THE DIGITAL RECONSTRUCTION OF A LARGE-SCALE CONSTRUCTION SIMULATED BY USING 3D LASER SCANNING TECHNOLOGY – A BRICK KILN'S CHIMNEY IN KAOHSIUNG CITY OF TAIWAN AS AN EXAMPLE

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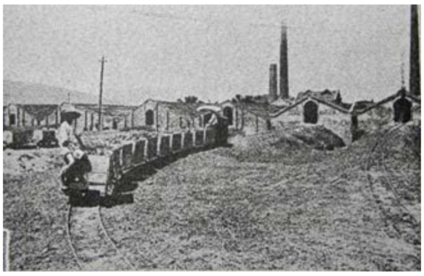
Abstract:
Being the few remaining Hoffman kiln systems left in the World, the Tang-Rong brick factory complex (previously known as 'Samejima ceramic tiles factory' and 'Taiwan brick and tile production company – Takao factory') was gazetted as a National Historic Monument in 2005 mainly due to its technological importance in the Taiwan history.
Unfortunately, a 6.4-magnitude Chia-hsien earthquake hit Kaohsiung area in 2010, thus created significant damage to most of the buildings in the factory. Of which, the damge to the south chimney was the most severe as part of the chimney top portion collapsed during the shake. Emergency rescue work was immediately called upon to investigate the damage extent of the south chimney. Due to its towering height and possible structural instability, conventional surveying method was generally not feasible and advisable, hence 3D laser scanner and aerial ladder were used to conduct the site survey instead.

The point cloud data, consisted mainly of 3D coordinate data and color data (Red, Blue and Green values), obtained from the laser scanning was subsequently converted to compatible data format so as to facilitate the use of 3ds max reversed engineer software. In this paper, a simulated model was created to provide a basis for future conservation work

1. INTRODUCTION

Erected in the year 1899, "Same-tō brick factory (鮫島煉瓦工場)" was the first ceramic-producing factory established in Kaohsiung city of Taiwan during the Japanese occupation period. With the advent of industrial technology, Hoffman kiln was introduced into the factory line in 1913 to increase the production efficiency. Invented and later patented by German Friedrich Hoffmann in 1858, the Hoffmann kiln is generally composed of a series of batch process kilns, commonly used in the production of bricks, roof tiles and other related ceramic products [1]. Being the first of its kind to be introduced in Taiwan, this sophisticated technology soon became a patented product during that period.

During the twentieth century, the factory had undergone several company transitions, namely, from the 1899 "Same-tō brick factory" to "Taiwan brick company –Takao factory (台灣煉瓦株式會社打狗工場)" in 1913, and finally to "Tang-Rong brick factory (唐榮磚窯廠) " in 1958. Having witnessed more than a century of industrial development, the old machineries and facilities could no longer sustain the competition and hence the entire factory officially closed down in 2002 (Figure 1).



1913, The Taiwan brick company [4]

1958, The Tang-Rong brick factory [5]

2002, The Tang-Rong brick factory officially closed down [2]

2008, listed a National Historic Monument [6]

Figure 1: Condition of the Tang-Rong brick factory in 2006

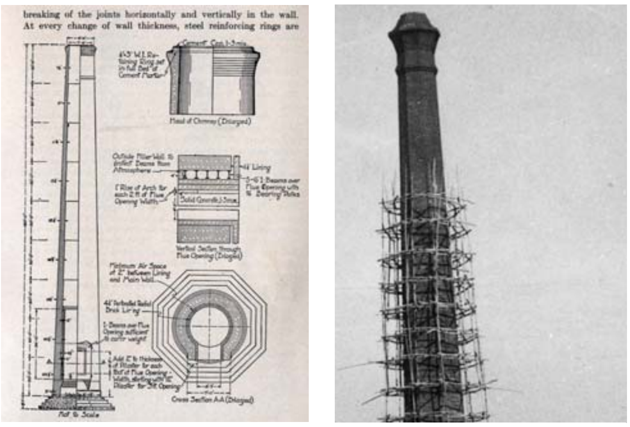


Figure 2: The chimney of Same-tō brick factory was made a traditional western-style method[1]

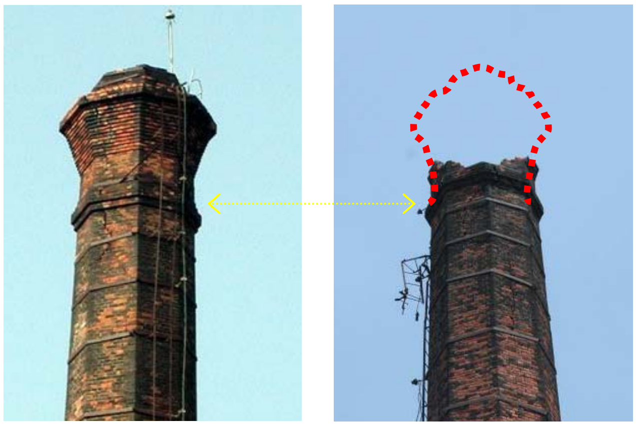


Figure 3: Damage extent of the south chimney top portion before and after earthquake [6]

Recognizing its historic, economic and technological contributions towards the Taiwan history, the entire factory complex, comprised of the Hoffman kiln, the north and south brick chimneys, an administrative office and all the related ancillary building structures, were eventually listed as a National Historic Monument in 2005 [2] (Figure 2). First time repairs urgently in the same year by April, including: 1) north chimney support reinforced; 2) the Hoffman kiln cavity interior protection support and the top-level scaffolding and protective support; And 3) The south side of the chimney of the openings flue by thick 1.5cm, width 50cm plate, produced opening location coating welded by steel plate reinforced. A series of Research and Investigative work and the subsequent reinforcement repairs had been conducted between 2006 and 2007 [3]. Unfortunately, a 6.4-magnitude Chia-hsien earthquake hit the vicinity of Kaohsiung area on 4th March 2010, thus created significant damage to most of the buildings in the factory. Of which, the damage impact of the south chimney was the most serious as part of the top chimney portion collapsed during the shake (Figure 3).

Emergency rescue work was immediately called upon to investigate the damage extent of the south chimney. Due to its towering height and possible structural instability, conventional surveying method was generally not feasible and advisable, hence 3D laser scanner and aerial ladder were used instead to conduct the site survey. In this paper, base on the scanning results obtained, a simulated recovery model was reconstructed so as to provide a basis for future conservation work.

2. RESEARCH METHODOLOGY

3D laser scanner was used to carry out the survey on-site. The point cloud data, consisted mainly of 3D coordinate data and color data (Red, Blue and Green values), obtained from the laser scanning was subsequently converted to compatible data format so as to facilitate the use of 3ds max reversed engineer software. The simulated models generated from 3ds max software was then used as the basis for future conservation work. In this paper, only the results of the south chimney will be presented.

The scanner includes features like a 360° horizontal field of view and a 320° vertical field of view as well as a measuring speed of 120,000 dots/sec. Accuracy range is said to be between 0.6m and 760m for the purpose built targets. Subject to the reflectivity of the surface, the accuracy of these points will vary accordingly (Figure 4). FARO Photon 80 series 3D laser scanner along with Nikon D200 digital camera were used to gather the point cloud data and for the subsequent image overlaying work.

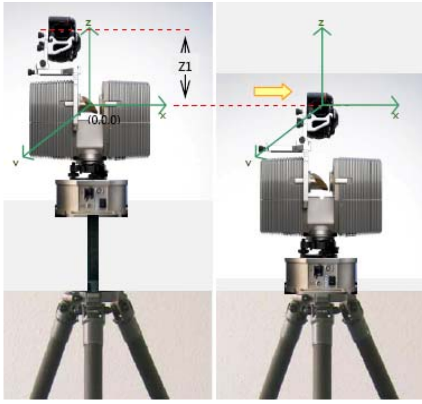


Figure 4: FARO Photon 80 series 3D laser scanner

In this emergency rescue work, the south chimney was subjected to three times of laser scanning, focusing mainly on the scanning of the existing chimney ruin condition, aerial scanning of the chimney's top portion and the affected surrounding area. The ruin chimney was numbered systematically (Figure 5) prior to the scanning exercise, so as to provide ease of reference for the later model simulation stage.

As the total height of the chimney is 34m, hence on-site scanning exercise was divided into two parts: (1) ground level scanning, and (2) high level scanning so as to effectively cover the entire chimney scanning range (Figure 6).

Figure 5: Numbering of fallen brick pieces prior to laser scanning

Figure 6: ground level scanning (left) and high level scanning (right)

3. RESULTS

3.1 The making of the south chimney model

a) Data conversion prior to model making

The 3D point cloud data was subjected to in-plane orthographic projection so as to display the profile, detail and accurate measurements of the 3D chimney. Base on these data, 3ds max reversed engineer software was used to begin the model simulation (Figure 7).

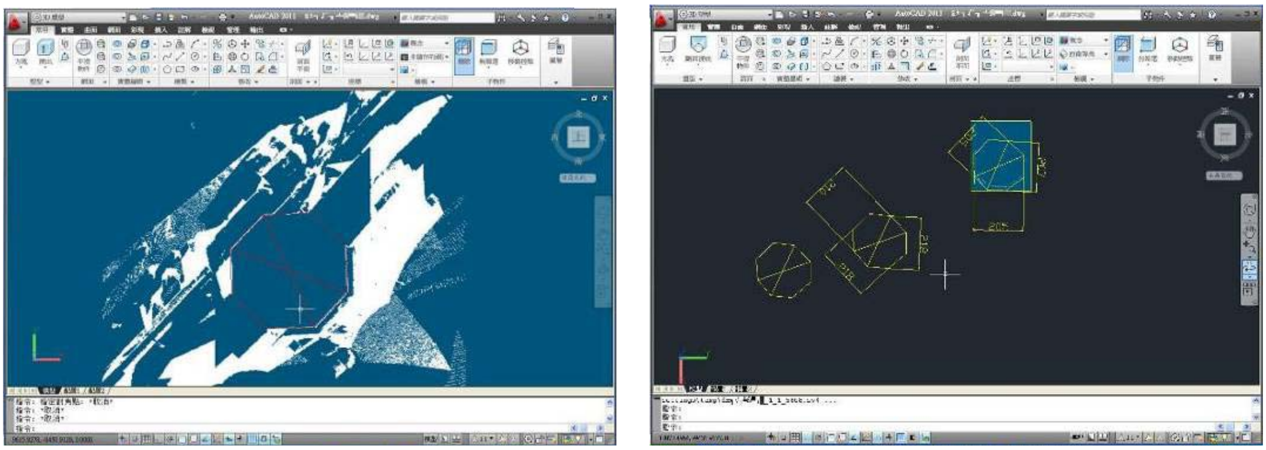


Figure 7: 3D point cloud data of south chimney foundation subjected to in-plane orthographic projection

b) Model regeneration

With the help of various sections and elevation views of the 3D point cloud data, a precise simulation of the 3D chimney model is eventually generated (Figure 8).

c) Model fine-tuning

After the completion of the initial stage of model-making, the ‘raw’ model was subjected to more fine tuning work with respect to the original data to ensure higher accuracy (Figure 9).

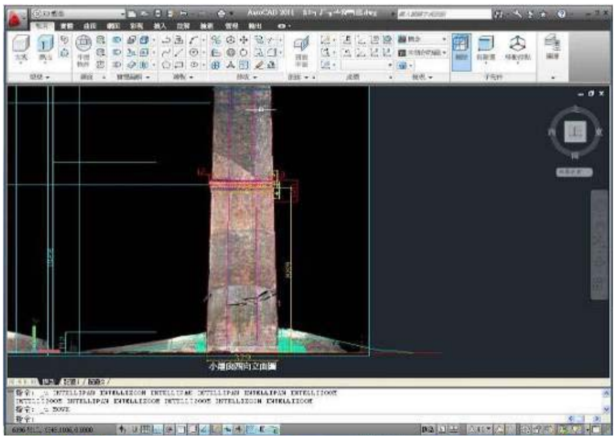


Figure 8: Using the 3D point cloud section data of south chimney to generate the 3D model

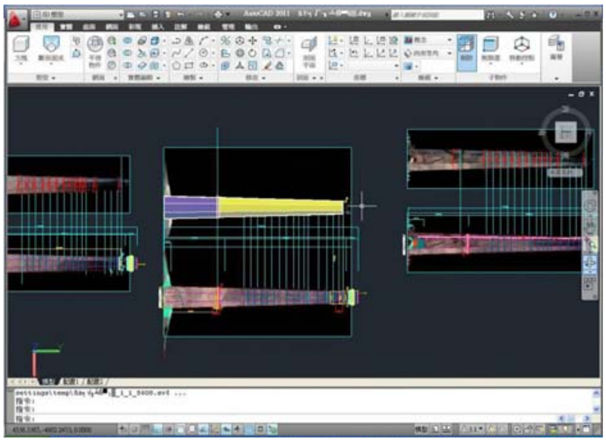


Figure 9: The process of fine-tuning the generated model with the original 3D in-plane orthographic projection

d) Model completion (Figure 10)

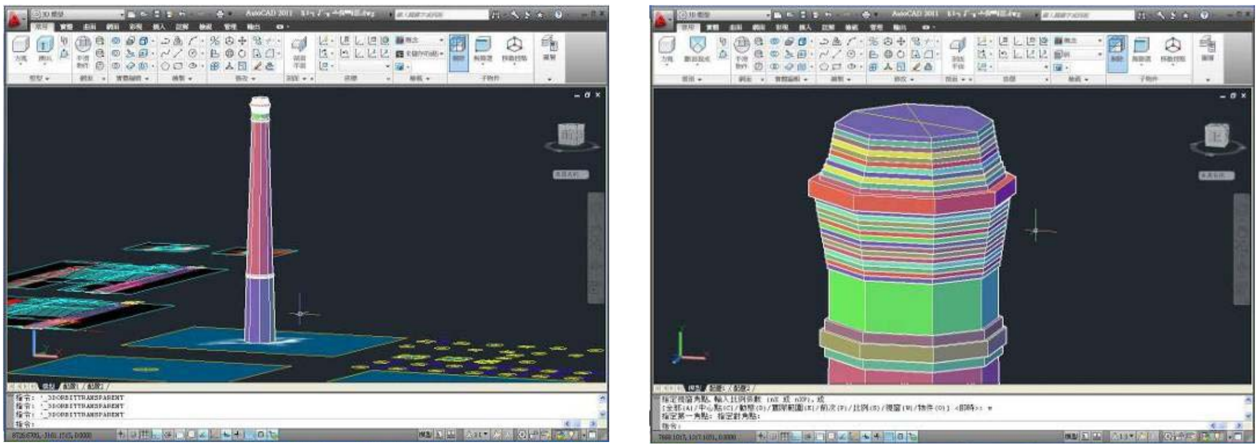


Figure 10: The completed model of south chimney and its close-up of the top portion

3.2 The recovery simulation of the south chimney

In order to obtain a 3D view of the surrounding site condition, rapid digitalisation technique for 3D scanning was used to achieve large scale data within a short period of time. With the help of tri-axes orientation, the exact positioning of the ruin south chimney and its fallen bricks could be reconstructed accurately. Besides conducting an overview scanning of the surroundings, a detail scanning of those fallen bricks found on-site was also carried out. During the scan, our team was able to identify and re-trace back the original positioning of the fifteen pieces of ruin bricks once reconstructed on the chimney top portion. All these information were then fed into the simulation model software to generate a realistic 3D recovery model of the south chimney (Figure 11).

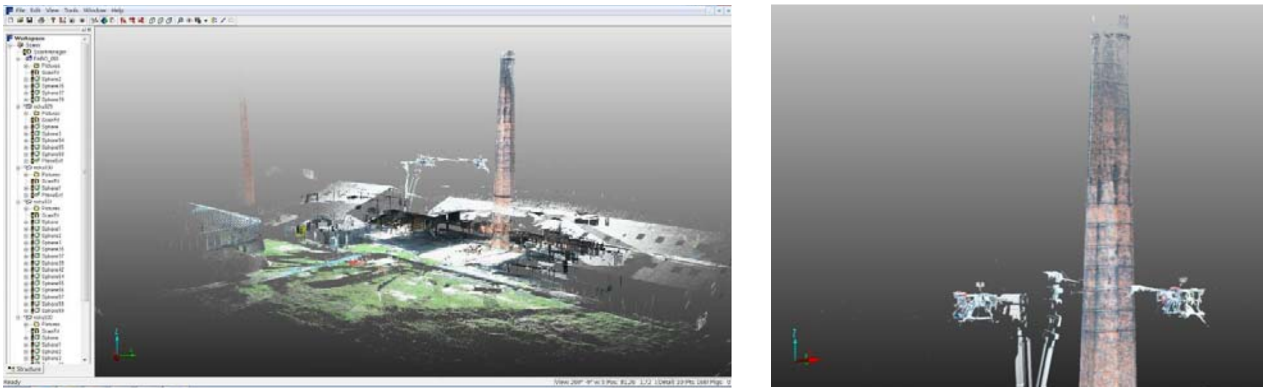


Figure 11: Rapid digitalisation scanning technique was used to obtain the 3D surrounding site view

a) The building and coloration of the ruin brick piece models

The reconstruction of the fallen bricks from the chimney top portion is achieved by using a commercially available reverse engineering analysis model software – RapidForm. With reference to Figure 12 and 13, the reconstruction of a single piece of ruin brick could be achieved via the continual overlaying and compilation of the point cloud data obtained from various elevations and positions. During the on-site scanning exercise, high resolution digital photographs were also taken, together with the use of MESH model construction function in the software (Figure 14), the coloration of the 3D brick model is made possible.

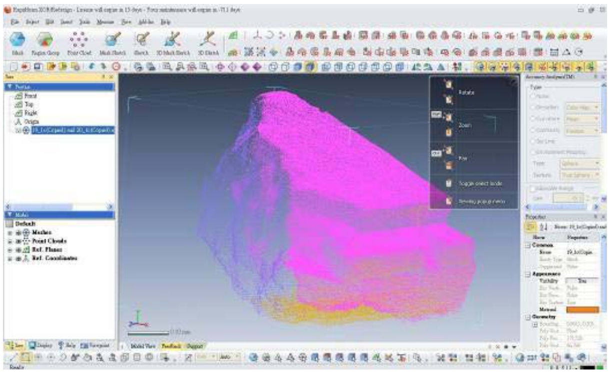


Figure 12: Point cloud data obtained from various positions are represented by different colour tones

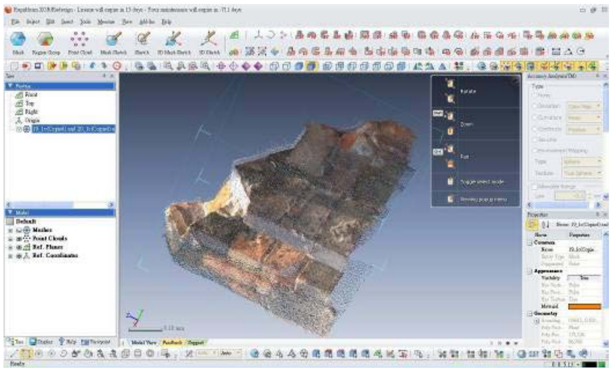


Figure 13: High colour definition point cloud data

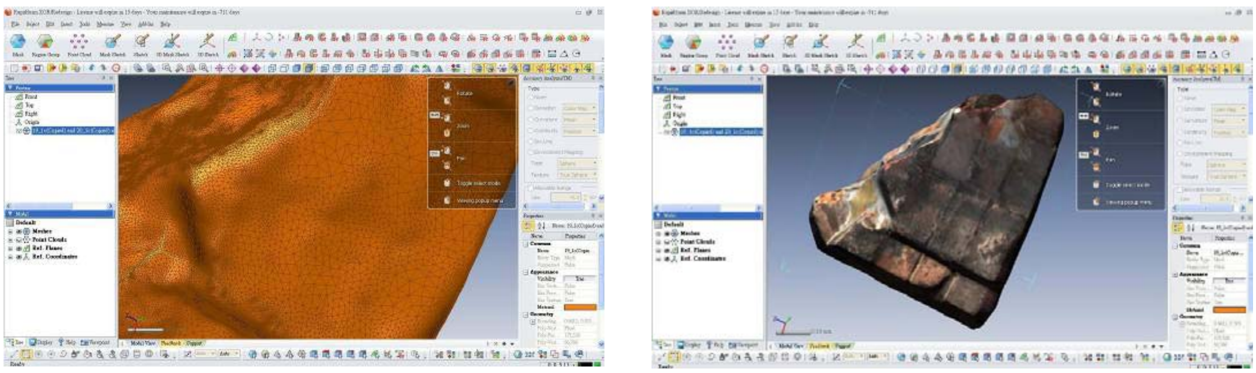


Figure 14: The construction and coloration process of a piece of ruin brick using MESH

b) The reassembly of the 3D smaller brick pieces to the ruin-state brick model

The reassembly of the all the smaller brick pieces into the ruin-state brick model is made possible by comparing the various angles and positions of the 3D scanning data. By using the 3D computer simulation program to continuously run repeated search to puzzle out the missing brick pieces, significant time and energy were saved during the course of reassembly (Figure 15).

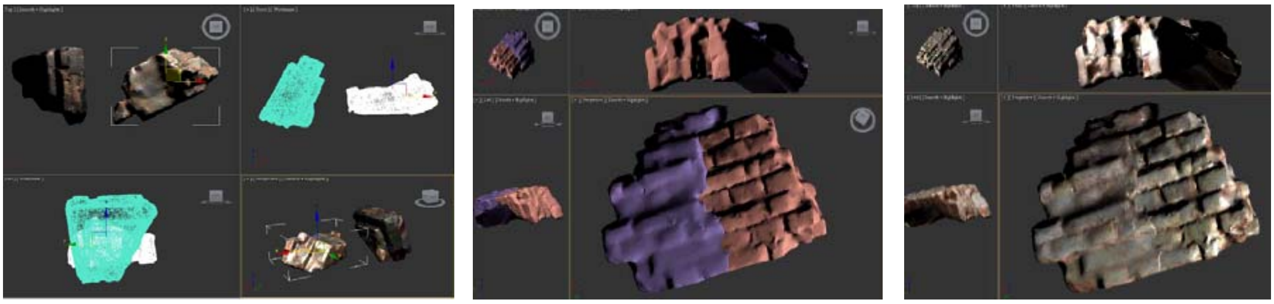


Figure 15: The reassembly of the ruin brick pieces

c) The re-confirmation of the assembled 3D chimney and its exact location

Upon successfully completed the reassembly of the fifteen ruin bricks models, these models were transferred to the overall site model for another round of reassembly. With reference to the existing on-site photographs and measurements recorded during the 2005 investigation, and the point cloud data obtained previously, the exact reassembly of these ruin bricks onto the damage chimney portion was achieved (Figure 16).

Figure 16: Simulated model of reassembly is achieved by cross-referencing with the existing pictures

d) The generation of the reconstructed simulation of the chimney model

Having completed the reassembly of the fifteen ruin bricks and the construction of the south chimney model, 3D MAX software was used to generate the reconstructed simulation of the south chimney model. The procedure is briefly summarised as follows (Figure 18):

- i) Importing of the south chimney 3D point cloud data into the 3D MAX environment
- ii) Importing of the south chimney 3D model into the 3D MAX environment
- iii) Importing of the south chimney 3D ruin brick models into the 3D MAX environment
- iv) Compare the ruin pieces with the overall model with respect to their specific characteristics and ruin patterns etc.

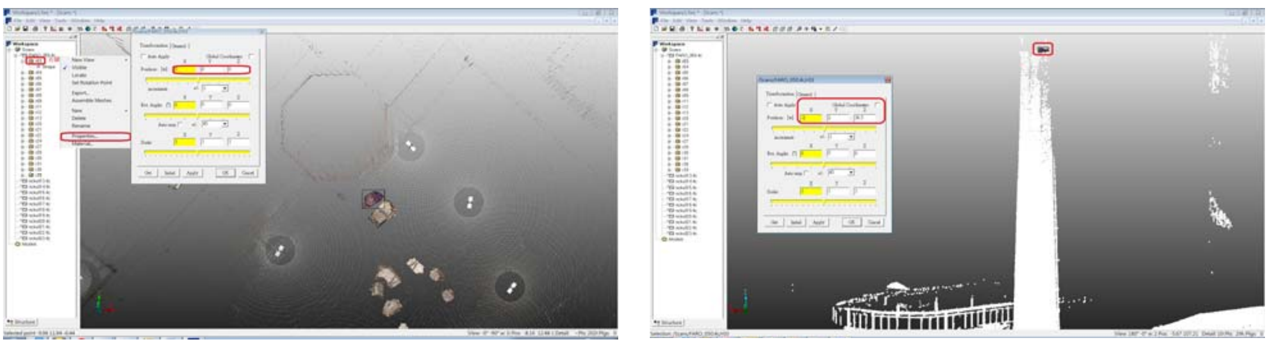


Figure 17: Importing of the south chimney 3D point cloud data into the 3D MAX environment

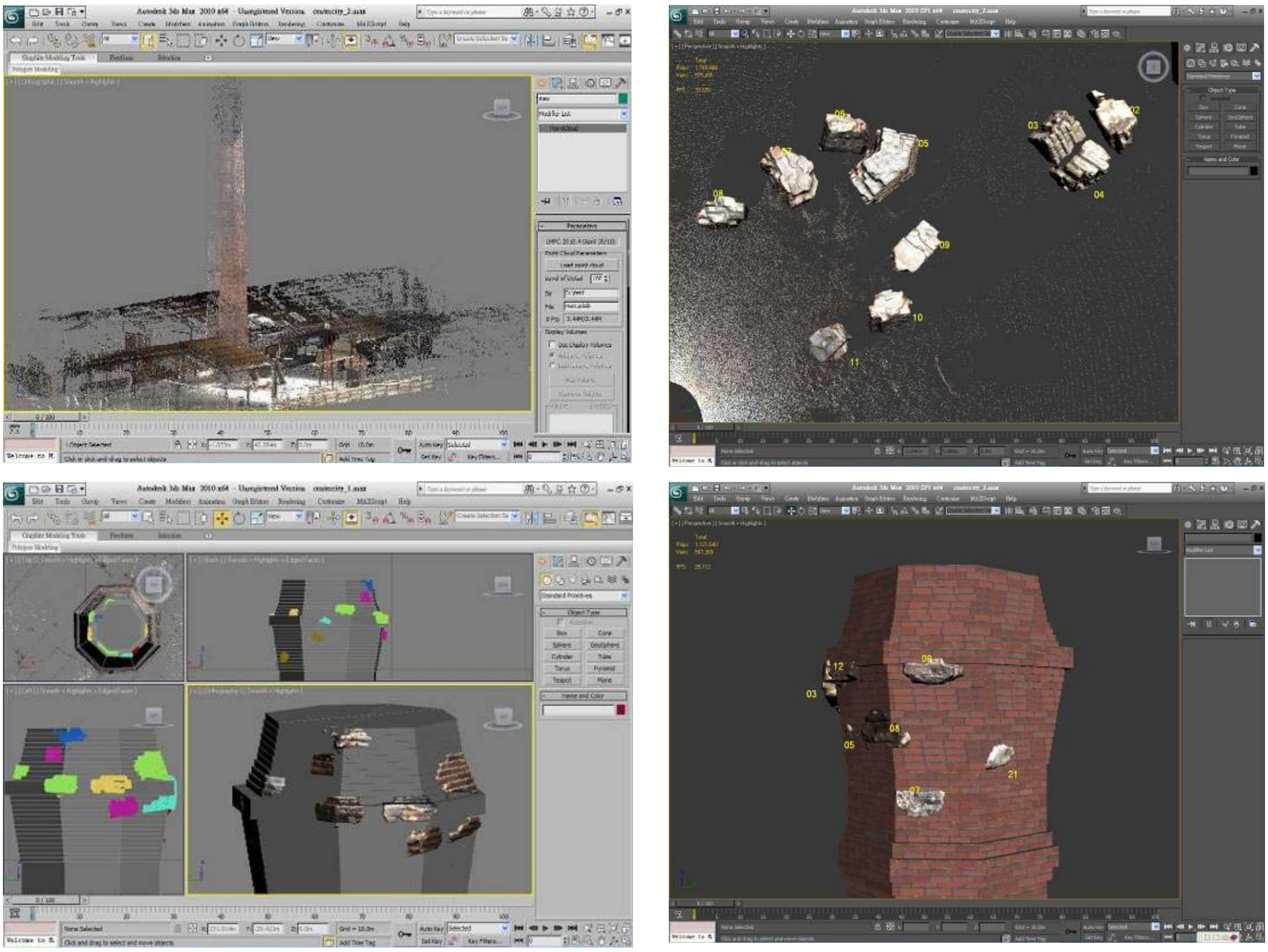


Figure 18: Digital reconstructed simulation of the chimney model

4. CONCLUSION

As a result of the 6.4-magnitude Chia-hsien earthquake that hit the Tang-Rong brick production factory area in 2010, the south chimney was severely damage during the shake. Due to its towering height of 34 meter and the possible of structural instability, 3D laser scanner and aerial ladder were used instead to conduct the site survey. Base on the scanning results, the 3D point cloud data was subjected to in-plane orthographic projection so as to obtain the 2D point cloud data of in-plane orthographic projection. For those identifiable damaged areas, 3D scanning was also conducted so as to carry out effective simulation model for the basis of future conservation work.

In this study, it was found that the south chimney top portion was severly damaged, of which part of it had collapsed during the shake. With the use of the reconstructed simulation model, it was found that the entire process of structural safety evaluation not only could be shortened significantly, the making of informed repair advice could be carried out more accurately.

Besides conducting an overall scanning of the chimney and the surroundings, a detail scanning of those fallen bricks found on-site was also carried out. Having completed the reassembly of the fifteen ruin bricks and the construction of the south chimney model, and together with the cross-referencing of existing on-site photographs, measurements and point cloud data obtained previously, 3D MAX software was used to generate the recovery simulation of the south chimney model. The results obtained from the combination of all the software technologies are generally successful as these techniques increased the level of accuracy in conserving historic fabric to its original position, hence it could be recommended as an alternative solution for future conservation work.

5. ACKNOWLEDGEMENT

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