the small annex, possibly a temple that is shown in the photograph, the only temple in the map being in the nearby village of Wai'an and described as Tian Hou temple (Tiān Hòu gōng). However, the Chinese sources do indicate both the general appearance of the original light and state that the rebuilt structure was only in small ways different to the old. One example of such a difference is that the size of Mazu temple was enlarged, though again we do not know any detail.

Other than these sources for the history of the light, there is nothing known in the Chinese record. We do have western contributions. The earliest is from the late 18th century attesting to the existence of the original structure. On 1st July 1797, passing the island to seaward, headed north, the Briton William Broughton noted (Broughton, 1804, p. 140):

> At 3 h. we were a-breast of Fisher's Island. On the S. W. extreme we remarked an obelisk of stones raised, I should imagine, as a land-mark for the advantage of the junks trading to these islands. In the course of the day there were many of them in sight, making their coasting voyages.

Early in the 19th century the eccentric Pomeranian missionary, Carl Gützlaff, visited the island. He arrived on the *Lord Amherst*, a ship chartered by the British East India Company, on 9th April 1832. In attesting to the existence of the light, Gützlaff revealed an all too common prejudice of the period (Gützlaff, 1834, pp. 163-164):

> We were surprised to find a lighthouse on the highest part of the island, for this is a thing no where seen on all the Chinese coast; perhaps it was built by the Dutch.

Our knowledge of the rebuilt 1828 Pagoda Light's story was further enhanced as a result of two Royal Navy survey exercises in the mid-19th century. In 1844 Captain Richard Collinson in HMS (Her Majesty's Ship) *Plover* completed the first systematic hydrographical survey of the Penghu Islands since a 17th century Dutch survey (Vingboons, 1665). The resulting notebook, draft chart and printed sailing directions (Collinson, 1844, 1844b, 1845) recorded a name for the light and the neighbouring village of Wai'an that still puzzle scholars. The name of the light was Litsitah Wandeng (the early Chinese for a lighthouse was 'tower (with a) night light'), the promontory on which the light stood Litsishan, and of the village near the light Dachijiao (Collinson's Romanization in his Surveying Journal (Collinson, 1844b) says it is pronounced "Ta-chi-kioh" in Mandarin). These names are unknown today and the first cannot readily be translated. The last two characters in the promontory name are probably best translated as West Island, since in Southern China the character for

mountain is also used to mean 'Island'. This name seems still to have been current when our last historical reference occurred, which we shall return to below. The very different to translate village name relates to today's Wai'an only in that both seem to connect to some sort of sheltered anchorage.

Collinson's work also gave a height of the lantern above sea level of 68.6 m (225'). The same height was repeated in the next western reference, which was by another British Royal Navy officer, Captain George Brooker (Brooker, 1859), who visited the islands in the summer of 1858 in HMS Inflexible. His observations, recorded in a new edition of the China Sea Pilot (King, 1861, p. 167), were:

> A fixed white light is exhibited at 225 feet above high water from a lighthouse standing on the south-west extreme of Fisher Island; but as part of the windows are glazed with oyster shells, and the apparatus very rude, it will not be seen much farther off than a mile.
>
> The lighthouse, 30 feet high, was built 90 years ago by subscription, and the expense of lighting is defrayed by a port charge of a dollar upon each junk entering Makung harbour.

We shall see it is almost impossible to reconcile Brooker's height for the structure with what our analysis has extracted from the photograph, the difficulty being in knowing what Brooker measured. This is a typical difficulty with historical sources that we shall return to in Section 2.

The final evidence bearing on the history of the pagoda light comes from a visit to Xiyu Island in 1874 by the American Joseph Beal Steere. Steere was on a five-year global tour, lasting from 1870 to 1875, before beginning a career as a zoologist and paleontologist at the University of Michigan. The purpose of the tour was to collect specimens for the University Museum and in January 1874 he visited the Penghu Islands, including a visit to Xiyu and the pagoda lighthouse. Despite Steere being a scientist, his description of the pagoda light is so bad as to be almost useless (Steere, 1874).

Unaccountably he describes the structure as "a pagoda of four sides and four storeys and about thirty feet in height". Whilst the description of the external appearance makes no sense at all, where the tower's height is concerned Steere seems to agree with Commander Brooker's thirty feet. We shall return to this below for, as with Brooker's data, the problem lies in what exactly was being measured or estimated. Steere also rather vaguely implied that the shrine to Tian Hou, far from being in the annex we see in the 1875 photograph, was in a small room at the base of the tower.

In Steere's very brief account of his visit, he also gave a hint to help us resolve the puzzle of the names given by Collinson. He notes that he visited "Sayson or Fisher's Island". At first blush Sayson is puzzling, but if one places it in the context of the last two characters of Collinson's name for the island, it would seem that what westerners had come to understand was that what today is called Xiyu westemers called Xishan, both having the meaning of West Island (a close look at the second character of the modern name indicates it has the 46th or 'mountain' radical). Pronouncing Xishan as that would be said in the Min dialect spoken in Penghu could well sound like Sayson to a non-Minan speaking westerner.

However, Steere gave us some firm data about the light's historical trajectory since its refurbishment in 1823-1828. We know from Jiang Yuanshu's stele that initially at least the light was under the supervision of the Qing army garrison in Penghu. However, Steere's account reveals that in 1874 the lighthouse keeper was a Buddhist monk. Obviously, this does not preclude continuing army supervision, but it does suggest no regular presence. The second point made by Steere updates the description of the light by Brooker, repeated by King. For Steere specifically states two things. First that there is what he describes as a 'lamp' and second that in the lantern there were glazed, if very dirty windows. This argues quite strongly that since Brooker's day both the light and lantern had been upgraded. Steere gives no specifics about the lamp, but given that he was a westerner and elsewhere in his work comments on 'primitive' arrangements where he finds them, his choice of the word 'lamp' argues that by 1874 something like a contemporary western oil fired Argand lighthouse lamp was in situ.

Steere also gave two bits of data that, within the grossly inaccurate description he gives of the pagoda structure, does match what we see in the photograph taken a year later. The first, which matches data from Chinese sources, is that the structure was built of granite, adding the detail that the granite came from Xiamen in Fujian Province on the western coast of the Taiwan Strait. Given the size of the pagoda, to which we shall turn next, this argues very significant engineering and transport achievements in both 1778 and 1823, in bringing across from the mainland of China several thousand precut granite blocks, some weighing several hundred kilograms, and then getting them carried up to the lighthouse site. We shall turn to some of the structural implications of this in our conclusion.

The final point where Steere adds useful data is where he describes bas-relief religious images on the external faces of the pagoda. That said, his description is as erroneous here as in that of the structure of the tower. By inference from his description of the tower he suggests sixteen bas-reliefs, where the photograph shows only twelve, with no evidence of any missing. He also described what is portrayed as "an image of the goddess of sailors". These bas-reliefs have survived and can be found today in the Cí Hángsì Buddhist temple in Wai'an. Exactly what they depict is a matter of continuing research, but so far what can be said is that the images are all of males, eight seem to be of the Buddha, and four are of lay figures like soldiers and magistrates.

The history of the Xiyu Pagoda Light ended in the summer of 1875. As part of the second lighthouse programme of the Chinese Imperial Maritime Customs Service (CIMCS), it was planned to construct a modern lighthouse where the old pagoda light was standing. The new light, a prefabricated cast iron structure designed by the CIMCS Chief Engineer David Marr Handerson, would seem to have been built in France, shipped to Xiyu and constructed in the late summer and autumn of 1875. It was lit for the first time on 20th December. For it to be constructed, the old light had to be demolished and, we conclude from our analysis, the photograph

was taken shortly before demolition began in the late spring of 1875.

3. Archive research for 3D reconstruction

The discovery of the old 1875 photograph confirmed the existence and appearance of the old 1778 lighthouse as this had been reconstructed in 1823-28. A two-dimensional image, however, does not show dimensions, orientation, or location and cannot obviously reveal either the light's characteristics or the type of lamp, or the materials from which the structure was built. Thus, using modern Revit software, which is powerful in running and keeping high coherence in both two and three dimensional drawings, we have combined data from the photograph, modern geographical sources and historical documents. These have been the keys to a virtual reconstruction of this piece of Chinese and Taiwanese lighthouse heritage. In the paragraphs below we present the raw data.

The dimensions, location and characteristics of the old Pagoda Light from historical sources are very far from exact. The sources are in two broad groups, those in Chinese and those in English.

3.1. Chinese source

These are the steles in Wai'an and in the present day Yuwengdao Lighthouse (漁翁島燈塔) Compound dating from 1778 and 1823, and a presentation, ink-painting map given to Jiang Yuanshu, the Taiwan Prefect who had the 1778 light constructed.

3.1.1. Size

The stele gives three dimensions. The first is that the pagoda stood on a podium five zhang square and that it had seven levels, though the nature of these levels is not specified. They also state that each level, again with no detail, was seven chi high. Elsewhere it is stated that the pagoda as a whole was five zhang high. The zhang was and is a traditional Chinese unit of measure of great antiquity that has a present day value, translated into SI units, of 3.043 m. One zhang was equal to ten chi, which makes a chi equivalent to 0.3043 m. Unhappily in dynastic times traditional Chinese measurements, like their medieval European equivalents, were subject to considerable variation by region and trade. G. R. G. Worcester (Worcester, 1947-48, 1, p. xiv) notes that in his days (1930s-40s) the value of the chi varied from 0.22 m (8.6") to 0.71 m (27.8") and that the *China Commercial Guide* of the day gave over 100 different values for the unit. A realistic estimate would be values for the chi of between 0.27 and 0.34 m (Levathes, 1994. p. 80).

In sum from Chinese sources, we have related only dimensions for the pagoda; there are none for the adjoining building that we can see in the 1875 photograph. And as far as the pagoda is concerned, prudence suggests establishing a minimum and maximum set of dimensions for podium extent and tower height. These would give a podium sided between 11 and 17 m. Using the same bracket of values that would make each floor between 1.54 and 2.38 m high and the ensemble between 10.78 and 16.66 m high. To this we should add the caution that we do not know whether the height of a floor included the roof and finial, where the top level with the lantern was concerned.

3.1.2. Characteristics

As far as the kind and characteristics of the light are concerned, the Chinese sources are unhelpful. The stele tells us that:

> "Glass was installed in all sides of the top floor. The lamp was lit every night inside the lantern chamber in order to shine out to sea for boats." (Lin, 2000, p. 160)

Elsewhere in Chinese sources we learn that the fuel was groundnut oil, which is an interesting comment on 18th and 19th century sustainability, since ground nuts were a staple product in Penghu.

3.1.3. Position and height above sea level

The Chinese sources have no precise data on the height above sea level and the geographical location of the light. The stele states:

> At night, a lighthouse can be seen. It is on the western end of the island's ridge.

This position is confirmed in the ink painting, but this does not locate the light much better than plus or minus 1 km.

3.1.4. Orientation

The stele texts made no mention of the pagoda's orientation. The ink painting presented to Jiang Yuanshu shows it facing south. However, this is unlikely to be a true guide since it is clear that the depiction of buildings is purely conventional. All five main buildings depicted, the pagoda, temples and magistracies, face in the auspicious southerly direction. Of the other thirty buildings, all dwelling houses depicted using a simple conventional image, face south (11), south west (14) or south east (5).

That noted, however, given that traditionally south was the auspicious direction and, if possible, houses faced south for *feng shui* reasons, it may have been assumed by the ink painting's artist that the pagoda would have been built facing south, if no other considerations prevailed (Mak & So, 2015. pp. 83-85; Wang, 2003. p. 50).

3.1.5. Other detail

The Chinese sources offer no substantive description of the structure. The image in the presentation ink painting is a merely conventional depiction of a generic pagoda. There is no mention of any of the features that can be seen in the photograph.

The sources do mention that the pagoda was built of granite, not the local basalt.

3.2. Western sources

Western sources with any quantitative data are entirely from the period 1844 to 1874. They begin with the work of Captain Richard Collinson RN, who was surveying in HMS Plover in 1844 and comprise his notebooks, manuscript chart and subsequent printed sailing directions. Supplementing these are the subsequent editions of the sailing directions in 1855 and 1861, which add some, but not very much further information. None of these sources add greatly to the data from Chinese sources in either quality or quantity.

3.2.1. Dimensions

Here the western sources are remarkably deficient. Only the third edition of *The China Pilot* gives any figure, which was derived from an 1858 report by Commander G. A. C. Brooker. This gave the tower as being thirty feet (9.144 m) high. The problem with this, cognate with the problem with the Chinese data, is that we do not know what constituted the 'tower' that Brooker had measured. Was it the entire pagoda including the podium, in which case the discrepancy between the Chinese and western sources is significant? Or was it only the tower on the podium, which if the podium was three metres or so in height, would bring Brooker's measurement within the bracket we have established from the Chinese sources? We return to this issue with our comments on position and height below.

The western sources are silent as to the number of storeys and as to the footprint of the structure. They do not mention the attached small building that can be seen in the photograph.

3.2.2. Characteristics

Collinson describes the light as being a "fixed white light". That is, there is no flashing or occulting. In all of Collinson's original sailing directions and the second and third edition of *The China Pilot* we read that the light is only occasional, that is, it is not always or even often lit. In the third edition King adds that because the glass in the windows is in part made of oyster shell, the light is partially obscured and is not likely to be visible beyond about a mile.

Steere confirms the obscurity of the light, though in his case arguing that the windows were of glass and that accumulated salt and dust were the cause of obscurity.

The earlier sources are silent on the type of lamp. However, in an extensive caption to the photograph we read:

> The light is one of the 'first order' and never gets out of order, but frequently is not lighted for many successive dark nights. It consists of an immense iron saucepan filled with oil and numerous wicks hanging over its sides.

By contrast Steere describes the light as having a 'lamp', which suggests by 1874 something more sophisticated than described in the photograph, albeit that the latter dates from 1875.

3.2.3. Position and height above sea level

Collinson confirmed the broad location of the pagoda light as given in the Chinese sources. In his journal, he went somewhat further in that he gives a position of the light in latitude and longitude. This is 23º33.6' N, 119º24.7' E. It followed that Collinson is offering a position, derived from sextant observations, purportedly accurate to with one tenth of a nautical mile, so ±185.2 m. Our research team has not managed to adjust this position for differences between Collinson's 1844 datum in Magong Harbour and today's WGS 84. The present day lighthouse's position on the latter datum is 23º33.75' N, 119º29.34' E. The WGS 84 latitude is 0.15 nautical miles (277.8 m) further north than Collinson, which is well within acceptable limits given mid 19th century geodesy. The problem comes with the longitude, which is 4.64 nautical miles (8.6 km) to the east of Collinson's position. Collinson's longitude error is a consistent one. On his chart (Collinson, 1844) he gave the position of his survey datum point in Makong Harbour as 23º32.9' N, 119º30.2' E, that is, approximately 1.296 km (0.7 nautical miles) south and 10.19 km (5.5 nautical miles) east of the Pagoda Lighthouse. Today's approximate values place the same datum approximately 1.11 km (0.6 nautical miles) south and 9.445 km (5.1 nautical miles) east of Yuwengdao Lighthouse. The geographical positions were within acceptable error margins given mid-19th century survey accuracies and were thus relatively the same. In 1844 the longitudes of much of the world outside Europe in relation to the Greenwich meridian were still extremely uncertain, and the establishment of more accurate values for the world's main ports was a project of official hydrographic agencies throughout the 19th century. It follows that we can disregard the datum error and focus on the geographical conformity, which argues strongly that the position of the Pagoda Light was within two hundred or so metres of today's lighthouse compound.

Brooker and the third edition of *The China Pilot* add no more detailed positional data to Collinson. Steere has no better positional data than the original Chinese sources.

Where height above sea level is concerned the western sources have very accurate detail, by implication accurate to ±1' (0.305 m). All give a height of 225' (68.6 m) "above high water". During his survey in 1844 Collinson established basic tidal data for the Penghu Islands by observing a tide pole he had placed in Makong Harbour. His data made the rise and fall of tide at springs 9' 6" (2.896 m) and at neaps 4' 4" (1.32 m) (Collinson, 1855). This suggests that ordinary high water would have been around one metre above mean sea level, so for modern calculations, which use mean sea level to calculate ordinary land heights, the height of the pagoda would have been around 69.6 m.

This introduces a second problem, which is what on the pagoda the Royal Navy officers were measuring. They will have been calculating the height by a vertical sextant angle (α) from a known distance away by observation. This was important navigationally because with a land object of known height, a vertical sextant angle of it gives the distance of the observer from the light ($d = h/\tan \alpha$ where d = distance of the observer from the object, h = height of the object and α is the observed angle corrected for dip). Combined with a bearing observed by compass, the observed distance off by vertical sextant angle will have established a vessel's position. However, navigating at night the only observable entity is the light itself. It follows that the convention that was observed was to use, as the height reference, the centre of the lantern (this is still in practice today for the same reason). It follows that the data we derive from the western sources in this regard is problematic, but most probably gives the height of the centre of the lantern.

3.2.4. Orientation

Here Collinson's manuscript draught chart is significant. First, the chart has a miniature 'view' of the pagoda light from seaward. In the chart conventions of the day, the inclusion of 'views' to help orientate the mariner was very much to the fore (Fix, 2008; Waters, 1989). In an era before cameras, such depictions of the appearance of a coast from seaward were common. An additional object was to aid the navigator in identifying visually prominent topographical features such as tall hills, singular patches

of vegetation, etc. or large, readily identifable built structures like lighthouses. As with Jiang Yuanshu's presentation ink painting, however, such views, despite their embedding in what were intended to be dimensionally exact topographic and bathymetric representations, were every bit as much products of conventions. The 'eye of the beholder' necessarily interpreted what was beheld in terms with which the beholder would be familiar. Thus Collinson's depiction of the pagoda light forces it into what would have been contemporary mariners' expectations of how a lighthouse should be expected to look –as we noted at the beginning of this article, an iconic tower topped by a lantern. Thus not too much should be made of the mismatch between Collinson's miniature sketch and the image we see in the photograph.

What matters here therefore, as with Jiang Yuanshu's ink painting, is to put the view into its context. This is as a view on a carefully observed, representationally exact modern chart. Befitting his status as a professional hydrographic surveyor, and within the limitations imposed by prevailing prejudices, Collinson was aiming at representational precision. In this aim, his depiction of the pagoda can be contrasted with that of the ink painting. Where the latter showed some thirty fine conventionally depicted buildings all facing between south east through south to south west, Collinson's chart is significantly different. He shows some 160-165 buildings of all sorts orientated, as we might expect, all around the compass. There is no conventional detail, merely black marks. That is because navigationally what the observer will see from some distance offshore is the appearance of a block of buildings, further detail is otiose unless a building is sufficiently distinct –as with the Pagoda Light, Makong fort and the Old Dutch fort on the opposite promontory in Makong Harbour –to be a navigational mark in its own right.

With that in mind, we can return to Collinson's depiction of the Pagoda Light as it would be seen from a certain point of view by the mariner. This then makes it significant, despite the conventional 'tower lighthouse' depiction and recalling the importance of representational precision, that Collinson shows the pagoda as facing south with a door visible to the observer. In short, Collinson's chart suggests the structure of the Pagoda light had its entrance facing south. We shall see below how our 3D reconstruction exercise provides a tool to evaluate such a conjecture.

3.2.5. Other detail

The western navigational sources have no other detail. Steere, however, specified that the structure was built of granite from Amoy (Xiamen).

3.3. Summary

These were the data with all their ambiguities, which would be all anyone normally seeking to interpret a photograph would have to go on. What we have learned can be summarized thus:

- The Pagoda Light was built in 1778 and reconstructed to an unknown extent after serious damage 1823-24.
- There was a Tian Hou temple, possibly in a separate building, that was enlarged with the 1823-28 reconstruction.
- The light was situated on the south west tip of Xiyu Island within around 200 m of the present day site of the Yuwengdao Light.
- The light was fixed, fuelled by oil and may have had a modern lamp by 1874.
- The pagoda structure was most probably built facing south.
- The pagoda had 7 levels.
- From ground to top the pagoda on its podium was 10.78 – 16.66 m (5 *zhang)* high.
- The pagoda stood on a podium 11 – 17m (5 *zhang*) square.
- The centre of the light was c. 69.6 m above mean sea level.
- The pagoda and possibly the whole structure was built of granite from Xiamen.

All of these fitted the photograph we had before us (Fig. 1), but none of its uncertain data could either help us decode the photograph or use the photograph to resolve the uncertainties. It was therefore to help turn such ambiguous and quantitatively inexact data into more precise SI units that this research project turned to using modern computer-aided design (CAD) software to develop a testable 3D model using the photograph as the basis and such quantitative data as we had or could derive from the photograph as controls.

4. 3D Reconstruction

As explained above, any reconstruction of the Xiyu lighthouse pagoda is difficult because the building was dismantled more than 140 years ago. General reconstruction methods people use nowadays, such as traditional surveying or laser scanning of substantial ruins or an intact building shell was not possible. Luckily, the detailed 1875 image (Fig. 1) shows the front and side surfaces of the lighthouse pagoda, sufficient to reveal that the structure was bilaterally symmatrical. This fits the context since symmetry, expressing hormony, is the key feature in Chinese architecture. Given the bilateral symmetry around the building's north-to-south centreline the software allowed us to recreate a 360º view of the building's exterior. This was achieved by a simple, step-by-step process:

4.1. Step 1: Rough Modelling

The perspective image of the photograph, which we have established from internal evidence that was taken in 1875 (see below Section 4.3), is the major evidence for the exact appearance of the original Chinese pagoda light. Our first step visually to reconstruct the original was to treat the photograph as if it was a completed 'rendering' derived from architectural plans by the software through the creation of a three dimensional (3D) wireframe. We could thus work as if we were reverse engineering the process, by using the implicit perspective in the photograph to establish the correct block proportions without at this stage being concerned with dimensions. As Figure 2 shows, this was done using the photograph as the background on which block proportions were configured in the perspective mode of the Revit software.

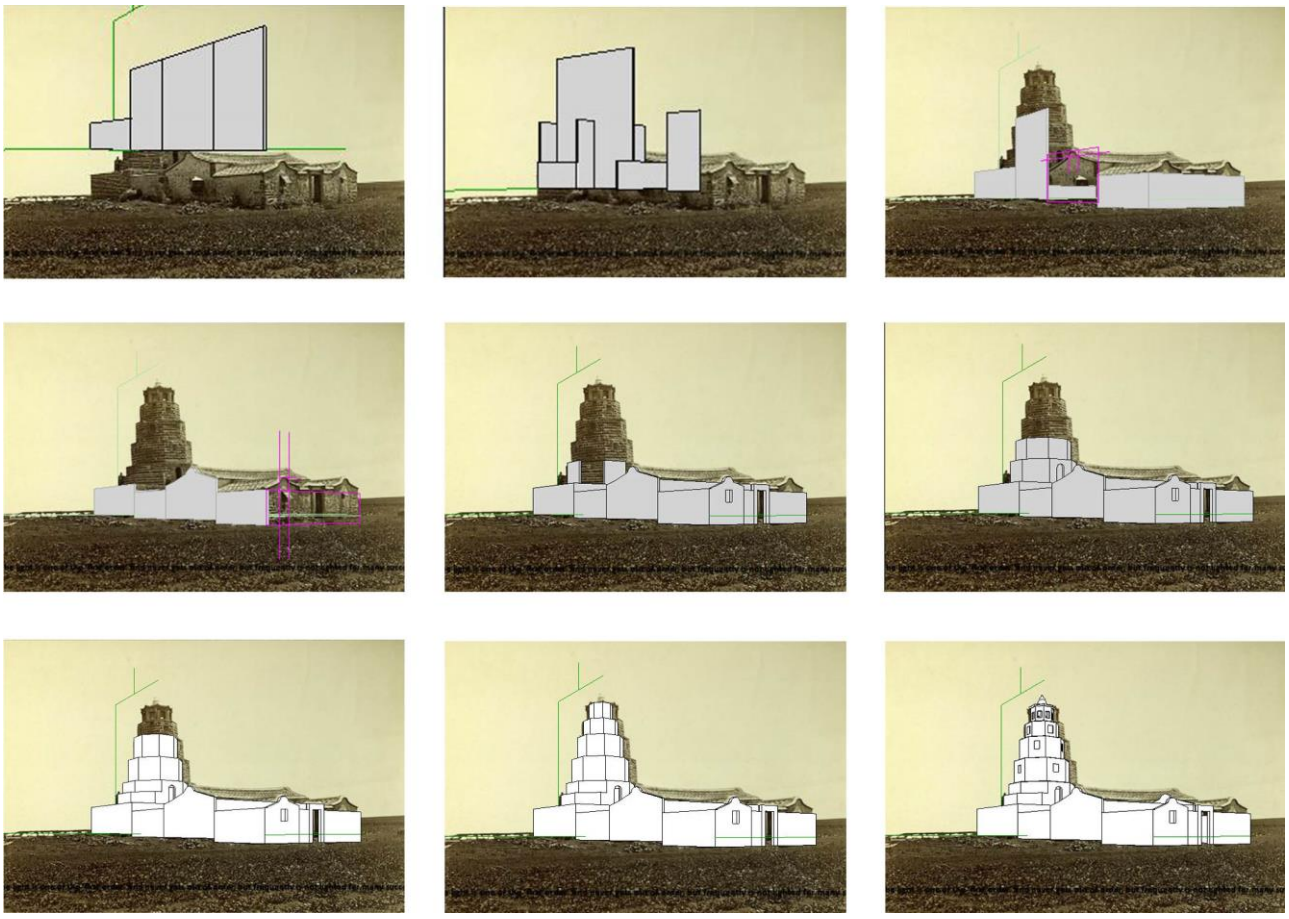
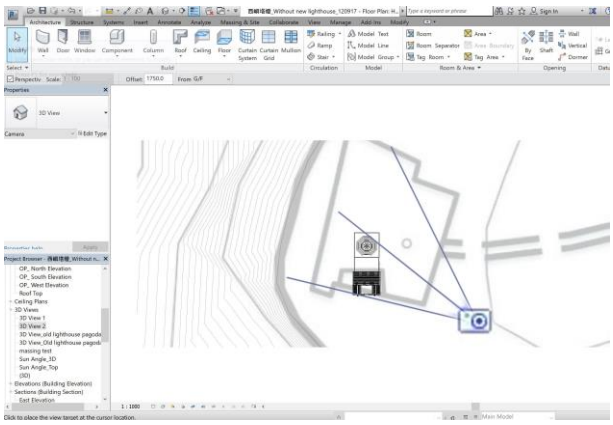


Figure 2: 3D modelling process.

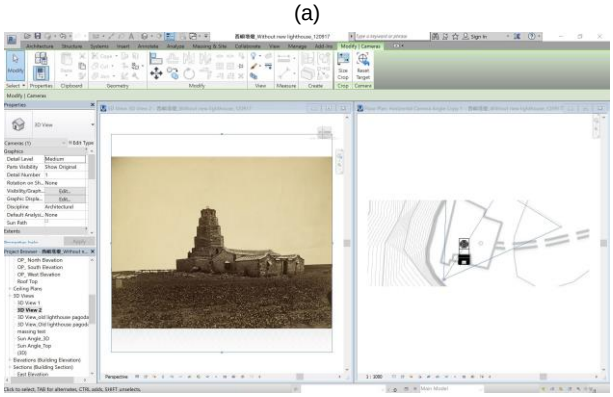
The key first step here, once the method had been decided, involved presetting a similar focal point and perspective view as the 1875 image before the rough modelling stage began. The detail process to set this perspective view in Revit included:

1. Open a plan view from Project Browser.
2. Click camera and set the focal point on the floor plan for generating a perspective view (Fig. 3a).
3. Insert 1875 historical image (Fig. 1) as the background in the perspective window which had been created (Fig. 3b).
4. Open both windows showing perspective and plan in parallel (Fig. 3b).
5. Build rough massing in the perspective view and check if the camera has been set correctly.

Adjust the camera if the rough massing forms are not fitting well to the shape and proportions in the 1875 image and iterate until a good fit is achieved.



(a)



(b)

Figure 3: Setting the perspective view: a) How to set a camera viewpoint in the plan view; b) Inserting the historical image and adjusting the perspective view.

4.2. Step 2: Combining the data from the literature review

Contemporary documentation is always a necessary historical source to complement the insufficiencies of an old image for building any computer model. Thus, the second step for the 3D re-construction was to combine the data from archive research with the fixed proportional model constructed from the photograph. Our initial data for the height and width of the pagoda were taken from the text of the contemporary stele by the Taiwan Prefect,

Jiang Yunshu, described above. It is clear from Section 2 that the historical data is full of ambiguities. Modern SI related values for the traditional unit the *chi* (0.3043 m), assuming the data given embraces the full height of the pagoda from ground to finial, would be 14.91 m and its base would be 15.2 m x 15.2 m. The bracket of values we established as described in Section 2 fall either side of this.

The anomaly we were most concerned with came from Commander Brooker's height of the tower of thirty feet (9.144 m), although as indicated above, we accepted that there were ambiguities depending on what Commander Brooker had been measuring, whether the whole tower ground to finial or some lesser measure as, for example, from podium top of the centre of the lantern.

To help resolve those ambiguities we used the data we had for the height above sea level and data from the modern topographical source Google Earth. This gave us a mean value for the height above mean sea level of the ground on which the pagoda light was built. Since little has changed today since 1875, this was within ±0.5 m of 50 m. Taking the observed height of the lantern as 225' (68.6 m) plus 1 m to correct for the difference between ordinary high water and mean sea level, and assuming that the centre of the light was c. 2 m below the top of the roof finial, this gave a rather startling possible height for the pagoda of 21.6 m, which led us deciding to ignore this approach until we had a more secure ballpark height derived from other sources.

Our initial estimates for the height of c. 16 m, which we fed into the 3D model, when comparing it with the photograph, was that it was too tall and slim. What we needed was some sort of proxy, taken from within the photograph that would act as a transformation rule between the traditional and modern units. This we hoped would allow us both to evaluate the traditional units and try to work out whether the British surveyor's numbers were the product of observational error. We approached this via a number of experimental paths.

4.3. Step 3: Further experimental verification: data estimation from the 1875 photo

One standard route to estimating dimensions is to use a common object with a known upper and lower bound and mean. From the photograph, we used the two human figures that appear in it – one we thought either European or American and the other Chinese – and the known size of important decorative stones (which still exist) set into twelve of the tower's facades (of which six are visible in the photograph). Europeans in 1875 had heights of around 1.67 m, North Americans around 1.73 m and Chinese people around 1.63 m (Roser, 2017). The general variance in the mid to 1870s for average heights is ±7 cm, therefore, working numbers were taken to be 1.55-1.65 m and 1.75-1.85 m for our experiment. We estimated that the arched doorway in the first floor of the pagoda was probably around 2 m to the tip of the arch. Finally, we turned to the bas-relief carvings on the façade of the pagoda. Because these still exist, ranged either side of the main altar in the Wai'an Buddhist Temple, we were able to measure them and, assuming that in the process of their removal not a great deal of material had been lost, we found them to be each ~0.5 m^2. After scaling the 3D model with those values above, it led our research team to use a plinth height of 3.151 m, which helped to calculate the gross pagoda height of around 15 m.

The plinth height, which we counted as level 1, then became our measuring stick by which we could gauge the heights of each of the other levels. Typically for an exercise in vernacular architecture, the levels are not uniform. However, we suspect this was not entirely a function of the loose tolerances of pre-industrial stone cutting and masonry work. We shall return to this below.

The ratios and measurements ignored whatever there may have been that was hidden by parapets, although the photograph suggests there was only a parapet walkway around the lantern level. Exactly how these ratios were come upon we do not know and work is ongoing to see what might be the explanation other than a skilled artisanal mason's rule of thumb.

That said, it is our general conjecture that the massiveness of the podium and the heights and spreads of the levels did represent a rule of thumb on structural engineering estimate of what was needed to create a structure that could bear its weight and stresses, but would do so –unlike the original 1778 design– despite the extremely severe weather to which the Penghu Islands are frequently exposed.

After the comparison of the data from historical sources (Section 4.2. Step 2) and estimation from the 1875 photo (Section 4.3 Step 3), we arrived at a conclusion that the building height derived from the *zhang* and *chi* (14.91 m) and that from the proxies Step 3 (16 m) were sufficiently close, given ambiguities about what the Chinese data measurements included and what they didn not. By contrast we have been unable to resolve the problem of the ostensibly more exact western sextant angle measurements, which is a puzzle on which we are still working on. A height of nearly 22 m seemed unreconcilable with the photograph and our proxies, so we discarded it. Thus, 14.9 to 16 m become the range reference height for scaling the rough software model made in Step 1 (Fig. 4). Our refined model is zeroing in on a total height of just over 15 m (Fig. 5).

4.4. Step 4: Orientation of the Pagoda

After deciding the broad dimensions, orientation was our next research goal. This stage was again a matter of combining our sources and using the CAD software. First we have Collinson's view of the Pagoda Light described above. Compared with the 1875 photograph, this could have suggested that the pagoda had a ground level 'back door' entering the podium, since the photograph clearly shows a main door at first floor level. Rethinking what Collinson may have been seeing in the light of the photograph, however, and recognizing that his small image faces due to the south, suggested the possibility that he was seeing the south elevation from a distance, and that it was unable to distinguish the building in front of the pagoda on its podium, and instead drew what looked like a pagoda with a ground floor entrance. Thus if the structure in the 1875 photograph was aligned north-south because the historical evidence pointed that way, the question became how to establish the truth of such a conjecture.

A second advantage that is provided by the 3D reconstruction relates to understanding Collinson's sketched view of the old Pagoda Light on his draft chart. Our conjecture above is that Collinson was both 'seeing' through the perspective of someone who 'knew' what a lighthouse should look like and doing so probably never having actually visited the site. That latter supposition

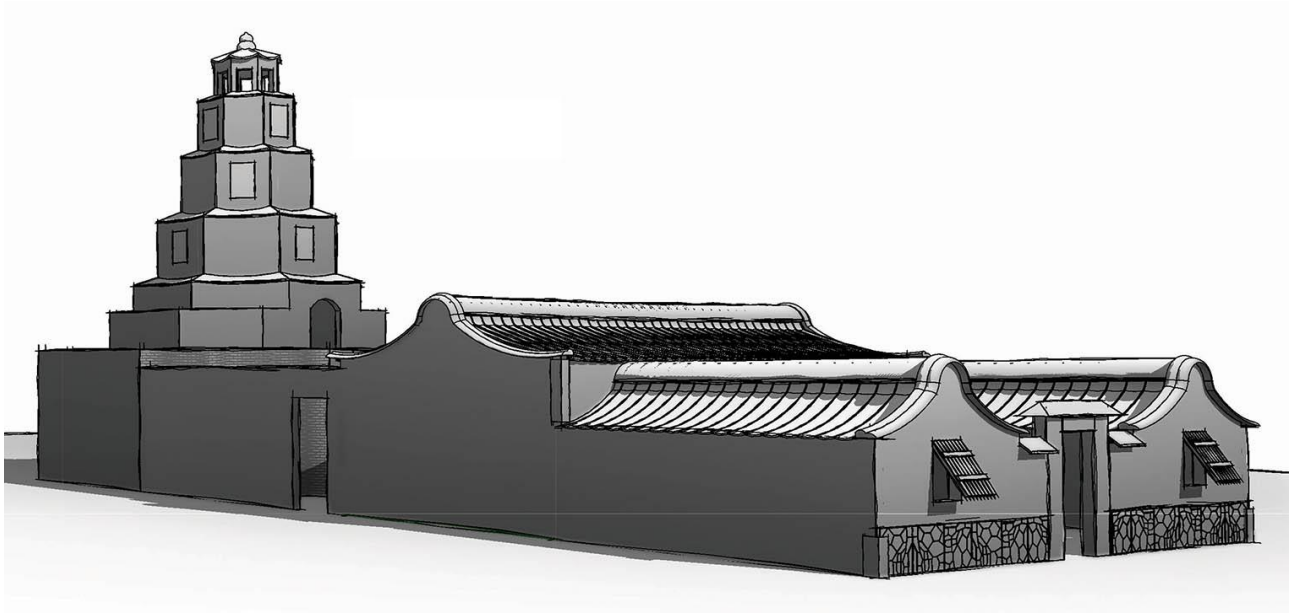


Figure 4: First draft of the modeling process.

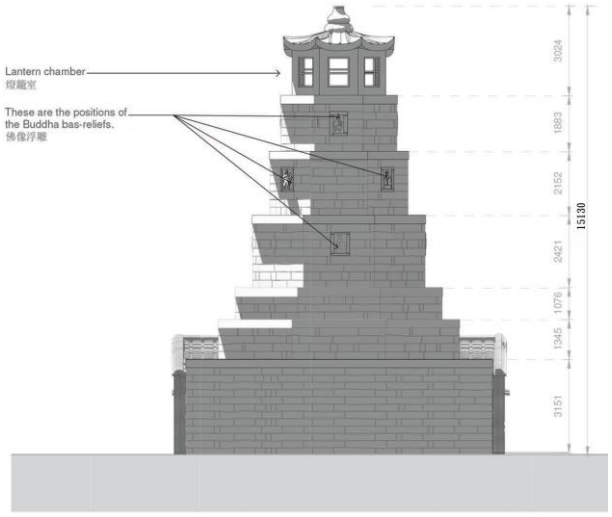
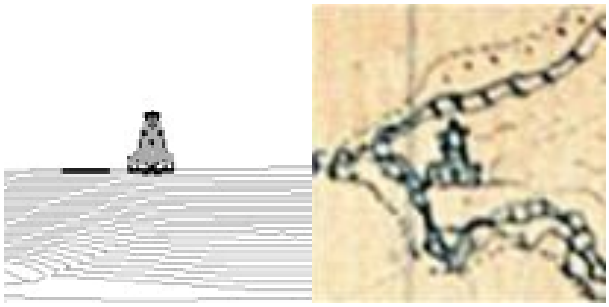


Figure 5: Old light house back elevation showing the building height.



(a) (b)

Figure 6: Old light house pagoda viewed from a distance: a) scaled down image from the computer model; b) Collinson's thumbnail sketch.

would follow from the complete absence of any detailed description in Collinson's Journal and subsequent sailing directions. What the reconstruction allows us to do is illustrated in Figure 6.

With the facility offered by the software, we can change the scale of the image until it more or less matches the small, thumbnail sketch that Collinson put on his draught chart. Suddenly we can see that Collinson's image is far closer to what he could see than appears to be the case at first blush and would have served as a very satisfactory aid to mariners approaching Xiyu Island, who had never visited the waters of the Penghu Archipelago before.

Our use of Autodesk's Revit CAD software also allowed us to check the orientation by matching the shadows on our derived model with the shadows on the photograph. A first step here, again a precursor desktop exercise, used three steps:

1. A crude estimate using the 1875 photograph, a ruler and a protractor, of the likely elevation of the sun given the shadow cast in the photograph. This gave a value of c. 80º with an error factor of ±5º.
2. Using a table of declinations and a modern Global Navigation Satellite System (GNSS position. We worked out a broad date bracket within which the sun would have the roughly calculated elevation in the geographical position of the Xiyu Pagoda Light.
3. Using an almanac we established the range of azimuths of the sun in the position for the range of dates.

Obviously in any given calendar year the sun will have a given elevation over two periods –in the approach to the summer solstice from the spring equinox and in the approach to the autumn equinox from the summer solstice. We were able swiftly to eliminate one of these for the photograph's year, 1875, by recourse to Chinese Maritime Customs sources and contemporary notices to mariners, which showed that the construction programme for the Yuwengdao light would have meant the old pagoda light would have been demolished during the summer and autumn 1875. It followed that our focus was on the spring and our desktop exercise indicated a probable date bracket of late April through early June 1875. The approximate elevation suggested that the sun would have cast the shadows seen when it was within two hours either side of solar midday

(c.1300 h modern +8 standard time), so within the period c. 1100 to c. 1500. Which side of midday would depend on the exact orientation of the structure's façade. Could this be refined?

A valuable part of the Revit package was an inbuilt solar calendar for ensuring the 3D renderings had accurate and realistic shadows. Repurposing this to match a shadow in an image showed the 3D reconstruction placed on a 360º compass (Fig. 7) card below a 180˚ sun path arching overhead, inclined south by the declination of the sun at the chosen date. What followed was a simple trial-and-error exercise to try to find a setting for the software solar calendar within our April to June bracket that had the sun in the orientation that would project shadows on the 3D reconstruction to match the shadows on the photograph. Our conclusion was that the best match was achieved for 11:05 am on 17 April. We also concluded, thanks to the compass card in the Revit rendition, that the only way we could match the shadows at all was if the structure was orientated true south. Any attempt to match the shadows by shifting the orientation resulted in shadows that did not and could not match.

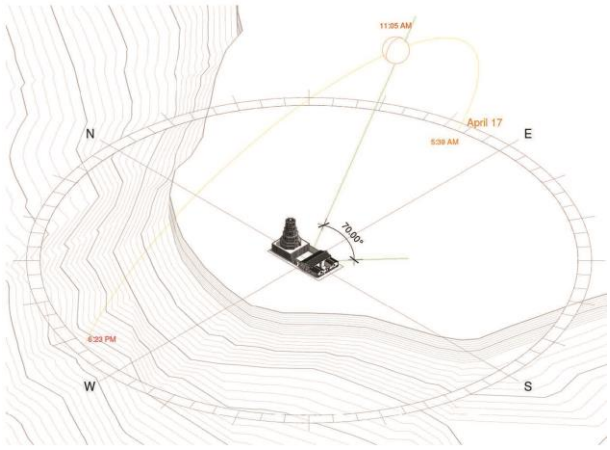


Figure 7: 3D reconstruction placed on a 360º compass.

This broadly technological or scientific analysis also matched what had been suggested to us from our reading, which was that Tian Hou temples in general face nearby sea and, if it is possible, ideally facing south. Often both of these requirements cannot be met and, because Tian Hou is the Goddess of the Sea, priority is given to facing the sea (Mak & So, 2015; Wang, 2003). Happily at the western end of Xiyu the sea wraps the peninsula on three sides (NNE through SW), so it would have been possible to satisfy both criteria and thus have a south facing temple that faced the sea. Our reconstruction indicated that this was what was done.

Figure 8 shows the shadow matching test of our 3D model with the old image (Fig. 1). The experiment was successful in showing that the structure faced south with the added benefit, thanks to the software, of indicating the time and day on which the photograph was taken. This in fact was a somewhat spurious accuracy since on the one hand the Revit solar calendar did not extend back beyond 1900, and on the other because our shadow matching was entirely visual and thus subject to some degree of observer error. The seemingly exact time and day (11:05 a.m., 17th April 1875) is thus to be taken generously with an allowance of a few days either side. Let us say the photograph was taken in mid-April 1875.

Figure 8: Shadow matching test from Revit showing the shadow on 17 April 11:05 a.m.

4.5. Step 5: Location of the Pagoda

The final research question was to confirm the exact location of the old pagoda. Commander Collinson's drawing and his positional data showed it certainly to have been in the general area where today's lighthouse stands. The question in relation to today's structure was exactly where the old tower and temple were. In the 1875 photograph a prominent and puzzling feature is a row of sixteen grey objects to the left of the pagoda. Fieldwork at Penghu revealed that these are identical to the sixteen, radial foundation stone segments that form the base of today's lighthouse. A strong inference, given that each full-sized stone would have weighed at least quarter of a tonne, is that the new lighthouse stands close to where the old one stood. In addition, a review of a plan of the existing lighthouse compound showed an anomaly. In general, the modern compound is an irregular polygon with its axes orientated NNE/SSW and ESE/WNW. However, within the compound two existing walls are orientated, as was the old pagoda, N/S and E/W. It is therefore possible, as local Wai'an belief suggests, that these may be remaining parts of the old pagoda. Our hypothesis, yet to be tested by further fieldwork, is that the old pagoda was located in relation to today's lighthouse compound as in Fig. 9.

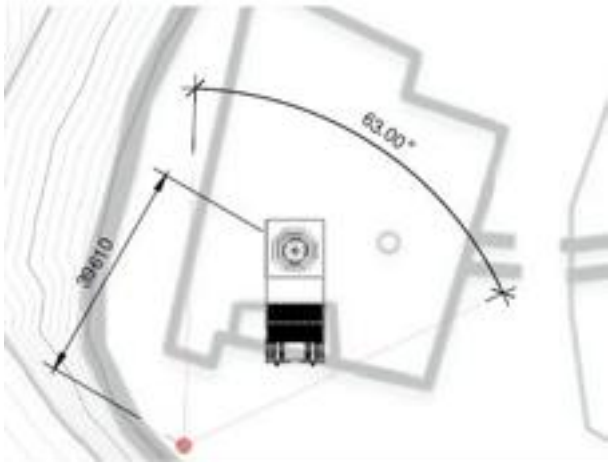


Figure 9: Location of the Pagoda.

In default of fieldwork, but also as a preparation for it, and again using the photograph, software model and software, we sought to ascertain our more precise location of the pagoda; this time again in conjunction with the useful interactive geographical data software Google Earth. Our first step, using Google Earth with cursor

height above sea level switched on, was to derive a rough contour map of the location of both old and new lighthouses. A conspicuous feature of the area is a roughly 10 m high cliff that runs around the location of the lighthouse. With the location of today's lighthouse and hence the location we consider to have been that of the pagoda plotted on the contour map, we were able to use the cliff edge for further analysis. First, if our location is correct, the photograph should show evidence of a clear cliff edge on the left-hand side of the image. We conclude that it does. Second, given the south orientation of the pagoda and temple, it follows that the photograph must have been taken to the south-east of the ensemble. If our location is correct, it must have been possible for a standard variant of what was called a 'view' or 'landscape' lens of 1875, with its c. 70° angle of view, to have been placed roughly south-west of the pagoda such that it could have taken the photograph we have and have been inside the line of the 10 m cliff. Our software analysis shows that this was indeed the case, further supporting our conclusions as to orientation and location.

4.6. The Tian Hou Temple and annexes

Other than mentioning its existence and indicating that it was enlarged during the 1823-1828 restoration, the historical sources are silent on the Tian Hou Temple and its annexes. Although the focus for the team was the pagoda lighthouse itself, it was important that we not fall into the trap of seeing and understanding the lighthouse as if it were, culturally, merely a forerunner to the modern western lighthouse that replaced it. It seems clear that in the context in which the Xiyu Pagoda lighthouse was conceived and built, it was simultaneously and indistinguishably both what today we call an 'aid to navigation' and a religious structure. That is, a lighthouse alone was not sufficient to aid mariners. They needed the protection of their goddess, Tian Hou. The efficacy of the light as an aid to navigation depended on the protection and guidance of the deities, and that protection and guidance was itself dependent on the observation by the temple guardian and the seafarers of the correct rituals.

Thus the temple and its annexes were as much an operating part of the Xiyu Pagoda Lighthouse as the light that occasionally shone in its lantern. Indeed in the eyes of the seafarers who depended on it, the temple may even have been more important than the light. Lights may fail. Tian Hou never sleeps.

In default of assistance from historical sources, the most important element in the project as far as the temple and annexes were concerned was minute and exhaustive attention to the detail of the photograph. By paying attention to every detail that could be elicited from the photograph, a more accurate rendering could be made in the Revit software.

4.6.1. Relative dimensions

Looking closely at the photograph, it seems probable that the additional building, which we assume may have been the temple, although Steere's account argues against this, was wider on its E-W axis than the podium of the pagoda. The small courtyard between the podium and the back (north) wall of the temple begins at its north end flush with the western side of the podium. Careful observation suggests, however, that at its southern end it is not flush with the western wall of the temple. Rather, the wall seems to abut the rear wall of the temple inset slightly –we consider perhaps as much as 0.5-1 m– from its north-western corner. Given that the pagoda and annex would both seem to be symmetrical around their joint N-S axis, it would follow that the pattern will have been repeated at the eastern end, with the east wall of the courtyard running from flush with the eastern side of the podium to the same distance inset westwards along the rear wall of the temple.

4.6.2. Annexes

The annexes are interesting in that on inspection they are not symmetrical around the N-S axis. To clarify that, we may note that the western annex appears to be symmetrical around its N-S axis and has a large, shuttered window symmetrically placed in the centre of its southern wall. The main entrance and the small courtyard it fronts also appear to be symmetrical around their N-S axis. It follows that the east wall of the west annex and the west wall of the east annex are in turn symmetrically distant from the N-S centerline of the courtyard (Chiou & Krishnamurti, 1995).

It is in the east annex that the asymmetry is found. First, it is clear that the symmetry we have so far observed continues to the N-S axis of the eastern annex. The asymmetry would seem to lie with the eastern side of the eastern annex, which would appear to be up to 1 m greater in width than the western side. It is also the case that the windows in the south walls of the two wings are distinctly different in size and in placing.

It follows from this, if the observation is correct – we are continuing to test possibilities using the Revit model - that there are two possibilities. One is that the ground plan of the annexes is slightly wider than the ground plan of the main building, which we are assuming to have been the temple. The other is that when the temple was enlarged in 1823-28, the enlargement was made to the eastern end and, to maintain a continuous eastern wall, the eastern side of the eastern annex was also enlarged. It would follow from this second possibility that the ground plan of the temple and its annexes may then no longer have been symmetrically located with respect to the N-S centerline of the pagoda, but offset slightly to the eastward. However, given the general practices of traditional Taiwanese architecture, in which bilateral symmetry around the N-S axis was a key element in a 'fortunate' building, any significant asymmetry would have been avoided (Chiou & Krishnamurti, 1995, p.548).

4.7. The roofs

The final detail addressed in the modeling by the software was the roofs. The roofs of the temple and its annexes (Fig. 10), whilst they are clearly examples of vernacular Mindong (eastern Fujian) roof construction, are so in a singular way. As with other Mindong roofs of the sort one can see, for example, in the remaining traditional roofs in the Matsu Archipelago, the tiles used have a very shallow curvature. These are laid in the traditional Chinese manner with the lower tile rows concave, capped above a large mortar upstand, creating a deep drainage runnel, by the convex upper tile row. All the individual tiles themselves are laid with some two-thirds of the tile nearest the roof ridge overlapping the tile nearest the eave. The eave end of the upper, upstanding tile rows is finished with heavy, rectangular cement/mortar mouldings with the drainage runnel outlet between them.

Although the annex in front of the lighthouse was also demolished, if local lore about the remaining N-S orientated walls is correct, further site visits including excavations may help clarify detail. To that end, the team reviewed similar traditional buildings in Xiyu, finally visiting Erkan village, an old rural community a few kilometers northwest of the lighthouse, where several older style buildings similar to the annex can still be found in various states of repair. It was clear from the visit that the shape, size and style of the pagoda lighthouse annex and traditional dwelling houses in Xiyu are similar.

Where the Erkan old village house roofs (Fig. 10 & Fig. 11) were concerned, we noticed that the *'yǎng hé'* tile was the major style and this matches what we see in the 1875 photograph. In traditional Chinese architecture, building types were hierarchically ordered. *'Yǎng hé'* tile is related to *'bù'* tile, both plain fired tiles and unlike the glazed *'liú lí'* tile mostly used for official or imperial buildings. We can conclude that the roof style of the pagoda lighthouse used plain tiles, probably in the same colour range of yellow and brown clay that are found in Erkan.

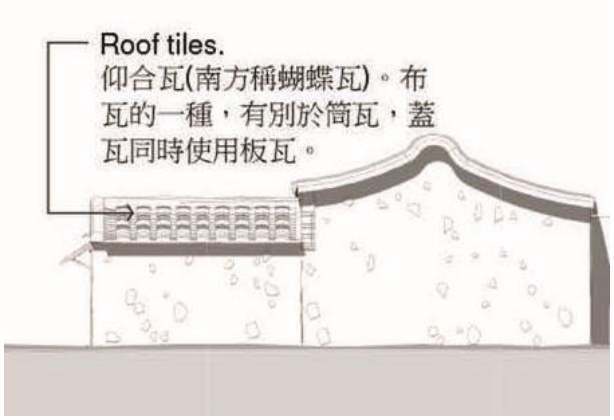


Figure 10: Roof tile called *yǎng hé*.

Figure 11: Existing *yǎng hé* tile in Erkan village.

Where the Xiyu Pagoda Light structure is concerned the singular addition that can be seen is in the manner of implementing the traditional Mindong offshore island practice of weighting down the tiles with stones. Traditionally –as it can still be seen in remaining traditional coastal village architecture in the Matsu Archipelago– rows of naturally shaped stones are placed on the upper layer of tiles to hold them in place. The photograph shows that in the Xiyu Pagoda Light Temple complex a more systematic practice was instituted, creating regular lines of blocks –probably made of cement– across the roof to hold the tiles in place in the face of the prevailing very strong winter winds and occasional summer typhoon.

The roof to the pagoda itself is clearly of a traditional Chinese octagonal, raised eave-tip style. The manner of its construction, however, cannot be discerned from the photograph. The best that can be managed is the inference that the roof may have been both thick and heavy, possibly constructed of several layers of tiles on a heavy timber frame. The roof finial, in the form of a Buddhist water jar, seems nearly identical with a remnant to be found in today's Yuwengdao Lighthouse compound –said to be "the old light"– made of carved granite. If indeed it is the same, or a similarly constructed piece, then clearly the pagoda roof was massive, designed to be hard for even the strong winter winds of Penghu (frequently Beaufort Force 8-10) to dislodge.

5. Additional advantage: 3D model printing

An advantage of 3D software modeling based on a photograph has been that the CAD software not only develops a rotatable, 3D virtual model so that the building can be reviewed from all sides but, suitably scaled, it also provides the input to a 3D printer. We have accordingly been able to print a 3D scale model (Fig. 12) to enable us to see 'into' the photograph to consider additional questions. Mostly these questions are products of a detailed, forensic approach to the photograph itself, above all identifying as clearly as we can not only all that the photograph can tell us, but also being as clear as possible as to what the photograph cannot tell us. Formulating these questions is enhanced by being able to look at the structure, not only virtually but actually, from different perspectives.

Figure 12: Printed 3D model in solid plastic.

Where the photograph is necessarily silent falls into two areas. On the one hand, there are the obvious aspects of the structure that are out of view. Some of these we can infer because the pagoda is a symmetrical octagon. For example, the conclusion as to there being twelve of the bas-relief tablets given six in view. Less obvious, but similarly evaluated, is the presence of two doors from the lantern chamber out onto an upper walkway, marked by protruding curved stones on top of the doorposts either side of the lintels. Such things can be modelled in 3D and the result evaluated from different perspectives helping to answer the implicit question: does what we think we are seeing make sense?

A further silence in the photograph is the access from ground level to the top of the podium on which the pagoda stands and hence to the tower's entrance. Was there an external staircase on the southern wall of the podium in the small courtyard behind the annex? Was the visible doorway the only way into the pagoda? Was the podium solid, or was there a chamber within it with a staircase leading up into the interior of the tower, with the visible

doorway being only an access point to the podium's platform? We do not know the answers, but the 3D model allows us clearly to see the range of possible solutions.

The other area of silence is the interiors of the structures. Neither virtual nor actual 3D model can help in this regard. It follows that the one area of 'reconstruction' on which our technique has at present offered no help is with how the buildings were constructed and what they looked like inside. That said, however, now that we have a 3D model, it is possible to narrow down conjectures by testing them in structural engineering terms. For example, to the north of the existing lighthouse compound is a debris area with a lot of brick remains. If the pagoda had a brick interior and a stone exterior, how might that have been built? Equally, how was movement achieved from floor to floor? Was there an internal spiral staircase? Was it enclosed within an inner and an outer wall as in some traditional stone pagodas in mainland China? Or was the construction simpler with wooden beams, wooden floors and simple ladders between levels? Creating alternative interiors is a step that the Autodesk software is only at the threshold of making, but it indicates the possibilities.

Our starting point here has again been provided by the photograph. One route we are taking to evaluate the design and structural engineering issues of the pagoda lighthouse, as well as to form conjectures as to its interiors begins with an evaluation of the stonework in the photograph. Our estimate of the average height of each stone course is c. 0.28 m. This seems to us to argue stones of an approximate standard thickness of what may possibly have been a Fujian stonecutter's *chi* of around 0.27 m with a stonemason's chi, which included a layer of mortar of around 0.28 m. Level 1, the podium, is twelve courses plus a capstone. The two half-levels with the entrance doorway, Levels 2 and 3, are four and three courses respectively, plus a course constituted by the capstones for a total of eight. Level 4 was equal to the sum of the two half levels below it at eight courses but, plus a capstone. Levels 5 and 6 were each seven courses plus capstones. That would be 44.5 stone courses plus the equivalent of around 11 courses for the lantern, roof and finial for a total 'course height' of 55.5 courses.

If the conjecture of the Fujian stonemason's *chi* is correct, the total of 55.5 courses, divided by ten makes 5.55 Fujian stonemason's *zhang* (15.54 m). This quite elegantly fits the Chinese sources that state the total height of the pagoda to be five *zhang*, though by inference a different *zhang* of some slightly greater value to that of the stonemason's unit. It also gives us a clue to at least one possible aspect of vernacular design and construction in Qing Dynasty Fujian. The hypothesis would be of construction determined by the number of stone courses based on a standard height stone. For looking at the photograph, it seems clear that the stones in the podium were more or less standardized at something like a full stone (c.1.4 x c. 0.27 x c. 0.27 m), a half stone (c. 0.75 x c. 0.27 x c. 0.27 m), a quarter stone (c. 0.375 x c. 0.27 x c. 0.27 m) and an eighth stone (c. 0.1875 x c. 0.27 x c. 0.27 m). The stones in the pagoda, however, are a great deal more varied, sufficiently so indeed as to lead to the hypothesis that they were cut to fit on the spot and that, therefore, there was a resident group of skilled stonemasons from Xiamen engaged in the construction.

That also allows us to approach structural engineering issues raised by the mass of the built structure. Using standard density values for granite of 2.691 tonnes/m^3 a 'full stone' on our estimate is 0.10206 m^3, so 0.275 tonnes. One part of our continuing work will be to come up with a rough count of the number of full, half, quarter and eighth stones used in the construction of the visible external surface assuming symmetry and equivalents in the main pagoda structure. This will enable us to establish a ball park gross weight for the visible exterior. This would then be added, via rough volumetric estimates of the interiors of the podium and the pagoda based on assumptions of how these were constructed. The former we would assume to have been filled with a solid interior of rammed earth and rubble –and this in its turn might argue an excavation pit to look for in the general area of the present lighthouse. Alternatively, again as with some traditional pagodas, there may have been a small room in the podium, accessed from the courtyard between the pagoda and the Tian Hou Temple, from which an inner stair gave access to the pagoda.

Assuming a solid podium, a rough measure indicates from our reconstruction that the podium occupied c. 715 m^3 at approximately 1.52 tonnes/m^3. The pagoda itself we conjecture to have been constructed possibly of the visible stone, with an interior of brick, timber and, in the lower levels at least, if an all brick interior had been deemed too costly, wall filler of rammed earth or rubble.

The Revit software will allow us to model various possibilities based on these conjectures to come up with a gross weight, which we can use to estimate wall thicknesses and then, depending on the solution, iterate to get closer to how the pagoda would most likely have been built to withstand the climatic rigours of its very exposed site.

6. Conclusion

With the recursive, re-alignment 3D modelling process and a comparison of existing historical sources, the final products of this research include a virtual 3D reconstruction model, a physical 3D printed model and a set of architectural drawings of the exterior of the Fisher Island Lighthouse Pagoda that almost certainly never existed and certainly do not exist today. In addition to the dimensions, location and orientation of the pagoda the exercise has also highlighted questions to be addressed by subsequent archaeological fieldwork. Key areas for investigation that have been placed in centre field by our virtual reconstruction exercise are:

- Evaluating the debris field, said to be of brick, to the north of the present lighthouse compound.
- Getting permission to make a sample excavation of the raised area within the lighthouse compound that is possibly the remains of the old Pagoda Light's podium.
- Thoroughly measuring and evaluating the remaining N/S and E/W walls within the present day compound.
- Looking at the many granite stones remaining in the present compound, measuring them and evaluating their locally reputed possible source as 'full stones' in the old Pagoda Lighthouse structure.
- Conducting a survey of the plateau area in the vicinity of the present lighthouse compound to see if there is an excavation pit of c. 700 m^3 from which spoil for the construction of the podium could have been drawn.

- Experimenting with camera positions and lenses to see if the virtual reconstruction conjectured position from which the photograph was taken is correct.
- Devising various models for possible interiors of the pagoda.
- Continuing evaluating the photograph and elaborating structural models of the interior to estimate the general structural loads of the old Pagoda Lighthouse and evaluate the environmental loads of strong winds.
- Continuing fieldwork with the inhabitants of Wai'an to identify all extant remains of the old Xiyu Pagoda lighthouse and fully document them.

Finally, one of the benefits of Revit software is that it can export its digital files in a large range of formats. This has had the inestimable value of enabling us to join a virtual project by the Center for GIS, RCHSS (Research Center for Humanities and Social Sciences), Academia Sinica in Taiwan. They have built a 3D GIS platform, which allows the general public to see via different layers virtual structures, like cities or major buildings, and see the changes that occurred to them through different eras. If our digital model can be inserted into their system, it can take Penghu's lighthouse history back to 1778 from 1875.

Table 1 shows our general findings with respect to the old Xiyu Pagoda Lighthouse, resulting from our desktop and virtual explorations.

Table 1: Conclusions

Dimensions & Footprint	Total Height: 15.130 m^2 Total Length: 25.337 m^2 Total width: 10.300 m^2 Footprint Ground Area: 260.97 m^2
Location	Middle south part of existing old animal enclosure wall of existing Yuwengdao Lighthouse Compound extending south beyond the compound but ending on its north side at about the northern side of the new 1875 light tower
Orientation	Facing directly True South (180°)
Function	Occasional light at night and seamark by day
Materials	Small temple: constructed by uncoursed, random rubble construction technique with ashlar quoins Pagoda: Exterior: constructed of Amoy (Xiamen) granite for the podium cladding and the exterior of the tower; Interior: Unknown Lantern: at the time of the photograph wood framed, glazed windows Roof: Pagoda roof in traditional curved eave style with Buddhist 'water jar' finial and possibly of a different construction to traditional tiles. Temple and annexes Traditional clay tiles on timber. Visible tiling with unusual reinforcement weights.

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