ICOA1687: DIGITAL RECORDING AND NON DESTRUCTIVE INVESTIGATION OF NYATAPOLA TEMPLE AFTER GORKHA EARTHQUAKE 2015

Subtheme 03: Protecting and Interpreting Cultural Heritage in the Age of Digital Empowerment

Session 3: Application of Digital Technology in Disaster Management Practices
Location: Silver Oak 2, India Habitat Centre
Time: December 14, 2017, 11:15 – 11:30

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Abstracts: As a result of the Gorkha earthquake in Nepal on April 25, 2015 and the aftershock that followed on May 12, a large number of heritage structures in Nepal were destroyed and significantly damaged. In particular, the seven monument zones of the Kathmandu Valley World Heritage Site suffered extensive damage. Out of 195 surveyed monuments, 38 have completely collapsed and 157 were partially damaged (DoA, 2015). This paper focuses on one of the areas with the highest heritage value, the historic city of Bhaktapur. It is recognized as a UNESCO World Heritage Site (WHS) and contains many structures of significant cultural and religious importance for the population of the Kathmandu valley. The understanding of these historical structures is principal for the reconstruction and maintenance of the heritage value of the area. In order to achieve this objective, an interdisciplinary collaboration between local experts, engineers and architects is proposed to understand the traditional construction technology and physical response to the earthquake. This paper develops the study of the Nyatapola Temple in detail. The documentation and evaluation of this temple is achieved only from non-destructive techniques: laser scanning, terrestrial and aerial photogrammetry, geo-radar and micro-tremor dynamic analysis. The purpose of this study is to form the basis for a structural analysis to assess the anticipated future seismic performance of the Nyatapola Temple. The use of digital technology aims to shed light on the structural behaviour of the temple and its response to an earthquake. The particular interest in the composition of the plinth and its articulation with the superior hybrid structure has the objective of understanding the structural behaviour of the whole for the future structural rehabilitation.

Key words: *digital workflows, 3D imaging, georadar, photogrammetry, risk preparedness*

Introduction

Natural disasters like fires, earthquakes, flooding, landslides, storms and hurricanes are among the major causes of loss and damage to physical objects and human lives. These disasters result in an irreplaceable loss in the sector of cultural heritage by damaging the artistic and cultural assets (Taboroff, 2000). The loss to cultural heritage due to disaster further increases in the phase of restoration if proper documentation and information is not available of the damaged heritage structure. Hence, proper documentation and management of information of cultural heritage is important in every heritage conservation project. Likewisely, activities to conserve cultural heritage should persist in a long-run, even after the intervention is completed. This is done through one of many processesses including: documenting and recording site through traditional as well as advanced technologies (Hassini, 2015).

Information obtained from the recording process provides the basis for monitoring, management and routine maintenance of a historic site and facilitates the transmission of knowledge about the heritage places to future generations. Additionally, the International Charter for the Conservation and Restoration of Monuments and Sites (The Venice Charter, 1964) in Article 16 states “In all works of preservation, restoration or excavation, there should always be precise documentation in the form of analytical and critical reports, illustrated with drawings and photographs. Every stage of the work of clearing, consolidation, rearrangement, and integration, as well as technical and formal features identified during the course of the work, should be included.

Recently, the Gorkha earthquake of magnitude 7.8 (USGS, 2015) severely damaged cultural heritage structures in Nepal. According to a survey report by Department of Archaeology, 745 monuments within twenty districts of the Kathmandu Valley and out of Kathmandu Valley were damaged by the earthquake (DoA, 2015). As per record, 133 monuments were totally collapsed, 97 monuments partially collapsed and 515 suffered partial damage. In Kathmandu Valley, 447 monuments were affected by the earthquake and out of which, 83 monuments were totally collapsed to the base (DoA, 2015). In this regard, the use of digital technologies in data acquisition and recording and documentation of damaged and survived monuments could be very substantial.

In particular, the study location, Bhaktapur Durbar Square is a recognized UNESCO World Heritage Site (WHS) containing many structures of significant cultural and religious importance to the people of the Kathmandu Valley. Damage mapping of the heritage structure after the Gorkha Earthquake 2015, within the Bhaktapur Durbar Square monument zone, is shown Fig.1. Sustainable reconstruction and restoration of these heritage structures are critical to maintaining and restoring their outstanding value. To achieve this goal, it is important to work with local experts, engineers, and architects to understand the traditional construction techniques and existing condition of these structures. This study includes the recording and documentation of representative buildings in the historic city of Bhaktapur using non-destructive methods.

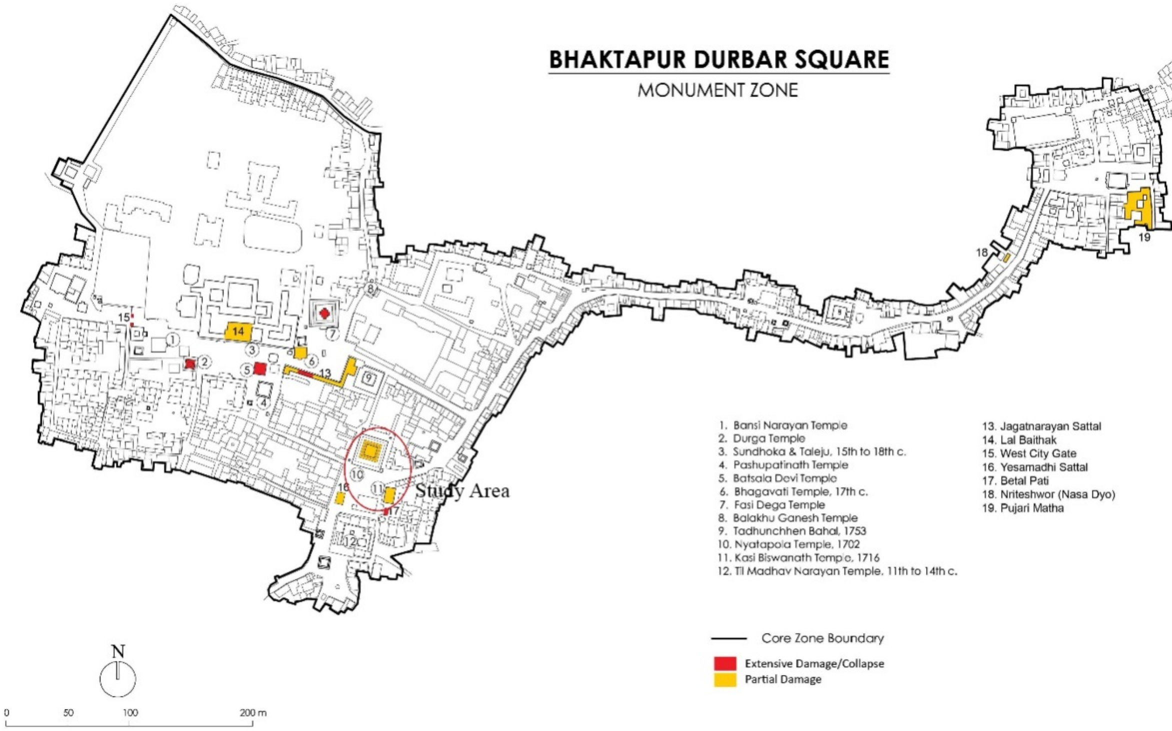

Fig.1- Damage mapping of monuments in Bhaktapur Durbar Square WHS
(Source: Department of Archaeology, Nepal)

The scope and objective of the present work include:

- to record the representative historic structure of Bhaktapur DurbarSquare after the disaster situation;
- to understand and implement of recording techniques to quickly capture the current conditions of heritage structure of Kathmandu Valley;
- to capacity buildup in the documentation and recording of historic monuments in accordance with the guidelines and standards, through on-site training to local professional during fieldwork;
- use of the nondestructive technique to understand the sub-surfacemorphology of the structural elements.

Case Study Site: Nyatapola Temple in Taumadhi Square

Nyatapola temple, located on the northern side of Taumadhi Square, is one of the finest examples of Newari Architecture built in 1701/1702 A.D by the contemporary king of Bhaktapur King Bhupatindra Malla. The temple is dedicated to Goddess Siddhilaxmi which represents prosperity and good fortune and also represents the Goddess of war. It is believed that temple was built to calm down the destructive avatar of the Bhairaba Temple, which is situated in the east south of the Nayatapola temple. This is the only temple that is named after its architecture rather than named after its deities inside the temple whereas in most of the monuments of Kathmandu Valley are named after its deities inside the monument (Shrestha, 2005). In Newari language, *nyata* means five and *pola*mean roof (tier). In this way, the temple is named for its external architecture which simply means the five-tier temple. It is the tallest tiered temple in Nepal built with fire burn bricks and timber, which stands on five huge external exposed plinths.

There were several earthquakes with magnitude greater than M6.0, that shook the Kathmandu Valley in last 300 years. Among them, great Nepal Bihar earthquake of Magnitude M8.0 in 1934AD, and Gorkha Earthquake of Magnitude M7.8 in 2015 are the major ones.[1]. During these earthquake events, it was observed that Nyatapola temple experienced minor damages in the upper tier, but surrounding monuments, e.g. Bhairab Temple collapsed completely during the 1934 AD. In this regard, Nyatapola could be taken as one of the finest examples of traditional construction technology, both from architectural as well as structural stability perspectives, due to its resistance to powerful earthquakes from past 300 years.

Digital documentation techniques and data acquisition

Recording of the proposed monument was divided into two phases: field work and post-processing work. Fieldwork was carried out duringmid-February 2017 for the two weeks of duration. Digital workflow used for the case study is presented in Figure 2.

The digital documentation of the Nyatapola Temple in Taumadhi Square has been carried out using different techniques like Electronic Distance Measurement (EDM), terrestrial and aerial Photogrammetry, Laser Scanning, Record Photography and Hand Measurements etc. Different advanced digital recording tools such as Total Station, DSLR Camera, Laser scanner, Drone, and Georadar were used for the recording of surface and sub-surface data of the structure (Fig.3).

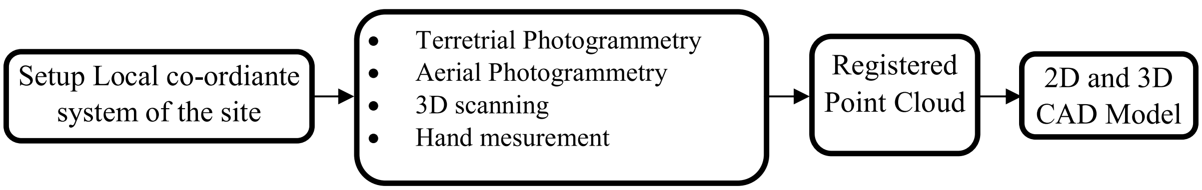

Fig.2- Digital workflow used for the acquisition of data

Set up the local coordinate system:

Leica Geosystem TS06 Total Station was used for setting up control points in local coordinate systems. Standard checkerboards were used as targets and set up in the different location of the surveyed monuments. The local coordinate system, thus generated by the means of total station was retrieved in *.txt and *.dxf format. These control points are required to georeferenced the 3D model obtained from the photogrammetry and laser scanning. In addition, Ground Control Points (GCP) were also established in order to georeference the data obtained from the aerial photogrammetry.

[1] https://www.ngdc.noaa.gov/

Fig.3- Digital equipment used for the acquisition of data
a) Leica Total Station b) Nikon DSLR Camera c) Faro Laser Scan d) Geo-Radar

Photogrammetry:

Close range terrestrial and the aerial photogrammetric process became much easier and more cost-effective in terms of the advantages that can be achieved in heritage documentation. With the advancement in the high-quality digital cameras and UAVs, and due to its affordability, reliability, and ease of use, photogrammetry has become a common workflow in cultural heritage documentation research (Yilmaz, 2007; Remondino, 2011; Rinaudo, 2012; Themistocleous, 2016). The outcome of the photogrammetric process can be used to generate the 3D models, rectified photos and orthophotos, creating an accurate metric archive for analysis (Naci, 2007; Hassini, 2015). Moreover, the productions of photogrammetry can also be used for measuring the deformation of buildings, analyzing the changes, and predicting the future changes, for example, cracks and fissures, with the use of point cloud models generated in the different periods of time (Hassini, 2015).

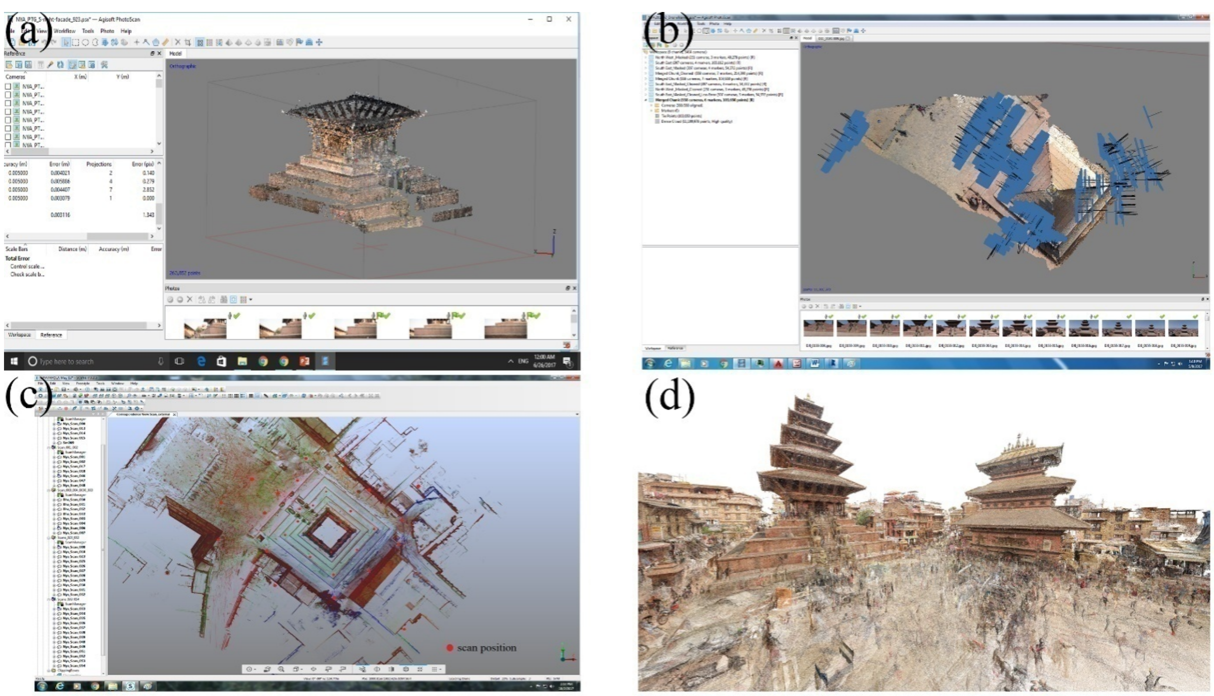

Fig.4- Post-processing in Agisoft Photoscan Pro and Faro SCENE

a) Dense Point Cloud b) Camera position in Aerial Photogrammetry c) Scan Position d) 3D point Cloud

In this case study, both terrestrial and aerial photogrammetrywas used. Nikon D800 DSLR Camera was used to capture the images. Ground-based image data acquisition has limited possibility to capture the data of higher elevation due to the lesser point of view. Hence, in this case, only the data of plinth and ground floor level was able to capture using the DSLR camera. For the higher elevation data, aerial photos using DJI Phantom 4 Drone was taken. Agisoft Photoscan Pro software[2] is used for the post-processing of data to obtain the dense point cloud. For the georeferencing of the data, coordinates of control points obtained from the total station survey are used. Different stage of post-processing in Agisoft Photoscan using photos captured from DSLR camera and Drone is shown in Figure 4a and 4b.

3D scanning:

3D scanning or a laser scanning is a surface recording techniques which uses the laser beam to measure the surface points of the structure. Due to ease of operation and portable, a huge amount of data can be recorded in the lesser time throughout the site. With the advancement is laser scanner series, it enables to capture fast and accurate measurements of complex objects and buildings. Scan data obtained from laser scanning can also be used for the monitoring the displacement of the structure which is an optimal way to discover damage in the heritage structure. Different research work has been carried out for the structural monitoring, evaluation and understanding the building performance using geomatics (Arias, 2005; Sanjose, 2007; Dominici, 2014; Lee, 2015).

For the case study, Faro Focus^{3D} X 330 was used. The scanner can record the objects ranging from 0.6m up to 300m. In each second of work, 976000 points can be recorded, with a precision of +– 2mm. Point cloud data thus obtained from each scan is then registered in Faro Scene Software[3]. Once, all the scan data are registered, then point cloud data is geo-referenced with the measured control points retrieved from the total station to obtain the global position of the registered point cloud. In this case, 50 scans were carried out from the exterior of the monument and 3 scans were carried in inside of the monument (Figure 4c and 4d)).

Geo Radar Investigation:

With the use of photogrammetry and laser scanning process, it is only possible to obtain the surface data of the structure. For the proper documentation and from the aspects of conservation principle, it is important to study the internal morphology of the structure as well. This became crucial when the structure is constructed before the implementation of any building code and there is lack of the historical documentation about the construction technologies.

In this case study, the GPR (Ground Penetrating Radar, also called Georadar) investigation of Nyatopola Temple in Bhaktapur Durbar Square was conducted to investigate the internal construction details of the plinth and superstructure. GPR is a travel time tomography method that works by recording electromagnetic waves which are reflected at dielectric interfaces (generally caused by changes in the material). GPR is a useful tool for investigating details of historic structures, which provides the

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[2] http://www.agisoft.com/

[3] https://www.faro.com/

identification of internal morphology, voids, discontinuities, and damage structural element (Binda, 1997; Binda, 2004; Colla, 1997). The horizontal and vertical faces of each of the plinth were scanned with a 270 MHz GPR antenna, which detects larger targets penetrating to a higher depth. Additionally, a 900MHz antenna, which can detect smaller targets but cannot penetrate deeply as the 270MHz antenna, was used to scan the superstructure of the temple.

The data has been processed in three different formats to obtain the maximum information return. The initial processing of the data was done after processing similar scans at Jaisi Dega. Previous excavations at Jaisi Dega conducted by the Department of Archaeology provide information about the thickness of different layers and construction of the plinth to compare to the scans at this location and to scans of other locations. This excavation data allows us to determine the depth of features and the velocity of the 270 MHz antenna in the plinths. This velocity information is necessary to convert the recorded travel times into depths. This account for the two-directional travel of the GPR signal: down to the object and backs up to the surface so it can be recorded by the antenna. In this case, the velocity obtained is about 0.16m/ns for the 900 MHz antenna and about 0.04 m/ns for the 270 MHz antenna. This is validated against plan drawings of Nyatopola Temple, which estimates the thickness of the walls on the ground floor to be about 1.45 m, travelled by the GPR signal in about 18 ns.

Matgpr was used for the initial processing because this open source MATLAB based program accepts a wide variety of GPR data formats and provides the most flexibility in data processing. The manufacturer's proprietary software, Radan 7 (GSSI), was also used to produce the coloured GPR scan images from the 270 MHz antenna. In general, the data is processed to remove the lead time between the antenna and the arrival of the first reflection, redefining the reference time zero. The average horizontal background is removed and the data is gained (ACG unless noted otherwise) to clarify later arrivals.

Results and discussion

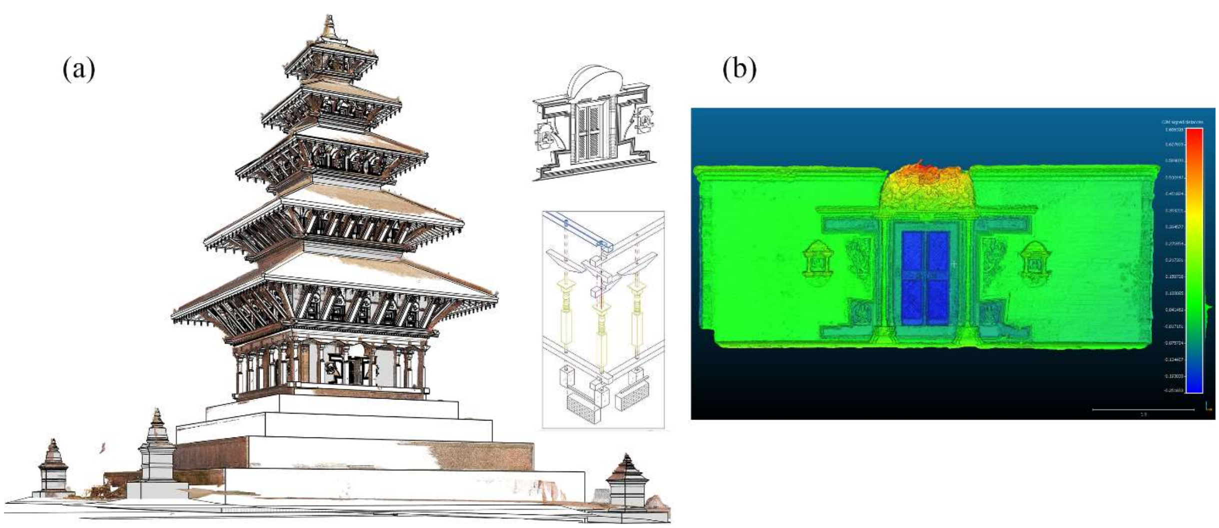

Fig.5- a) BIM Model b) Deformation Analysis of North Facade wall

Point cloud generated from the aerial, terrestrial photogrammetry and laser scan has been combined with using the control points measured from the total station. Autodesk Recap Pro[4] is used to combin the point clouds from different techniques and obtained the consolidated point cloud of the whole structure. These point cloud data were then exported to the different file format to obtain the deliverable. In addition to details of structure in the accessible areas, scan results were also able to capture some of the construction details of monuments in higher level which was not easy to access due to its internal layout. The internal structure of monument is tubular from the inside, without any floor on the upper level and measurement of the upper beams and supporting walls, in higher level was difficult to achieve. These details were able to capture from a laser scan, recorded from the first-floor level. Though, due to a narrow width in the upper areas and obstructing of laser rays by the cross beam, many of the point cloud data in upper level was missing. These were then extrapolated with some of the hand measured data and previously available drawings. The required CAD measured drawings like plans, sections and elevations were produced by manual tracing of points clouds by importing *.rcp file format from Autodesk Recap to Autodesk Autocad. In addition *.pod file was imported to Bently point tool software[5] to generate the high-quality orthoimages. These images can also be used for the condition mapping and trace out of the details of the elements in the structure. Autodesk Revit software[6] is used to develop the Building Information Model (BIM), which is an intelligent 3D model having the physical characteristics of every element. Different pieces of information such as material properties, construction details, height, thickness,etc. can be added to each component of BIM database (Fig.5a).

The data acquired from laser scan and the photogrammetric process is also used for the deformation analysis of the ground floor walls. An open source software cloud compare[7] is used for the analysis. The result in Fig.5b provides the deviation of surface scan point from the reference plane. With this process, rapid initial evaluation of the deformation of the wall in out of plane direction is achieved. This information can be used for development of a framework for the further investigation, analysis and decision making.

With the Georadar scan results in the plinth of Nytapola Temple (Figure 6a), it appears that the plinth construction is similar in the way as Jaisi Dega (Fig.6b). Scans of the vertical faces (lateral scans into plinth) at each level do not present any internal structures of the plinth because the signal does not penetrate deep enough. The lower levels of the plinth have a different penetration depth than the upper levels, but this is the only significant feature of the GPR scans of these faces. The horizontal face scans (vertical scans) also present evidence for a consistent composition of each tier. The scans on the outer and inner edge of each tier illustrate the signatures of the two different paving surfaces present on the tiers. The outer edges of the tiers are paved in large bricks or stones and the inner edges are paved in ordinary mud mortared brick. The plinth appears to be constructed of brick as deeply as the GPR can penetrate (about 1.5m). Additionally, the scans of the inner sanctum are quite similar to the scans of the upper plinth levels, indicating that the core of the plinth is constructed of the same material as the plinth in regular courses of brick. These scans have the same penetration depth (slightly deeper due to shielding from noise provided by the wall of the sanctum) of between 1.5 and 2m.

[4] https://www.autodesk.com/products/recap/overview
[5] https://www.bentley.com/en/products/product-line/reality-modeling-software/bentley-pointools
[6] https://www.autodesk.ca/en/products/revit-family/overview
[7] http://cloudcompare.org/

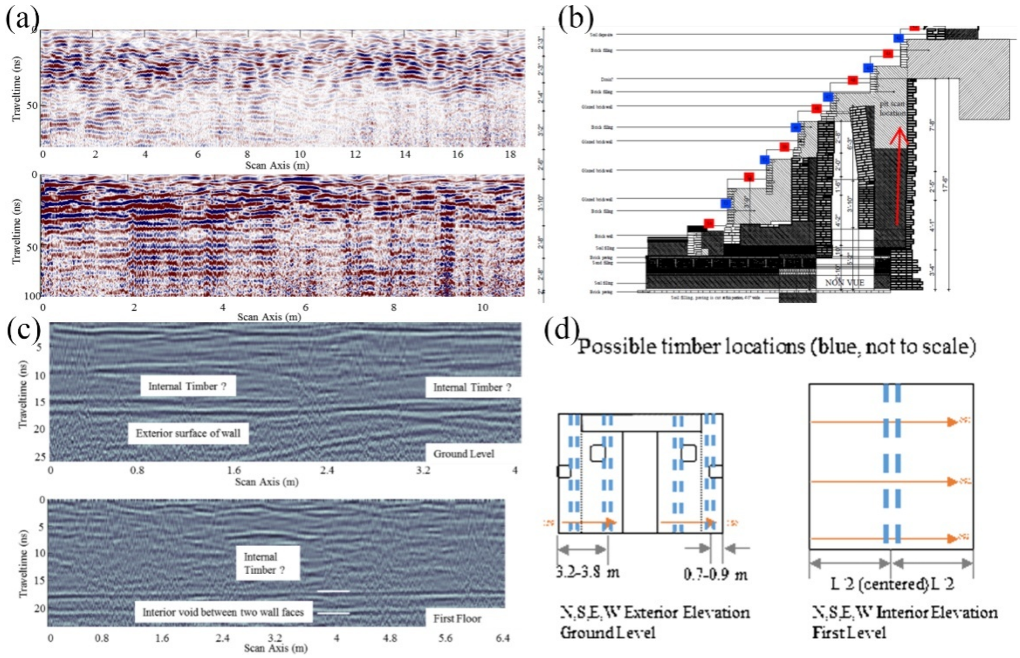

Fig.6- Geo Radar Scan result

a) Radargram of Nyatpola Plinth b) Excavation profile of Jaisi Dega(Source: Anie Joshi) c) Radargram of wall scan d) Schematic diagram of possible timber location in wall

On the ground floor, most faces of the temple present four possible internal timbers. The first occurs close to the outer corners, midway underneath the walls of the first story (70 to 90 cm from the exterior corner). The second occurs closer to the doorway or panelling in the centre of each ground level wall (between 3.2 and 3.8 m from the exterior corner). These are illustrated in the preceding Figure 6c and 6d.

Scans of the first story present a single element near the centre of the scan, likely timber. Because of the uncertainty associated with the uncalibrated odometer and the roll of the wheel in the interior corner, the location of the timber can only be estimated with a range of about 50 cm. Additionally, the size of the timber element cannot be determined from these scans. However, a similar anomaly appears on each face of the temple and likely indicates the same member in each face. This is also shown on the right in the preceding figure. The elements in the first and ground floors are not aligned, though there may be a more extensive internal framing system between these two levels. However, because only the two lowest levels were scanned, it is difficult to know if there is a more continuous system in the upper stories.

Conclusion

Various recording technologies were used in documenting Nyatapola, one of the important heritage structures of the Kathmandu Valley listed in the World Heritage Site.The point cloud data generated from laser scan and photogrammetry were used to generate the 2D drawings,high-resolutionorthophotos, and Building Information Model. These valuable information could be used for monitoring, analysis, and design of restoration plan in the future.

In addition to the surface information, georadar study elaborates the possible subsurface construction morphology (material) of the plinth and superstructure. In spite of some limitation associated with the accessibility to the whole superstructure and higher depth penetration of radar waves, it provides important information which can contribute towards the numerical modeling in the structural analysis.

Acknowledgement

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ICOA1687: DOCUMENTATION NUMÉRIQUE ET INVESTIGATION NON DESTRUCTIVE DU TEMPLE DE NYATAPOLA APRÈS LE SÉISME DE GORKHA 2015

Sous-thème 03: Protéger et interpréter le patrimoine culturel à l'ère de l'autonomisation numérique

Session 3: Application de la technologie numérique aux pratiques de gestion des catastrophes
Lieu: Silver Oak 2, India Habitat Centre
Date et heure: 14 Décembre, 2017, 11:15 – 11:30

Auteur: S. Shrestha, M. Reina Ortiz, M. Gutland, I. M. Morris, R. Napolitano, M. Santana Quintero, J. Erochko, S. Kawan

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Résumé: À la suite du tremblement de terre de Gorkha au Népal le 25 avril 2015 et de la réplique qui a suivi le 12 mai, un grandnombre de structures du patrimoine népalais ont été détruites ou considérablement endommagées. En particulier, les sept zones de monuments du site du patrimoine mondial de la vallée de Katmandou ont subi d'importants dégâts. Sur 195 monuments examinés, 38 se sont complètement effondrés et 157 ont été partiellement endommagés (DoA, 2015). Cette présentation se concentre sur l'une des zones ayant la plus grande valeur patrimoniale, la ville historique de Bhaktapur. Elle est reconnue comme un site du patrimoine mondial de l'UNESCO et contient de nombreuses structures d'importance culturelle et religieuse pour la population de la vallée de Katmandou. La compréhension de ces structures historiques est essentielle pour la reconstruction et le maintien de la valeur patrimoniale de la région. Afin d'atteindre cet objectif, une collaboration interdisciplinaire entre des experts locaux, des ingénieurs et des architectes est proposée pour comprendre les technologies de construction traditionnelles et l'impact physique des tremblements de terre. Cette présentation fait l'étude du temple de Nyatapola en détail. La documentation et l'évaluation de ce temple ne sont obtenues qu'à partir de techniques non destructives: balayage laser, photogrammétrie terrestre et aérienne, géoradar et analyse dynamique des micro-secousses. Le but de cette étude est de former la base d'une analyse structurelle pour évaluer la performance sismique anticipée du temple de Nyatapola. L'utilisation de la technologie numérique vise à faire la lumière sur le comportement structurel du temple et sa réaction à un tremblement de terre. L'intérêt particulier porté à la composition du socle et à sa relation avec la structure hybride supérieure a pour objectif de comprendre le comportement structurel de l'ensemble en vue d'une réhabilitation future.

Mots clés: *Flux de travail numériques, imagerie 3D, géoradar, photogrammétrie, préparation aux risques*