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Archival Recording of a Historically Significant Site Using 3D Laser Scanning Technologies

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ABSTRACT

The Windsor Bridge Replacement project required the survey and modelling of the State Heritage listed Thompson Square Conservation Area, existing Windsor Bridge and immediate surrounds using 3D laser scanning. This is one of the first times where a project's Condition of Approval has required archival recording to be completed using 3D laser scanning technology. An archival model of the project area was produced using a combination of an existing G73 compliant site survey, Terrestrial Laser Scanning (TLS), Mobile Laser Scanning (MLS) and multi-beam sonar bathymetry. The point clouds from the various surveys were combined into a single unified, spatially accurate, full-colour point cloud. 3D string lines were extracted for heritage building facades, the top and underside of Windsor Bridge, along with other streetscape detail. The resulting 3D point cloud and model was used to derive a range of deliverables, including detailed ortho-rectified elevations of the street frontages showing far more detail and colour than traditional CAD drawings, current views of the site that match location and perspective views of historic photographs enabling more recent features to be removed to reveal how the site could look if these features were removed, interactive panoramic images allowing virtual visits to the site from the desktop, and a number of video 'fly-throughs' that highlight the historical significance and issues associated with the site and construction of the new replacement bridge. Proposed design and changes could be dropped into the point cloud model to assess any potential issues early. The level of detail and accuracy captured by the 3D scanning process has set a new benchmark in the archival recording process for what is considered one of the oldest public squares in Australia. This archival recording will be put to use in the long-term strategic planning for conserving the heritage fabric within the township of Windsor.

KEYWORDS: *Laser scanning, TLS, MLS, archival recording, heritage.*

1 INTRODUCTION

Roads and Maritime Services are undertaking a project to replace the existing road bridge over the Hawkesbury River at Windsor with a new bridge located 35 metres downstream. Originally built for horse-drawn vehicles and foot traffic in 1874, Windsor Bridge is now used by up to 19,000 vehicles a day, which has contributed to the deterioration of the structure over time which no longer meets current engineering and road safety standards.

The alignment of the new bridge, selected during the option assessment phase, lies within the eastern approach of Thompson Square Conservation Area (TSCA). This precinct has a significant number of heritage-listed buildings of local and state significance in addition to the existing bridge, which is also a heritage-listed structure (Heritage Council of NSW, 2008). Due to this sensitivity of existing structures, appropriate management measures including 3D archival recording were required to be implemented to ensure appropriate recording has taken place and safeguards are in place prior to construction activities.

With the complexities of the existing constraints of the project, Jacobs demonstrated to Roads and Maritime the application and benefits of 3D laser scanning technology, not only for the 3D archival recording process but also for design and engineering purposes. While Jacobs was specifically only engaged for completion of the 3D archival recording, Jacobs have been able to utilise the spatial data for more definitive engineering analysis during progression of the detail design. The benefits of being able to interrogate the detail design with the comprehensive spatial dataset has enabled Jacobs engineers to visualise and assess with greater certainty the associated impact of the project's footprint against the existing heritage features of the site.

2 PROJECT BACKGROUND AND REQUIREMENT FOR ARCHIVAL RECORDING

In 2013, as part of the Conditions of Approval (CoA) for the project, *a detailed survey and analysis of the Thompson Square Conservation Area, Windsor Bridge and the immediate surrounds using 3D laser scanning* was set by the Director General of the then NSW Department of Planning and Infrastructure. The 3D archival recording, to be completed prior to commencement of pre-construction works, required capturing all the historic heritage sites within the Strategic Conservation Management Plan (SCMP) study area, existing Windsor Bridge and immediate surrounds highlighted in Figure 1. In addition, the project's selected archaeologist was required to complete standard photographic and archival recording of all affected heritage sites as identified in the Environmental Impact Statement for the entire project site inclusive of the SCMP study area.

The CoA detailed the 3D archival recording process is to be undertaken in accordance with the guidelines issued by the NSW Heritage Office (1998). However, this guideline does not include guidance specifically for 3D archival recording. In order to overcome this initial project challenge, Jacobs and Roads and Maritime worked closely together to develop a coordinated site plan to undertake the 3D survey so all captured data including heritage structures, existing road structures, bathymetry of the existing river and immediate surrounds would integrate seamlessly as one package.

This approach enabled multiple deliverables to be produced from the one dataset including the required archival recording but also a complete 3D survey model, which has assisted with design constraint reviews and progressing the detailed design for the project.

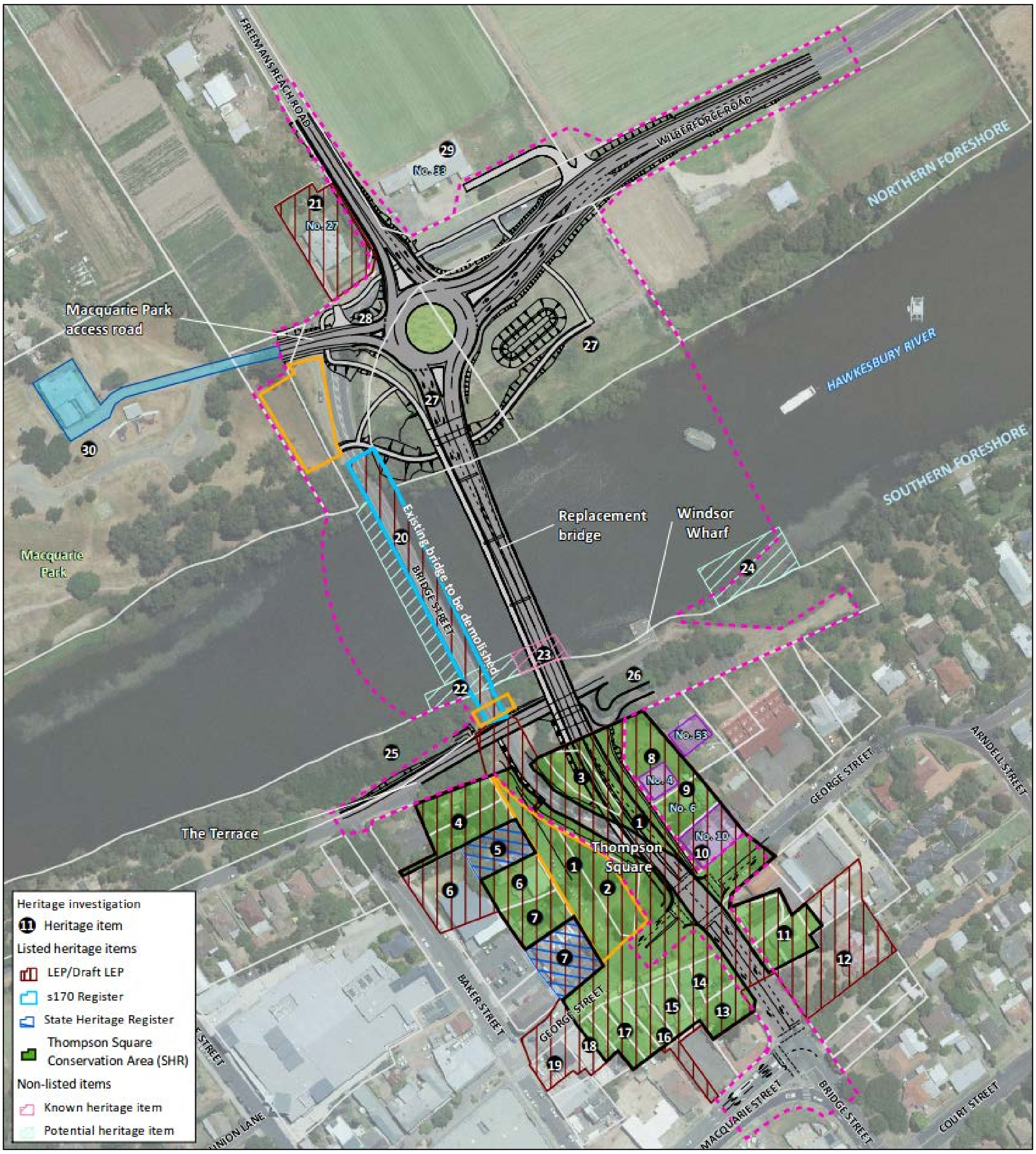

Figure 1: Heritage investigation units.

3 LOCATION

The project is located at Windsor in the Hawkesbury local government area about 57 km north-west of Sydney. The township of Windsor is located on the south bank of the Hawkesbury River at the foot of the Blue Mountains. The proposed bridge works and associated road works that make up the project extend from the intersection of Freemans Reach Road and Wilberforce Road in the north to the intersection of Macquarie Street and Bridge Street in the south. The extent of Jacobs's 3D scanning survey is shown in Figure 2.

Figure 2: Extent of survey.

4 METHODOLOGY

A multi-purpose model of the project area was produced using a combination of an existing G73 compliant site survey, Terrestrial Laser Scanning (TLS), Mobile Laser Scanning (MLS) and multi-beam sonar bathymetry. The point clouds from the various surveys were combined into a single unified, spatially accurate, full-colour point cloud. 3D string lines were extracted for heritage building facades, the top and underside of Windsor Bridge, along with other streetscape detail.

4.1 Existing G73 Roads and Maritime Survey

As with all Roads and Maritime projects, a state-based datum was used. In this case, the Map Grid of Australia 1994 (MGA94) and the Australian Height Datum 1971 (AHD71) were adopted. For this project, Roads and Maritime had already carried out a G73 compliant feature survey of the site, which is detailed in Figure 3. This existing survey was quality checked by Jacobs surveyors and used, along with a number of marks on public record in the Survey Control Information Management System (SCIMS – see Kinlyside, 2013), to help control and verify our 3D laser scan surveys.

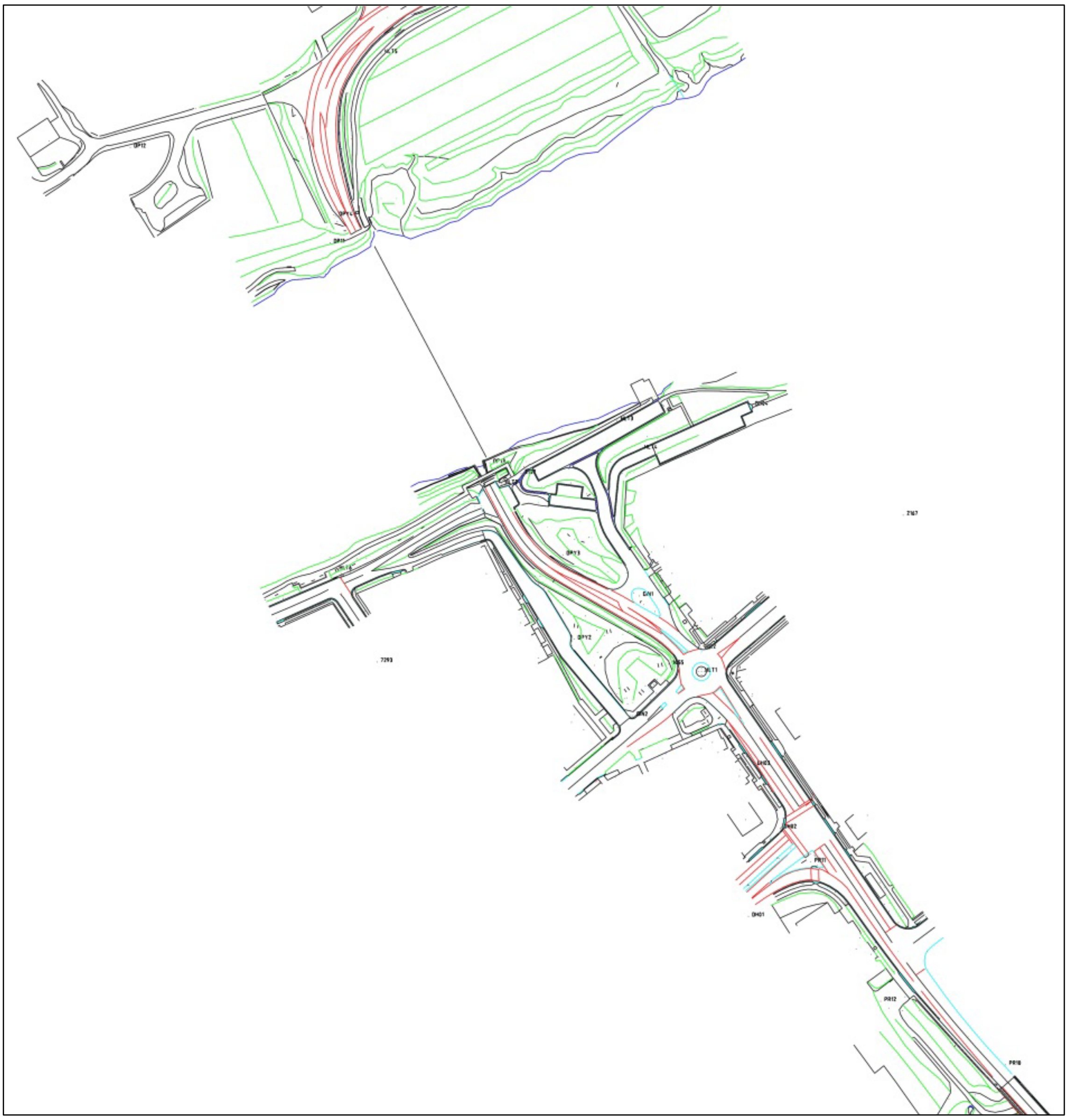

Figure 3: Existing G73 compliant survey provided by Roads and Maritime.

4.2 Terrestrial Laser Scanning

Terrestrial Laser Scanning (TLS) was carried out using a Leica HDS7000 scanner and a Pentax DSLR camera fitted with a fisheye lens. Static scans were acquired from a number of positions across the site from locations optimised to capture the multi-faceted heritage buildings, bridge abutments, Thompson Square Park and features unlikely to be visible from the roads or river. Capture was carried out without entering private property or interrupting traffic flow.

Using the existing Roads and Maritime survey control network, a Leica total station was used to coordinate targets visible in the scans as per general arrangement in Figure 4. These coordinated targets were later used to position and orientate each of the static scans onto the project datum. This is Jacobs' preferred method of TLS control in an outdoor and elongated project. This method minimises the propagation of errors that occurs using point cloud to point cloud registration.

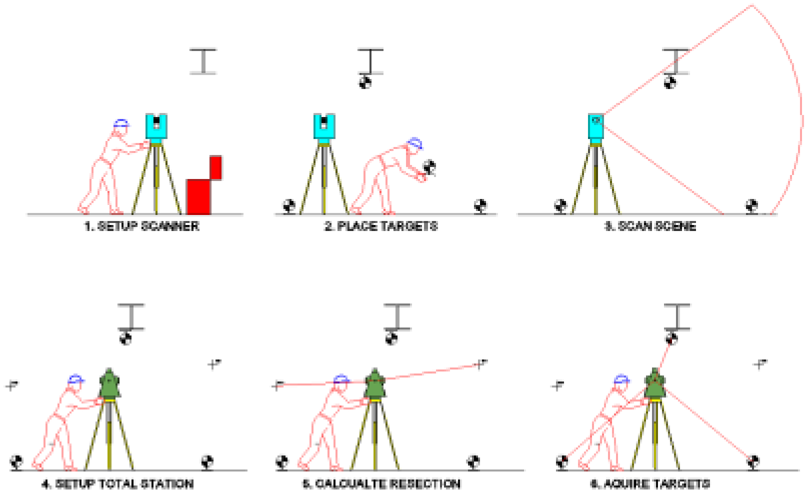

Figure 4: Static scanning process.

Photography was taken at each scan site using a Nodal Ninja tripod mount that allows the camera and the scanner to share a common focal point. Eight photographs were taken at each scan site, which were later stitched together to produce a high-resolution 360º panoramic image showing what was visible from each scan site (Figure 5). The panoramic images were later precisely referenced to the scans and used to colourise the point cloud, allocating each point in the point cloud its own unique colour value.

Figure 5: Panoramic image from TLS.

4.3 Mobile Laser Scanning (Land)

A Riegl VMX-450 Mobile Laser Scanner (MLS), fitted with a LadyBug 5 Panoramic camera system and mounted on a vehicle was used to acquire point cloud data from all trafficable areas throughout the site (Figure 6). The MLS point cloud was used to capture the road pavement, verify and/or update existing Roads and Maritime detail and complete the capture of the heritage building facades where it was difficult for the TLS to get line of sight.

Figure 6: Riegl VMX450 MLS system.

All trafficable roads within the site were driven between 2-4 times in each direction to provide redundancy, ensure maximum coverage and assist in maximising spatial accuracy. Capturing multiple passes helps eliminate anomalies caused by Global Navigation Satellite System (GNSS) or Inertial Measurement Unit (IMU) noise/error and eliminates data gaps caused by moving objects obscuring line of sight.

The GNSS and IMU trajectory data from the MLS system along with the GNSS base station data was post-processed to improve the resulting MLS point cloud. The calculated deviation vectors between multiple overlapping point clouds (from multiple passes) along with the trajectory quality file are used to adjust the trajectory and the resulting laser data to produce a single unified point cloud.

Distinct features from the original Roads and Maritime feature survey and the terrestrial laser scan point cloud were then selected and used as control to further refine the MLS point cloud to within better than ±15 mm of the original Roads and Maritime survey provided. Figure 7 provides a snapshot of this process. It was found that a few sections of kerbs and line work had changed since the original Roads and Maritime survey. These features were updated using the MLS point cloud.

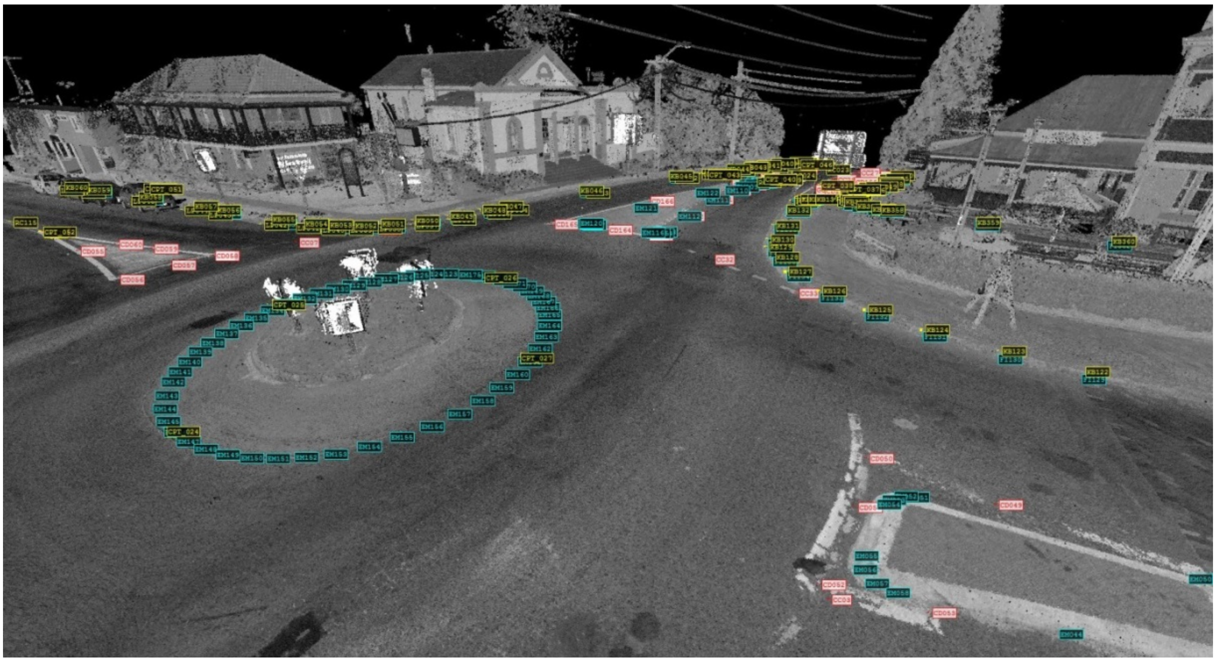

Figure 7: Example control points used to refine the position of the MLS point cloud.

The LadyBug camera is integrated into the Riegl VMX-450's system. The panoramic images from this camera are georeferenced with the laser data and then used to colourise the point cloud, allocating each point in the point cloud its own unique colour value (Figures 8 & 9).

Figure 8: Georeferenced images and point cloud from MLS.

Figure 9: Combined colourised point cloud from MLS and TLS.

4.4 Mobile Laser Scanning (Water) and Bathymetry

The river bed, adjacent banks and the underside of the historic Windsor Bridge were all surveyed from a small survey vessel operated by Astute Surveying (Figure 10).

Figure 10: Maritime survey vessel.

For surveying the river bed, the vessel was fitted with a Multi-Beam Echo Sounder (MBES) and a range of other sensors, including Motion Reference Unit (MRU), Differential Global Positioning System (DGPS) gyro or heading sensor, Real Time Kinematic (RTK) surveying system, and Sound Velocity Probe (SVP) for determining the velocity of sound within the water column.

For surveying the river banks and the underside of each span and the support structures of the historic Windsor Bridge, the vessel was also fitted with Jacobs' Riegl VMX-250 MLS system with its own dedicated GNSS and IMU systems.

Initially the MLS point cloud was processed to an estimated accuracy of ±40 mm using the GNSS and IMU data recorded during acquisition. The point cloud was further adjusted to match the overlapping multiple passes and the controlled MLS and TLS point cloud of the bridge structure and abutments captured from above. There was only a small amount of controlled point cloud overlap and some structural assumptions were required to fit the point cloud into position, as highlighted in Figure 11.

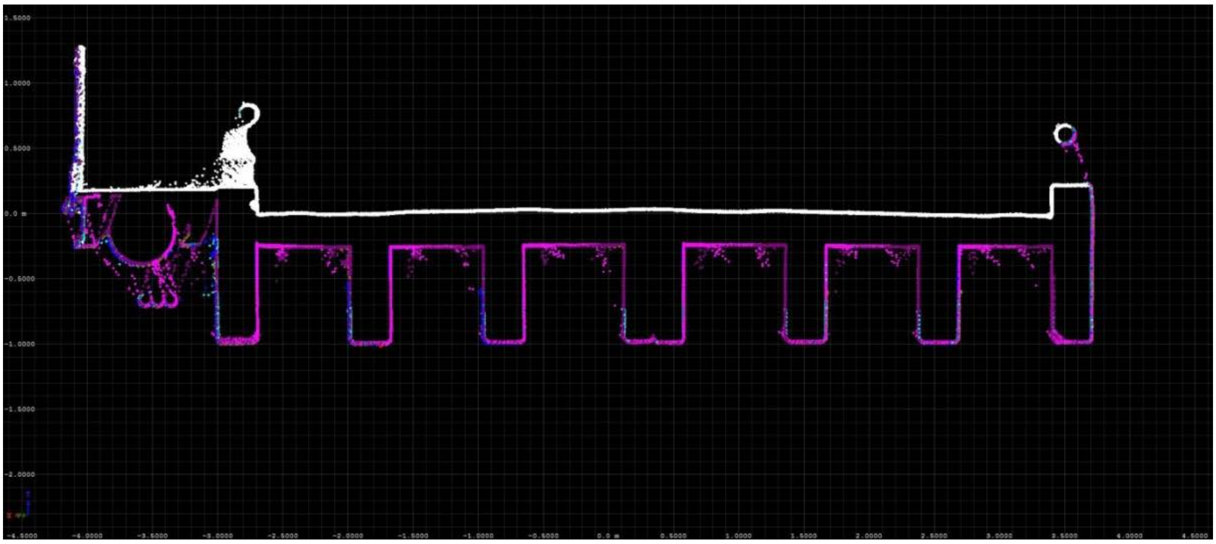

Figure 11: Adjustment of point cloud collected from vessel (purple) to point cloud collected from vehicle (white).

4.5 Combining the Various Surveys

Other than ensuring that all the individual surveys were accurately controlled and in the same reference frame, there were a number of other tasks required to bring all the datasets together into a single model. Figure 12 details the different surveys undertaken across the project area.

The intensity ranges for scanned points varies between scan systems. As a result, there was a requirement to adjust the intensity ranges so that the intensity values for points on similar objects were consistent, regardless of which of the three scan systems was used (Figure 13).

Classification of the points within the point cloud is helpful to assist in the extraction of 3D features and makes interpretation of the data more efficient. In this instance, to assist in modelling the area, the combined point cloud was classified into 'ground' and 'non-ground' classes using an automated approach. A manual cleaning process was then undertaken to remove noise and points on vehicles, people and other mobile objects picked up during the scanning phase.

Figure 12: TLS positions (red), road MLS trajectory (green) and water MLS trajectory (blue).

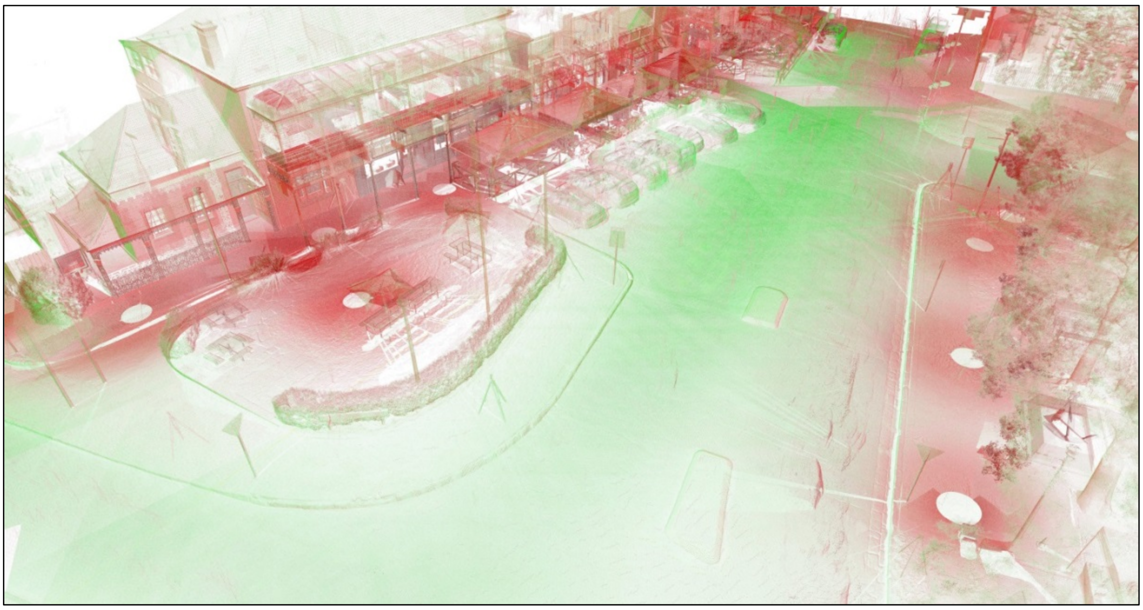

Figure 13: Combining TLS points (red) and MLS points (green).

4.6 Modelling of the Heritage Facades, Windsor Bridge and Streetscape

Using the combined, data-rich point cloud, 3D line strings of the main elements of the heritage buildings were extracted in 3D Computer-Aided Design (CAD). The detailed and colour point cloud was used to supplement the line strings and provide the finer detail and context.

A full 3D model of the historic Windsor Bridge including pylons, flanges, steel beams, services, road pavement, footpath, guardrails and fences was also extracted from the unified point cloud. In addition, the survey model provided by Roads and Maritime was further enhanced to include additional streetscape furniture and detail.

5 RESULTS

The final data-rich 3D survey model contains both point cloud and 3D line strings derived from traditional field survey, three separate scan systems and a multi-beam echo sounder. From this model a number of project deliverables have been produced to date, including those described in this section.

5.1 Combined Georeferenced Point Cloud (With Colour)

The combined point cloud provides maximum coverage and detail of all areas within the scope of the project. This point cloud is the base data for a snapshot-in-time record of the Windsor area. This data can be revisited time and time again to extract additional information for new purposes.

The dense coloured point cloud has the advantage of being both photo-realistic and spatially accurate, but is also measureable, and can be visually manipulated based on the characteristics of the laser return and post-processing (e.g. point source, intensity, classification, height, laser pulse deviation, pulse return number, RGB value, etc.).

The point cloud was converted to a number of formats to enable it to be referenced and used in a range of software platforms utilised by each of the engineering disciplines involved in the project.

5.2 Georeferenced Images

Position and orientation information was produced for the panoramic images. These images were imported into CAD software to assist in 3D modelling. Interactive panoramic images where produced for the project captured simultaneously during the 3D mobile laser scanning process. While similar to Google street view, these images provide a more up-to-date imagery dataset and ability to view completely in 360^{o} perspectives (Figure 14). To date this has helped with initial planning of pre-construction site investigations, assisting with identification of existing constraints on site.

An example was accurately determining the existing overhead cabling and tree crowns in proximity to geotechnical investigations. By reviewing the interactive panoramic images it prompted the use of a smaller sized drilling rig more suited to the surrounding constraints, allowing works to be completed on site safely and without delays (Figure 15).

Figure 14: Panoramic images from MLS and TLS.

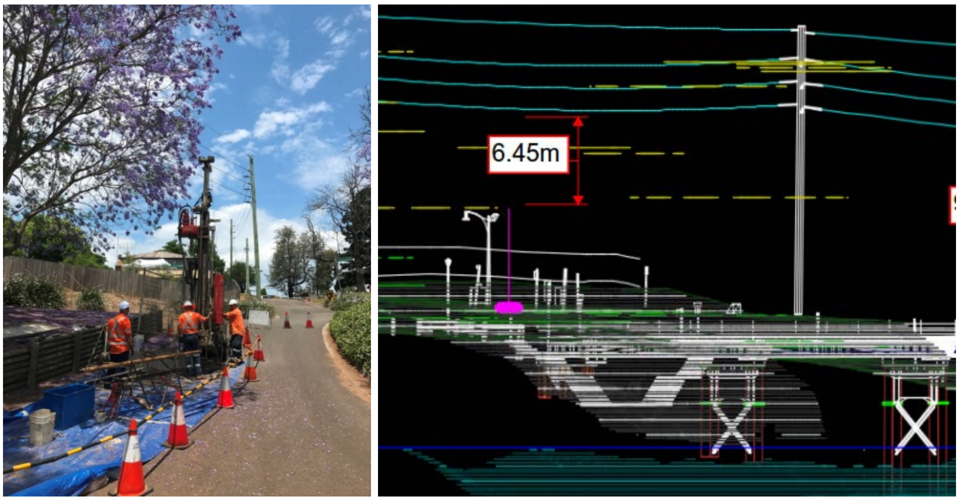

Figure 15: Geotechnical drilling works on site and survey clearance checks.

5.3 Historical Windsor Bridge: Plans, Sections and Elevations

Plans and sections, including both the extracted 3D model and point cloud, accurately detail the bridge structure above, underneath and below water. The point cloud is detailed and dense enough to show concrete condition (Figure 16).

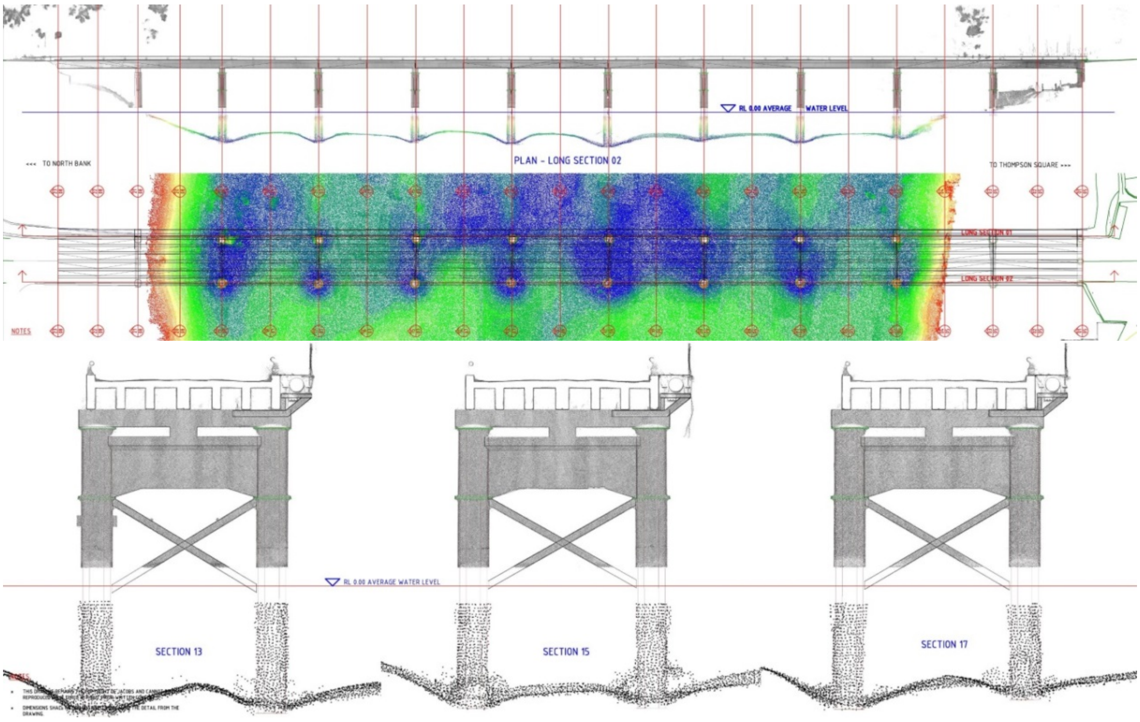

Figure 16: Plans and sections of Windsor Bridge.

5.4 Ortho-Rectified Elevations of Heritage Building Façades, Streetscapes and Thompson Square

Elevations, including point clouds, have greater detail and context than traditional CAD drawings alone. These elevations combine the spatial accuracy and historical context/detail. Due to the high density and photorealism, details as small as 10 mm have been captured and shown efficiently and accurately (Figures 17-19).

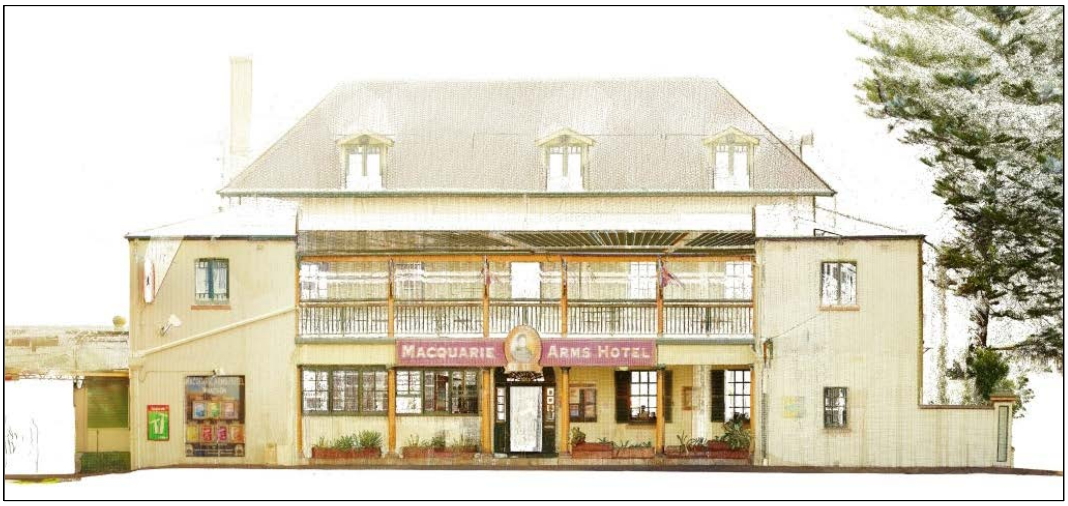

Figure 17: Street front perspective of the heritage-listed Macquarie Arms Hotel.

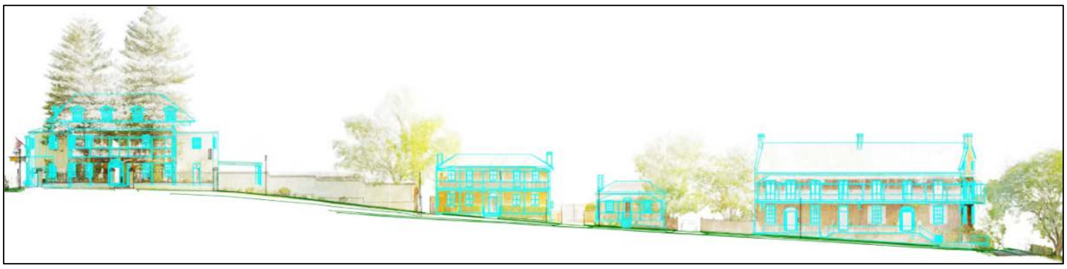

Figure 18: Streetscape of Thompson Square Road.

Figure 19: Section of Thompson Square Park.

5.5 Cross Sections and Elevations of the River Bank Including Above and Below Water

The twin scanners on Riegl VMX-250 (and 450) are capable of collecting multiple data points (targets) per laser pulse, enabling far greater penetration through dense vegetation. By filtering out all but single and last targets, the ground surface could easily be identified and extracted. This information was used by Jacobs' geotechnical engineers to plan river bank stabilisation for the proposed new bridge (Figure 20).

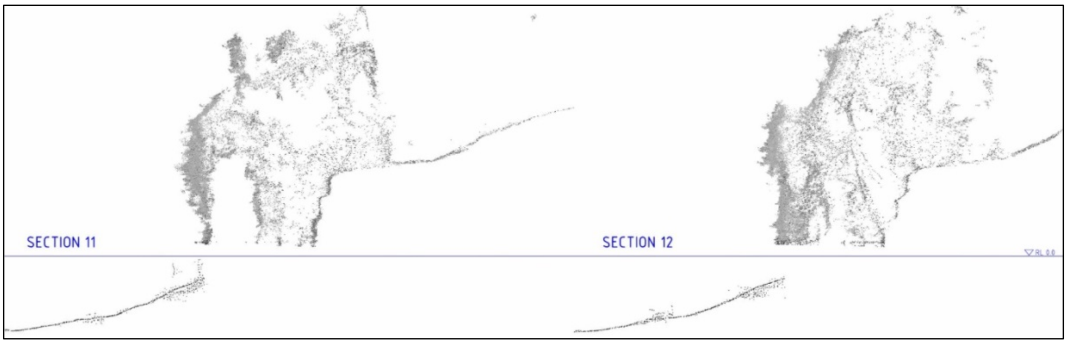

Figure 20: Point cloud cross sections of the south river bank.

5.6 Historical Photos Integrated into the 3D Point Cloud

Current views of the site that match location and perspective views of historic photographs were produced by Jacobs to investigate the visual impacts of removing more recent features, like trees, to reveal how the site might look if these features were actually removed. This has been a useful tool in the development of the urban design and landscaping plan for the project, which requires a design to be sympathetic to the historical views and heritage values of the Macquarie era township of Windsor (Figure 21).

Figure 21: Historical photos of Thompson Square overlayed with point cloud survey data.

5.7 Design and 3D Survey Overlays

During the development of detail designs for large scale infrastructure projects, conflict and constraints analysis is traditionally performed on plan in 2D. With capture of the 3D survey data, the Windsor Bridge project team has been able to go a step further and assesses proposed design changes and review clashes or constraints by dropping the design into the point cloud model (Figure 22).

This has been particularly important in identifying potential issues early on in the design phase with the ability to navigate the design through the existing urbanised environment which has significant heritage constraints present. The outcome of this design review process has given the project team greater confidence in mitigating possible impacts to heritage items during construction of the new replacement bridge and approaches.

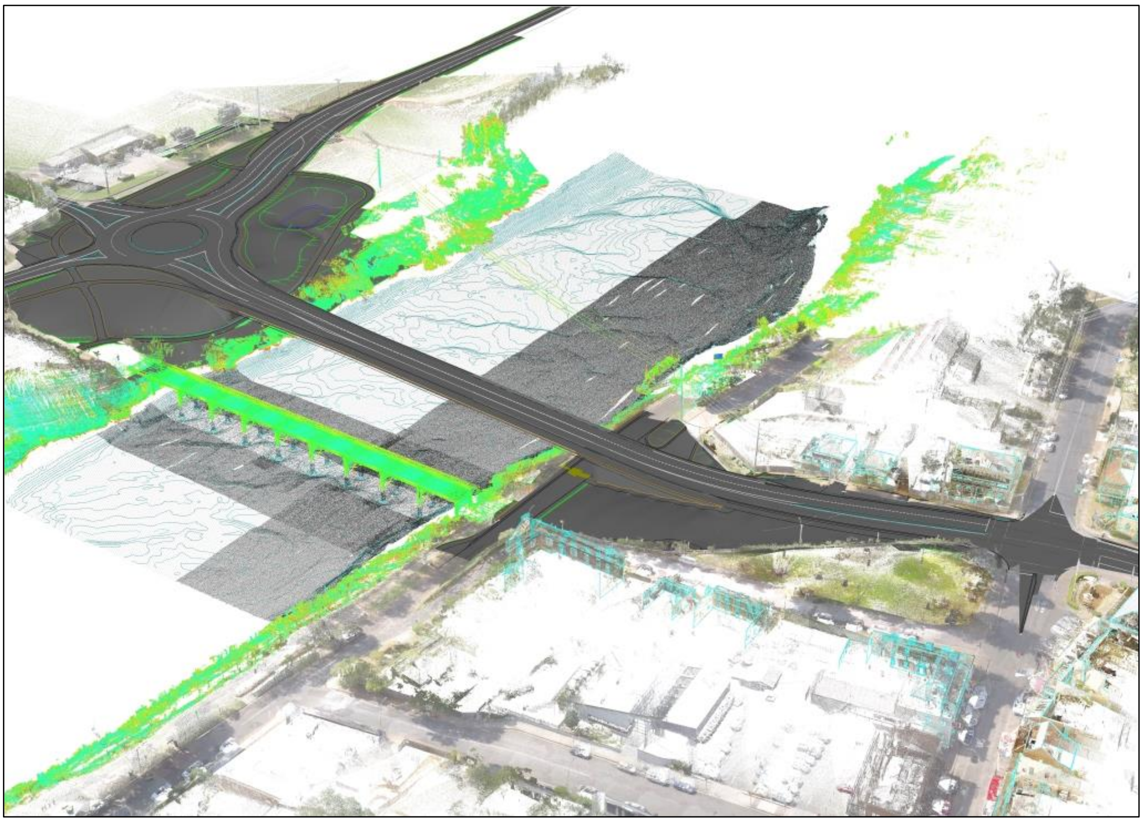

Figure 22: Point cloud data with detail design overlaid.

6 CONCLUDING REMARKS

The coordinated approach of undertaking the 3D archival survey and modelling of the State Heritage listed Thompson Square Conservation Area, existing Windsor Bridge and immediate surrounds using 3D laser scanning by Roads and Maritime and Jacobs enabled the various surveys to be combined into a single unified, spatially accurate, full-colour point cloud. This resulted in the development of a high-density, data-rich 3D model of the site which in turn has contributed to the project team developing multiple innovative survey outputs and archival recording techniques that have been received well by the Office of Environment and Heritage who are the Heritage Council of NSW's representative for the project.

The level of detail and accuracy captured by the 3D scanning process has set a new benchmark in the archival recording process for what is considered one of the oldest towns in Australia. Along with the improvements to the detail design associated with avoiding impacts to existing heritage structures, this archival recording will be put to use in the long-term strategic planning for conserving the heritage fabric within the township of Windsor.

ACKNOWLEDGEMENTS

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