3D Reality Modelling for Heritage Building Preservation and Reconstruction

Jeff Hosken
DCS Spatial Services
NSW Department of Customer Service
Jeff.Hosken@customerservice.nsw.gov.au

ABSTRACT

Stone masonry is one of civilisation's oldest professions, with skilled craftsmen carving stone and rock into intricately shaped blocks to construct buildings and monuments. The trade has remained largely unchanged over time, but what if there was a way in which cutting-edge technology could change the way in which stone masons do their jobs? This was the question put to Spatial Services by the NSW Governments' Heritage Stoneworks team, responsible for the restoration and preservation of NSW's historic sandstone buildings. Spatial Services, through its Imagery and Smart State team, has worked with Heritage Stoneworks to develop a proof of concept to determine whether 3D reality models could be developed with sufficient detail and accuracy to allow desktop-based inspections evaluating what restoration work is required and to assess the quantity and shape of the replacement sandstone blocks necessary to complete the work. Digital 3D reconstructions of real-world assets created through photogrammetric techniques using data acquired from Remotely Piloted Aircraft Systems (RPAS) and other remote sensing technologies are disrupting traditional approaches within the spatial and surveying industries. These 3D reality models form a basis from which assets can be analysed, annotated, inspected, measured and managed. The proof of concept focused on the capture and digital reconstruction for two sites: the Courthouse, Historic Hartley Village, and Fort Denison, Sydney Harbour. This paper discusses the techniques used to complete the capture and processing of these sites through the utilisation of RPAS, Light Detection and Ranging (LiDAR), automated ground control points and structure-from-motion software to create highly detailed, spatially accurate 3D digital representations. Additionally, the challenges and limitations revealed during the capture and processing stages are discussed. The results obtained from this proof-of-concept project demonstrate that the potential for 3D reality models to be effectively utilised to inspect, measure and manage historic buildings exists and show that innovative new techniques can be implemented to enhance the millennia-old trade of stone masonry.

KEYWORDS: *3D reality model, historic building preservation, digital reconstruction, RPAS, photogrammetry.*

1 INTRODUCTION

The ability to protect and preserve important historical buildings and monuments is becoming increasingly pervasive and new technology is being explored as an aid to achieving this by making the process safer, more time and cost efficient and open up further opportunities for these historical structures in the digital age.

The usage of 3D reality models is one such technology that may provide modern-day solutions to the millennia-old trade of stone masonry. Working with the NSW Government's Heritage Stoneworks division, Spatial Services, a business unit of the NSW Department of Customer Service (DCS), undertook a proof-of-concept project to capture imagery and point cloud data over, around and inside both the Historic Hartley Courthouse and Fort Denison by utilising Remotely Piloted Aircraft Systems (RPAS), or drones, a terrestrial Light Detection and Ranging (LiDAR) system and high-resolution cameras.

Highly detailed and spatially accurate 3D reality models of the two sites were produced, which provided Heritage Stoneworks with the ability to inspect the structures, assess the condition of the sandstone structures and undertake site measurements via the desktop without having to visit the buildings and undertake potentially risky and costly manual inspection work.

2 STONE MASONRY AND HERITAGE STONEWORKS

Stone masonry has existed as a trade for millennia, with examples of the trade existing over 6,000 years ago when stone masons began to source, mine, cut and shape stones for the creation of tools, utensils, weapons, monuments and buildings (Dipasquale et al., 2016). To this day many of the original manual techniques and tools developed by stone masons over thousands of years are still being used, although technology is beginning to make an impact and transform the industry through the use of digital saws and 5-axis Computer Numerically Controlled (CNC) cutting machines.

The choice of material for stone masons to construct monuments and buildings has been dictated by what is available locally, and in New South Wales (NSW) this has been sandstone, particularly within the Sydney basin and along the east coast. Sydney sandstone was a commonly used building material during the early years of the Sydney settlement, particularly from the 1790s through to the 1890s, and many of the city's historic landmark buildings have been constructed from it, including Central Railway Station, Customs House, Fort Denison, Sydney Town Hall and Victoria Barracks.

Although Sydney sandstone is an impressively strong material, with high compressive strengths being recorded, the stone is still subject to decay due to weathering, wear and localised stone weaknesses (Pells et al., 1998). As such, there is definitive need to conserve and restore the NSW sandstone buildings. The responsibility to repair and conserve NSW government-owned stone buildings falls to the Heritage Stoneworks team, which is a division of the Department of Planning, Industry and Environment.

The services provided by Heritage Stoneworks, based in Alexandria, Sydney, include sandstone preservation, restoration, replacement and protection, intricate carving and shaping of stone, heritage roofing, heritage refurbishment and maintenance, provision of sandstone blocks, sandstone processing and providing expert advice for construction and renovation projects. To undertake these services, Heritage Stoneworks are looking to modernise their work practices in order to enhance efficiencies around cost and time, but also to increase safety for their workers. As part of this modernisation, Heritage Stoneworks approached Spatial Services to undertake a proof-of-concept project to capture high-resolution imagery of heritage sandstone buildings and process the imagery to produce highly detailed 3D reality models. Heritage Stoneworks wanted to determine if these 3D reality models could be produced with sufficient detail to allow them to undertake desktop inspections of the buildings to find cracked, damaged, worn and weathered sandstone and to undertake accurate measurements of these sandstone blocks to produce replacement sandstone blocks without the need to visit the sites.

3 STRUCTURE FROM MOTION PHOTOGRAMMETRY

Structure from motion is a photogrammetric technique that produces 3-dimensional digital mesh models, textured meshes and point clouds of real-world objects from overlapping photographs. The structure-from-motion process has rapidly developed over the last few years as the algorithms have become more sophisticated and computing power has increased to the point that demand for 3D reality models is growing significantly across a number of industries (Lewinska and Pargiela, 2018).

Structure-from-motion algorithms rely on images being captured with overlap between each frame to allow the algorithms to recognise features in the images and follow their movement through the series of overlapping images to produce a point cloud based on the feature placement in the image series (Ryan et al., 2015). This process is visualised in Figure 1. The resulting point cloud of automated tie points is then reconstructed into a 3D mesh and textured with the images to create a photo-realistic 3D digital replica of the object.

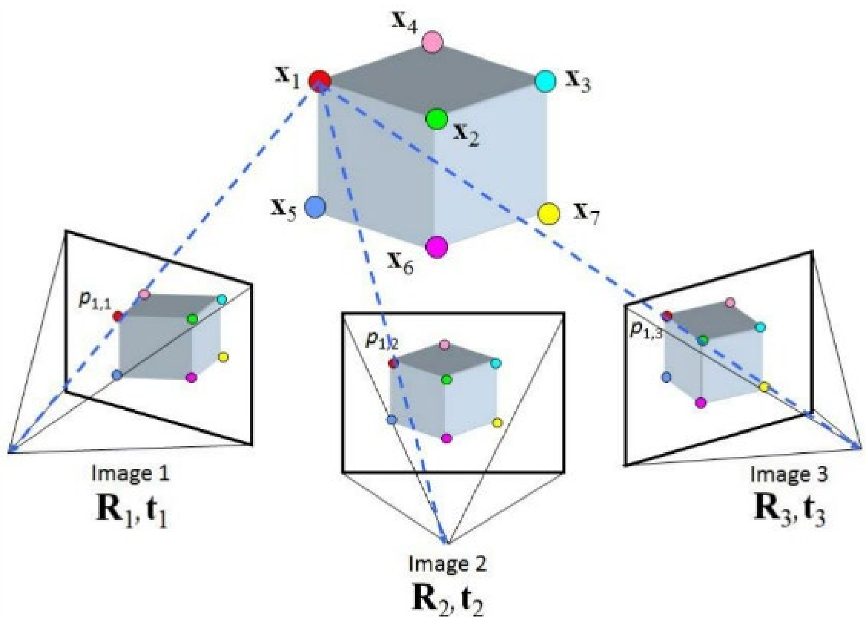

Figure 1: Structure-from-motion process (Yilmaz and Karakus, 2013).

Creation of highly detailed 3D models using structure-from-motion algorithms typically requires at least 80% overlap between each image frame, both forward-reverse and top-bottom overlap, and full coverage of the object being digitally reconstructed. Figures 2 and 3 illustrate recommended imagery capture procedures for undertaking 3D reality modelling of buildings and similar structures. The figures demonstrate that it is important for images to be captured overhead the building with both nadir and oblique camera angles and in orbits around the building with a highly oblique camera angle. These capture techniques provide full coverage and high levels of 3D detail on both the roof and vertical faces of the building being modelled.

Figure 2: Recommended capture techniques for buildings (Bentley, 2018).

Figure 3: Recommended capture techniques for buildings (Bentley, 2017).

4 CAPTURING REALITY

Spatial Services, through its Imagery and Smart State team, undertook the task of capturing two sites for the proof of concept. The equipment and techniques used to undertake the capture and processing of the sites are detailed below.

4.1 Remotely Piloted Aircraft Systems

Spatial Services operates a fleet of RPAS, also referred to as drones, for the purpose of capturing imagery that can be used in the creation of 3D reality models. Spatial Services operates these drones under a Civil Aviation Safety Authority (CASA) approved Remote Operators Certificate (ReOC) and each of its pilots hold a Remote Pilots Licence (RePL).

The primary RPAS platform used by Spatial Services is the DJI Matrice 600 Pro, which is a hexacopter RPAS with a 15 kg maximum take-off weight (Figure 4). The Matrice 600 Pro features several redundant systems (batteries, motors, Global Navigation Satellite System – GNSS, Inertial Measurement Unit – IMU) that enhance the safety of the drone in the air and reduce the risk to those on the ground. Spatial Services' Matrice 600 Pro RPAS carry a Sony A7rIII mirrorless interchangeable lens camera mounted to a Ronin MX gimbal. The design of the Matrice 600 Pro's control system allows for the remote pilot to be operating the drone separately to a second operator controlling the gimbal and the camera, allowing for finer control of the camera's positioning and safer piloting of the drone, particularly in close proximity to buildings.

The drone operates over and around the building, both following semi-automated flight plans and under full manual control, to capture imagery. This imagery is then used within the structure-from-motion software to produce a photogrammetrically derived 3D reality model.

Figure 4: DJI Matrice 600 Pro RPAS as used by Spatial Services.

4.2 Cameras

Cameras are the primary requirement for capturing data to be used in the creation of a 3D reality model. Whilst imagery from any camera can be used, those with a larger sensor size, interchangeable lens capability and higher resolution are typically preferred due to the ability to manually control settings and capture higher-quality imagery.

Spatial Services utilises Sony A7rIII mirrorless cameras, and a Canon 5D digital SLR camera to capture high-resolution imagery of the buildings. The cameras can either be mounted to the drone to capture airborne imagery or used handheld at ground level to capture imagery closer to the ground or building than the drone would be capable of achieving, or for capturing imagery under covered areas or inside the buildings.

4.3 LiDAR

Terrestrial LiDAR systems are primarily used to scan interior spaces for incorporation into the 3D reality model where capturing imagery is technically more challenging and time-consuming than it is for exterior areas.

Spatial Services utilises a Leica Geosystems BLK360 LiDAR scanner for this capture process. The BLK360 captures LiDAR point data in a near-complete 360º sphere, along with photo-sphere imagery for each scan location. This photo-sphere imagery allows the LiDAR point clouds to be colourised with real-world colours. As a result, the point clouds can be realistically integrated into the photogrammetrically derived 3D reality model to create a combined exterior and interior model.

4.4 Ground Control

Spatial accuracy is an important requirement for Heritage Stoneworks as they need to have confidence that any measurements they are making from the 3D reality model are accurate. This accuracy is essential to provide confidence that they can plan restoration or replacement works based on the 3D reality models and be assured that the work undertaken off-site based on these measurements will fit when physically at the site.

To achieve this desired level of accuracy, the Spatial Services team undertakes two processes: setting out Ground Control Points (GCPs) and measuring distances between two points on the building. These measurements can then be used as constraints when processing the 3D reality model.

Propeller Aeropoints are used by Spatial Services as ground control points. The Aeropoints are GNSS-integrated foam targets that can be placed around the building to capture GNSS data whilst the imagery capture is in progress (Figure 5). The GNSS data for each Aeropoint is uploaded to Propeller's online cloud-processing service where Continuously Operating Reference Station (CORS) data is used to determine accurate coordinates for each Aeropoint. These coordinates are then used when processing the data to create a 3D reality model that is essentially tied to known real-world coordinates.

Figure 5: A Propeller Aeropoint ground control point in place at the capture site.

4.5 Software

Spatial Services utilises the Bentley Context Capture software for its structure-from-motion photogrammetry reconstructions to produce 3D reality models. The software processes data through two main stages. The first is aerotriangulation, in which the images are matched to one and the user can input manual tie-points between photos, if necessary, and enter and measure GCPs and measurement constraints. The second stage of processing is the reconstruction of the 3D reality model based on the aerotriangulation results, with the ability to introduce LiDAR point clouds if required. This process produces a 3D textured mesh that can be output in a number of both proprietary and industry formats for use within Computer-Aided Design (CAD), Building Information Modelling (BIM) and Geographic Information System (GIS) software packages.

Spatial Services operates a Context Capture setup of two 'Masters' and ten 'Engines'. The Masters are the user interface component of the software, whilst the Engines utilise computing capacity to process the data. The Context Capture system is scalable, as shown in Figure 6, with the ability to add further Masters or Engines as required to increase processing throughput.

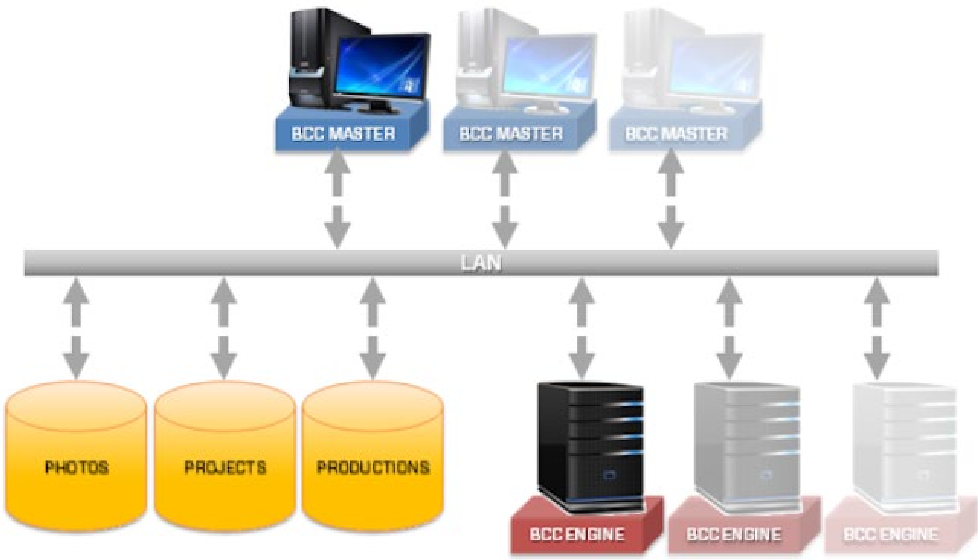

Figure 6: Scalable Bentley Context Capture (BCC) system setup (Bentley, 2019).

5 HARTLEY HISTORIC COURTHOUSE

The Hartley Historic Courthouse, located within the Hartley village on the western side of the Blue Mountains, was built in 1837 from locally sourced sandstone (Figure 7). Today it is managed by the NSW National Parks and Wildlife Service and still stands largely intact. The courthouse building was chosen as the site for the first proof-of-concept 3D reality model as the building is of a relatively small and simple design whilst its proximity to Bathurst allowed easy access for the Spatial Services team.

Figure 7: Hartley Historic Courthouse during RPAS imagery capture.

5.1 Capture

Capture of the courthouse called for the use of the DJI Matrice 600 Pro RPAS with mounted camera and the use of a handheld camera for imagery capture. The BLK360 was utilised to capture LiDAR from inside the courthouse and Propeller Aeropoints were used for ground control.

The RPAS was set up to undertake several semi-autonomous flights overhead the courthouse building and surrounding area (Figure 8). These flights consisted of a series of north-south and east-west oriented flight lines with the camera directed to face at nadir (straight down) and at an oblique angle for each set of flight lines. This imagery capture provided for complete coverage of the building and surrounding areas and is typically sufficient to produce a 3D reality model. However, the extra level of detail required of the model by Heritage Stoneworks necessitated the capture of additional RPAS-based imagery captured through manual flight with the drone flown at a lower altitude and around each of the sides of the building. This capture technique produces very-high-resolution imagery of the sandstone walls of the courthouse building and therefore provides Heritage Stoneworks with the detail required to see cracks and other imperfections in the sandstone. Over 700 photos were captured from the RPAS for this project.

Figure 8: Aerotriangulation results showing computed point cloud and location of nadir and oblique images captured from semi-autonomous RPAS flights.

The images captured from the drone were supplemented with imagery captured from a handheld camera. This was necessary due to the presence of an enclosed entrance at the front of the courthouse, which the drone could not fly under, and the inability of the drone to capture high-resolution imagery of the eastern corner of the building as it was obstructed by a tree. The handheld imagery was used to provide the required detail within the model of these areas. Figure 9 illustrates the positions (green points) of all photos used to complete the aerotriangulation of the imagery data.

Additionally, the BLK360 LiDAR scanner was utilised through all of the internal rooms of the courthouse to create a 3D point cloud of the interior. 55 scan locations were required to complete the interior scanning, the results of which are documented in Figure 10.

Finally, 10 Aeropoints were set up around the building to provide ground control points. In addition, a number of measurements around the building with a tape measure provided data to use for checking the accuracy of the 3D reality model.

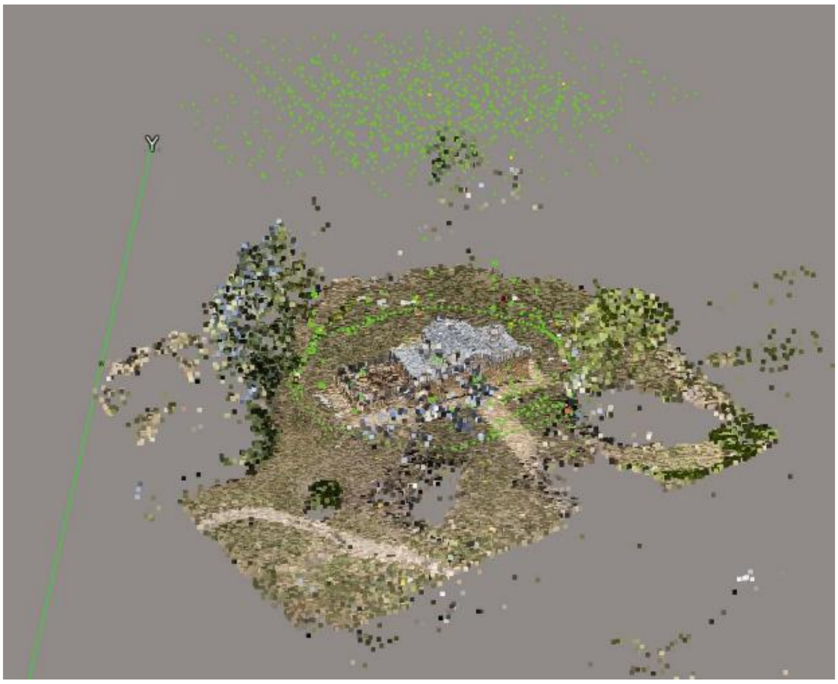

Figure 9: Aerotriangulation results showing computed point cloud and location of manually flown oblique RPAS images, handheld images and nadir and oblique semi-autonomous RPAS capture images.

Figure 10: LiDAR point cloud of interior scans, top-down view.

5.2 Processing

The processing of the captured data involved loading all the imagery into Context Capture, along with the positions of the Aeropoints, and the internal LiDAR point-cloud data (imported after post-processing and scan registration had occurred using Autodesk ReCap Pro). Manual measurement of GCPs occurred first, with each of the Aeropoint targets being selected in a number of the images that it was visible within. This allowed the aerotriangulation process to occur with the results being spatially located to their real-world position and to a high level of accuracy.

With the aerotriangulation computed satisfactorily and the RPAS-based and handheld images successfully merged together in the results, the LiDAR point cloud data from inside the courthouse was then integrated with the data. This process allowed Context Capture to create a textured 3D mesh that brings together the imagery and point cloud data to create a seamless exterior-interior reality model of the Hartley Historic Courthouse.

The final resolution of the reality model was 0.5 mm to 7.6 mm, with a total of 32.8 gigapixels. Figures 11 and 12 show views of the completed 3D reality model of the Hartley Historic Courthouse site.

Figure 11: Hartley Historic Courthouse 3D reality model, front view.

Figure 12: Hartley Historic Courthouse 3D reality model, rear view.

6 FORT DENISON

Fort Denison is an island fortification located in Sydney Harbour, 1.4 km to the east of the Sydney Harbour Bridge (Figure 13). The fort was constructed from 8,000 tonnes of Sydney sandstone with construction finishing in 1862 where it served as a military garrison and military fortress designed to protect Sydney Harbour from attack by foreign vessels. Fort Denison was selected as the second and primary site for the 3D reality proof of concept as Heritage Stoneworks are commencing restoration works at the site, allowing the model to be compared against works being undertaken through the more traditional method.

Figure 13: Fort Denison, Sydney Harbour.

6.1 Capture

Data capture of the Fort Denison site occurred over four days with the complexity, air traffic considerations and the weather conditions of the site requiring substantially longer capture time than that necessary for the Hartley Historic Courthouse. Fort Denison is located within restricted airspace managed by CASA, and as such flight approvals were required before Spatial Services could undertake RPAS flights of the site.

The flight profiles required to capture the imagery necessary for the production of a highly detailed 3D reality model called for overhead flights to be conducted in a north-south and east-west grid pattern with both nadir and oblique camera angles set. Additionally, the complexity of the structure necessitated a lot of manual flights at low level around the entirety of the fort to ensure that imagery capture was complete with the resolution and overlap required. In total over 5,000 photos were captured from the RPAS over the four days. In addition to this airborne imagery, over 5,000 further handheld photos were captured, both on foot and from the water. Figure 14 shows the location of each photo position (yellow points) used during the aerotriangulation of the data.

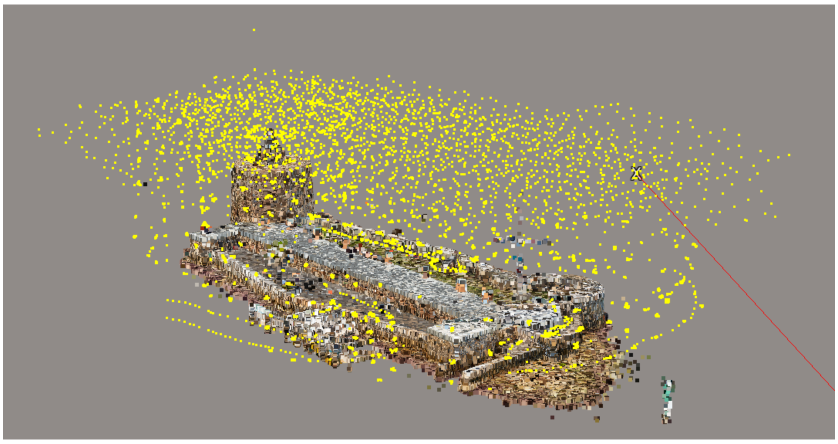

Figure 14: Imagery capture locations, Fort Denison.

The interior structure of Fort Denison is complex, with a row of interconnected rooms on the lower level of the site in addition to the 3-level tower structure with each level connected by a narrow spiral staircase. This complexity introduced challenges with the internal scanning of the site using the BLK360. It was necessary to scan the lower room section and tower separately. The narrow staircase sections within the tower meant that scan-to-scan point cloud registration was difficult to achieve and necessitated small distances between each of the scan locations, which in turn increased the time taken to complete the scanning process. In total, 93 scan locations were required to complete the internal scanning of Fort Denison.

20 Aeropoints were located around the site during each day of capture to provide GCPs. The GNSS data collected from the GCPs was post-processed through Propeller's cloud processing service using the Fort Denison CORS station belonging to CORSnet-NSW (e.g. Janssen et al., 2016; DCS Spatial Services, 2021).

6.2 Processing

The processing of the Fort Denison data proved to be extremely complex. This was due in part to the complexity of the site itself but mainly due to the sheer number of photos that were captured. As a result, the processing had to be undertaken in several stages, the first of which was to measure GCPs in a number of the nadir and oblique images captured through the semi-autonomous overhead flights. These images were then run through the aerotriangulation process to produce what effectively became a baseline aerotriangulation result that did not contain data from any of the higher-resolution manually flown oblique images.

The oblique images were processed in groups determined by their spatial location around the site. Coordinates were derived from the baseline aerotriangulation data for each of these image groups, which allowed them to be accurately merged with the baseline data following an aerotriangulation. Once all of the separate oblique image photo groups were merged with the baseline model, the LiDAR point cloud data from the internal scans could be imported and the final 3D reality model of the Fort Denison site produced.

The final resolution of the reality model was less than 7 mm, with a total of 301.7 gigapixels, and 7,154 photos and data from 93 LiDAR scans incorporated into the final model. Figures 15-18 show views of the completed 3D reality model for Fort Denison.

Figure 15: Fort Denison 3D reality model.

Figure 16: Fort Denison 3D reality model, outside view with GCP visible.

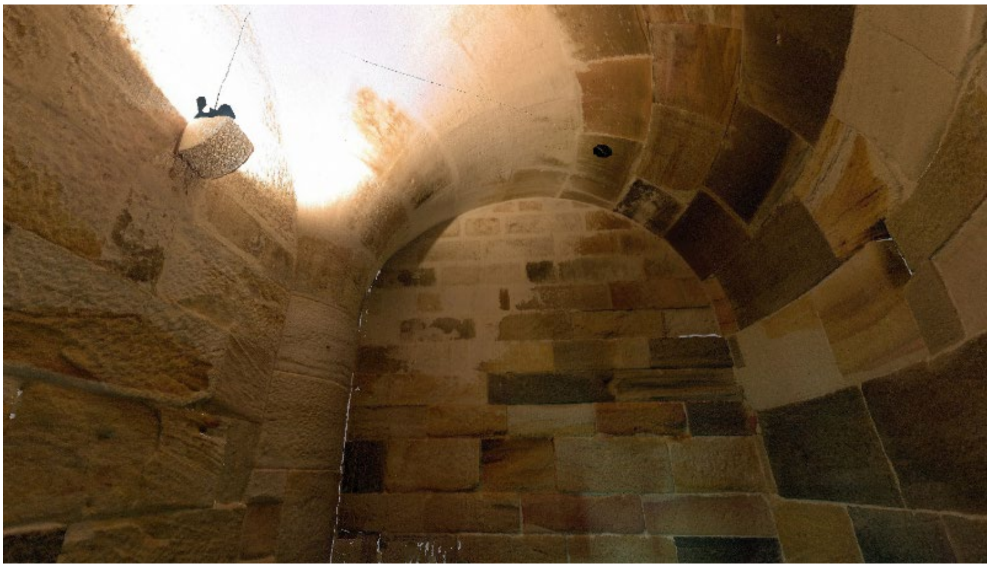

Figure 17: Fort Denison 3D reality model, interior view of the tower basement.

Figure 18: Fort Denison 3D reality model, outside view.

7 DISCUSSION OF RESULTS

The results obtained from the two 3D reality models created for this proof of concept demonstrated that 3D digital replicas of heritage sandstone buildings can be produced with a high level of detail and accuracy.

The models produced clearly show cracks and weathering in the sandstone and allow users to undertake accurate measurements of the dimensions of each block. Combining the external photogrammetrically produced model with the internal LiDAR scan data into a single, integrated 3D reality model, provides unique insights into the construction of the building and a modern method for Heritage Stoneworks stone masons to determine the thickness of internal and external wall structures amongst other benefits.

The spatial accuracy achieved within each of the 3D reality models is shown in Tables 1 and 2, which contain a sample of the GCPs used in each of the models.

Table 1: GCP results for the Hartley Historic Courthouse 3D reality model.

Control Points Errors								
Name	**Category**	**Accuracy [meters]**	**Number of Calibrated Photos**	**RMS of Reprojection Error [pixels]**	**RMS of Distances to Rays [meters]**	**3D Error [meters]**	**Horizontal Error [meters]** ⓘ	**Vertical Error [meters]**
7287503	**3D**	**Horizontal: 0; Vertical: 0**	**20 (20 marked photos)**	0.53	0.0024	0.00192	0.00177	0.00073
7268584	**3D**	**Horizontal: 0; Vertical: 0**	**8 (8 marked photos)**	0.56	0.00257	0.00124	0.00122	0.00024
7283338	**3D**	**Horizontal: 0; Vertical: 0**	**8 (8 marked photos)**	0.64	0.00287	0.00227	0.00211	0.00083
7269266	**3D**	**Horizontal: 0; Vertical: 0**	**10 (10 marked photos)**	0.58	0.00263	0.00081	0.00075	-0.00031
7286561	**3D**	**Horizontal: 0; Vertical: 0**	**16 (16 marked photos)**	0.51	0.0023	0.00308	0.00202	0.00232
7267040	**3D**	**Horizontal: 0; Vertical: 0**	**28 (28 marked photos)**	0.83	0.00362	0.00346	0.00307	0.00159
7267609	**3D**	**Horizontal: 0; Vertical: 0**	**36 (36 marked photos)**	1.18	0.00495	0.00446	0.00446	-0.00009
7282708	**3D**	**Horizontal: 0; Vertical: 0**	**38 (38 marked photos)**	1.48	0.00609	0.0056	0.0056	0.00015
7267158	**3D**	**Horizontal: 0; Vertical: 0**	**15 (15 marked photos)**	0.45	0.00194	0.00231	0.00085	0.00214
7284523	**3D**	**Horizontal: 0; Vertical: 0**	**18 (18 marked photos)**	0.71	0.0029	0.00143	0.00129	0.0006
Global RMS				**0.81**	**0.00346**	**0.00302**	**0.00277**	**0.0012**
Median				**0.64**	**0.00287**	**0.00231**	**0.00202**	**0.00073**

Table 2: GCP results for the Fort Denison 3D reality model.

	Name	Type	Position(s) Placed	Category	X (Long)	Y (Lat)	Z (Height)	Coordinate system	Horizontal ıccuracy [m	Vertical ccuracy [m	MS of repro error [px]	3D error [m]	3D horizonta error [m]	3D vertical error [m]
1	7287495	Control Point	10	Full	335835.319	6252480.627	28.102	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.492506	0.00202243	0.00198393	-0.000392739
2	7286561	Control Point	19	Full	335814.571	6252493.685	24.071	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.651158	0.00481616	0.00348082	0.00332856
3	7286440	Control Point	14	Full	335842.81	6252504.535	26.615	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.720554	0.00460062	0.00434406	-0.00151488
4	7284232	Control Point	12	Full	335869.266	6252522.14	28.546	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.627137	0.00280495	0.00280392	7.58832e-05
5	7282708	Control Point	18	Full	335815.941	6252505.016	27.595	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.545702	0.00312109	0.00237835	-0.00202104
6	7282609	Control Point	14	Full	335866.289	6252542.606	27.629	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.116271	0.000585527	0.000451779	-0.000372475
7	7269266	Control Point	20	Full	335830.051	6252512.153	24.266	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.367289	0.00190754	0.00121491	-0.00147061
8	7268780	Control Point	7	Full	335878.206	6252536.66	38.109	GDA94 / MGA zone 56 (EP...	0.01	0.01	1.62982	0.00364167	0.00305124	0.0019879
9	7267609	Control Point	19	Full	335855.035	6252532.978	24.252	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.465134	0.00179187	0.00144677	-0.00105719
10	7267040	Control Point	21	Full	335826.283	6252525.125	24.611	GDA94 / MGA zone 56 (EP...	0.01	0.01	0.282521	0.00149044	0.00119008	0.000897276

The screenshots shown in Figures 19-24 highlight the detail and user capabilities inherent within the model and how Heritage Stoneworks would be able to utilise these models for interrogation of the sandstone quality and to assess what restoration work would be required.

Figure 19: Level of detail, clearly showing cracks in Hartley Historic Courthouse 3D reality model.

Figure 20: Level of detail, clearly showing fine cracks in Hartley Historic Courthouse 3D reality model.

Figure 21: Level of detail, clearly showing stone mason marks in Hartley Historic Courthouse 3D reality model.

Figure 22: Level of detail, clearly showing cracks and weathering in Fort Denison 3D reality model.

Figure 23: Bottom-up view of Fort Denison 3D reality model, showing interior rooms of tower and external tower walls.

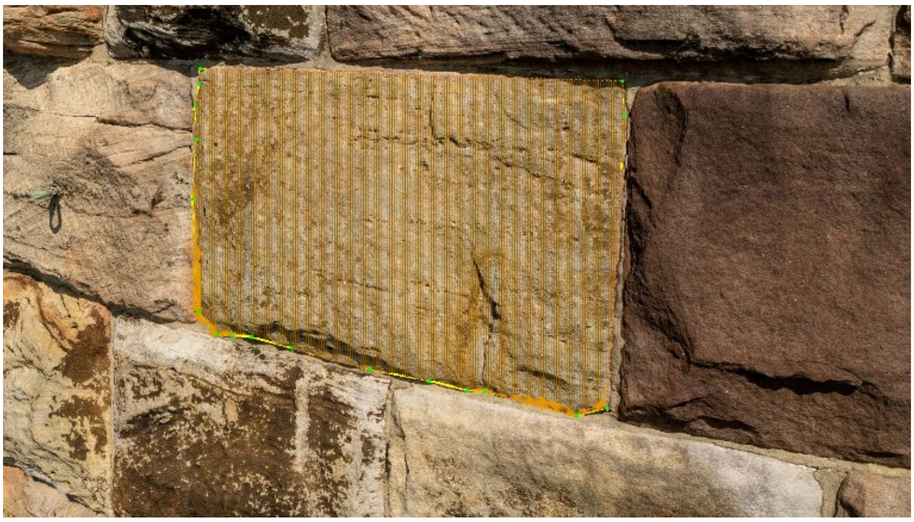

Figure 24: Measurement capability within the 3D reality model for precise measurements of sandstone.

8 CONCLUDING REMARKS

This paper has discussed the techniques used to complete the capture and processing of two sites for heritage building preservation and reconstruction through the utilisation of RPAS, LiDAR, automated ground control points and structure-from-motion software to create highly detailed, spatially accurate 3D digital representations.

The results from undertaking this proof-of-concept project with Heritage Stoneworks clearly demonstrate that highly detailed 3D reality models created from a multi-technology approach, such as those created for the Hartley Historic Courthouse and Fort Denison sites, can be used to evaluate what restoration work may be required on these buildings and to determine the quantity and shape of the replacement sandstone required.

The results also demonstrate that whilst the 3D reality models are not only ideally suited to providing a platform from which assets can be analysed, annotated, inspected, measured and managed, they also have uses outside their intended target, such as through tourism and educational experiences and as a detailed historic replica of that asset at a particular point in time.

REFERENCES

Bentley (2017) Context Capture guide for photo acquisition.

Bentley (2018) Reality modeling drone capture guide.

Bentley (2019) Context Capture user guide.

DCS Spatial Services (2021) CORSnet-NSW, http://www.corsnet.com.au/ (accessed Mar 2021).

Dipasquale L., Rovero L. and Fratini F. (2016) Ancient stone masonry constructions, in Harries K.A. and Sharma B. (Eds.) *Nonconventional and vernacular construction materials*, Elsevier, Sydney, 301-332.

Janssen V., Haasdyk J. and McElroy S. (2016) CORSnet-NSW: A success story, *Proceedings of Association of Public Authority Surveyors Conference (APAS2016)*, Leura, Australia, 4-6 April, 10-28.

Lewinska P. and Pargiela K. (2018) Comparative analysis of structure-from-motion software's – An example of Letychiv (Ukraine) Castle and Convent buildings, *Journal of Applied Engineering Sciences*, 8(2), 73-78.

Pells P.J.N., Mostyn G. and Walker B.F. (1998) Foundations on sandstone and shale in the Sydney region, *Australian Geomechanics*, 33(3), 17-29.

Ryan J.C., Hubbard A.L., Box J.E., Todd J., Christoffersen P., Carr J.R., Holt T.O. and Snooke N. (2015) UAV photogrammetry and structure from motion to assess calving dynamics at Store Glacier, a large outlet draining the Greenland ice sheet, *The Cryosphere*, 9, 1-11.

Yilmaz O. and Karakus F. (2013) Stereo and kinect fusion for continuous 3D reconstruction and visual odometry, *Proceedings of International Conference on Electronics, Computer and Computation (ICECCO 2013)*, Ankara, Turkey, 7-9 November, https://www.researchgate.net/publication/269327935_Stereo_and_kinect_fusion_for_continuous_3D_reconstruction_and_visual_odometry (accessed Mar 2021).