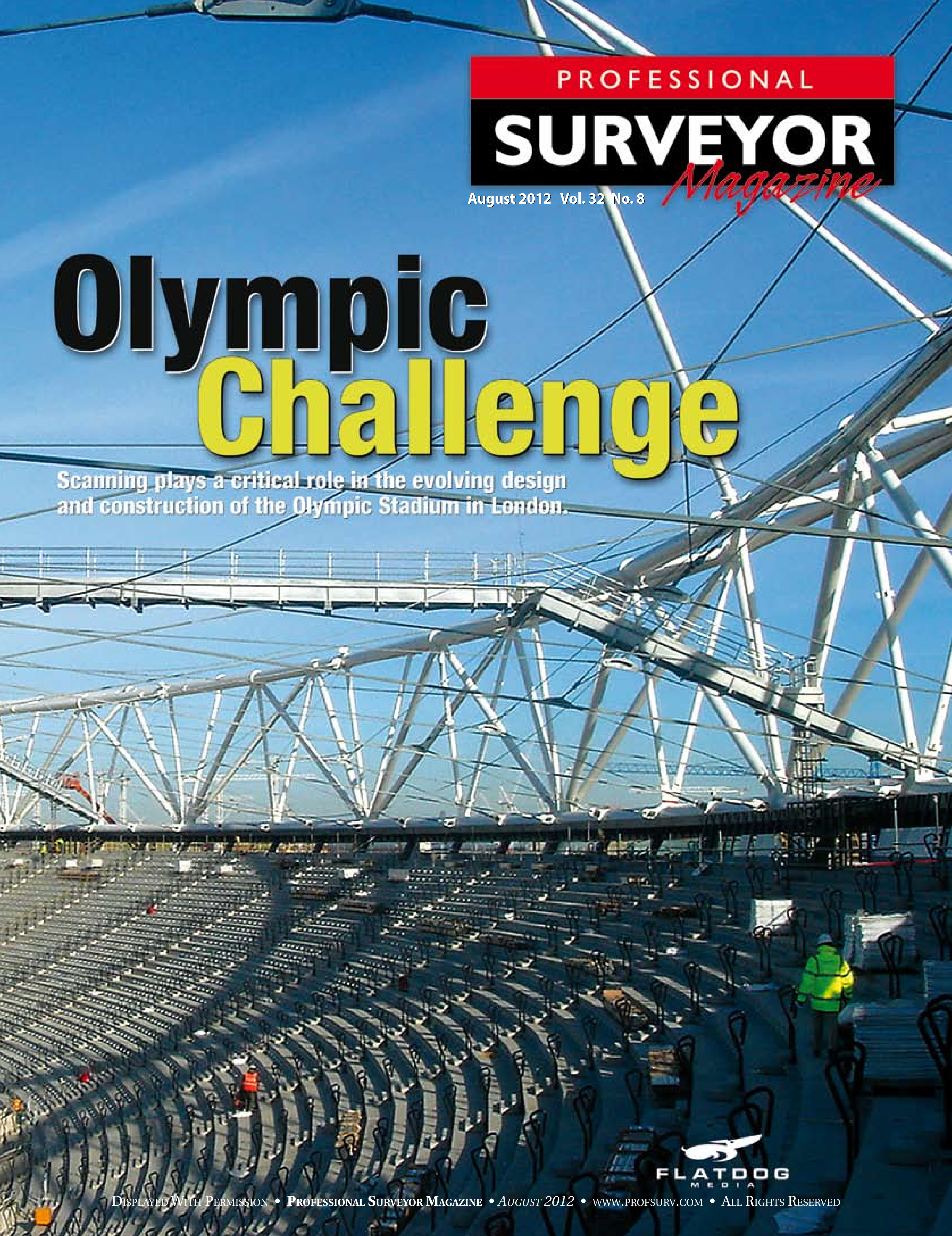
PROFESSIONAL SURVEYOR Magazine

August 2012 Vol. 32 No. 8

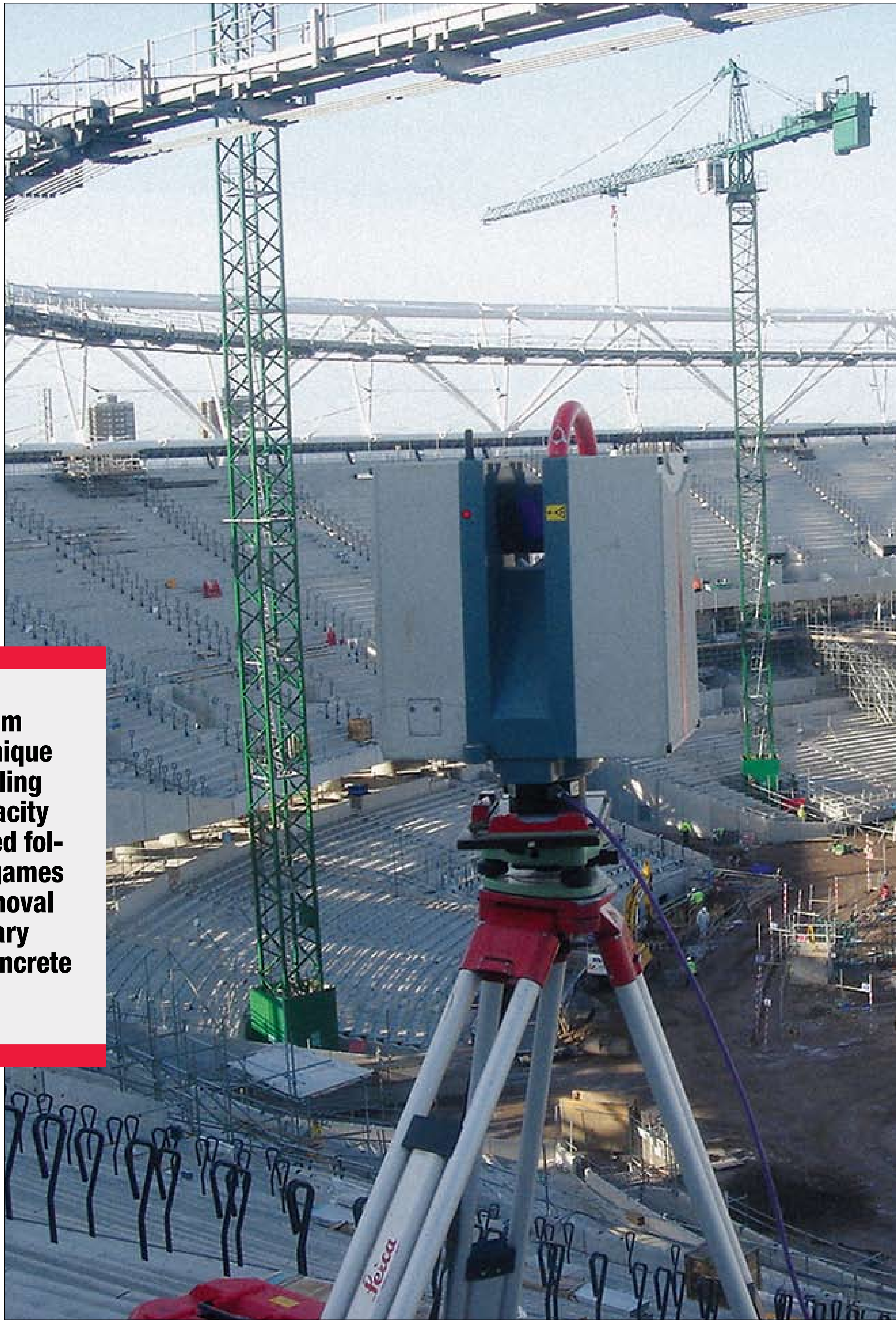
Olympic Challenge

Scanning plays a critical role in the evolving design and construction of the Olympic Stadium in London.



FLATDOG MEDIA

The upper tier terrace and roof-supporting structure are constructed from pre-fabricated compression truss- and roof-column connections with cables supporting a roof structure of PVC fabric.



Team Stadium created a unique design enabling seating capacity to be reduced following the games with the removal of a temporary steel and concrete upper tier.

Scanning London's

Olympic Stadium

The Olympic Stadium is built from prefabricated steelwork components in a demanding workflow where the final design of successive components is adjusted to fit the verified deformation of each previously installed component. A team of experienced surveyors met this challenge, along with tight deadlines, to keep construction moving.

By Alan Barrow

East London's Olympic Stadium was designed to become the centerpiece of the 2012 Summer Olympics and 2012 Summer Paralympics—the venue of athletic competition as well as host of the opening and closing ceremonies. With the capacity to seat 80,000 people, London's Olympic Stadium will temporarily become the third-largest stadium in Britain, behind Wembley Stadium and Twickenham Stadium.

Following London's successful bid in July 2005 to host the games, the London Organizing Committee of the Olympic Games and Paralympic Games selected Team Stadium, a consortium of architects, structural engineers, and construction companies to plan and build the massive new stadium. Ultimately, Team Stadium created a unique design enabling seating capacity to be reduced following the games with the removal of a temporary steel and concrete upper tier.

Designing a structure such as the Olympic Stadium to be built from prefabricated components—when the shape of the structure itself depends on the stage of its construction—presents a problem not only for the designers but also for the surveyors monitoring the construction. Any construction process using components that are prefabricated off site requires careful dimensional control of the mating surfaces. Generally such construction will be linear—either vertical, as in the case of a rig or tower, or horizontal, as in the case of a gantry or bridge—with mating surfaces generally falling within a confined footprint.

In these situations, surveyors with decades of experience can accurately forecast the deformations that may occur during construction. However, when the structure requires the joining of 224 structural components weighing over 2,400 tons, covering an area 1033' x 840', reaching a height of 197', there are altogether too many combinations of tolerance, fit, and temperature to allow final design of components "off the drawing board."

Such unpredictability requires that the final detail design be carried out as each stage is completed. Selected to monitor the erection of steelwork of the London Olympic Stadium was the United Kingdom-based company, ABA Surveying, Inc., specialist surveyors in the field of engineering and structures. They consider the work they did on the stadium, which is expected to remain a London treasure for decades, as among the most challenging they've done in recent years because of its scale and fast deadlines.

Construction

The upper section supporting the stadium's partial "roof" is constructed from pre-fabricated compression truss- and roof-column connections with cables supporting a roof structure of PVC fabric. Triangular lighting support towers stand on top of the roof structure.

During the construction and erection process, it was critical to establish that the steelwork, which was prefabricated off site and then lifted and bolted into position on site, would fit together exactly and perform under loading within the expected tolerances. Team Stadium had design models and simulations, but from the start, the need to obtain accurate, on-going, as-built information had been identified. Such information was critical to the design and fabrication of the next-stage components and the only way that the construction could proceed.

ABA, which previously had worked on many high-profile infrastructure projects such as the Channel Tunnel Rail Link and the Thameslink Rail upgrade, have been pioneers of laser scanning in the UK since 2000 and currently operate three Leica HDS6100 phase scanners.

Scanning Work

Team Stadium required data for center line and locating hole positions for the upper tier steelwork—to be monitored during the construction process between June 2009 and February 2010. During this period ABA Surveying made five site visits to undertake monitoring exercises, deciding to use laser-scanning technology because it can accurately and rapidly capture survey information difficult to obtain by conventional methods.

The construction of the steel components monitored is all tubular, up to 3'6" in diameter in places and notoriously difficult to survey with a total station. The ability to model in Leica's Cyclone software became the only practical solution. As with all scan projects, they needed to be careful to include control in all scans in order to ensure a valid and accurate registration. Team Stadium had already established a site grid and had a team of surveyors on site.

For the project, ABA designed (and had professionally made) self-adhesive black and white targets that were stuck to the exposed concrete in the stadium. These targets were strategically placed in prominent positions on the rear wall of the upper tier and on the back of the stairwells to be clearly visible from each scan location.

On each site visit, ABA used its three laser scanners positioned around the stadium to record a total of 28 scans, deciding to use a high-resolution, low-noise setting, which generates a point spacing of approximately 7 mm, for example, at a 10 meter range. Each scan took a little over six minutes and contained approximately 20 million points of data, recording both location and intensity values.

This high-resolution scan of the roof-supporting structure was taken using a high-speed phase-based 3D laser scanner. The point cloud is displayed in grey-scale intensity mapping, with locating holes and individual rivets visible.

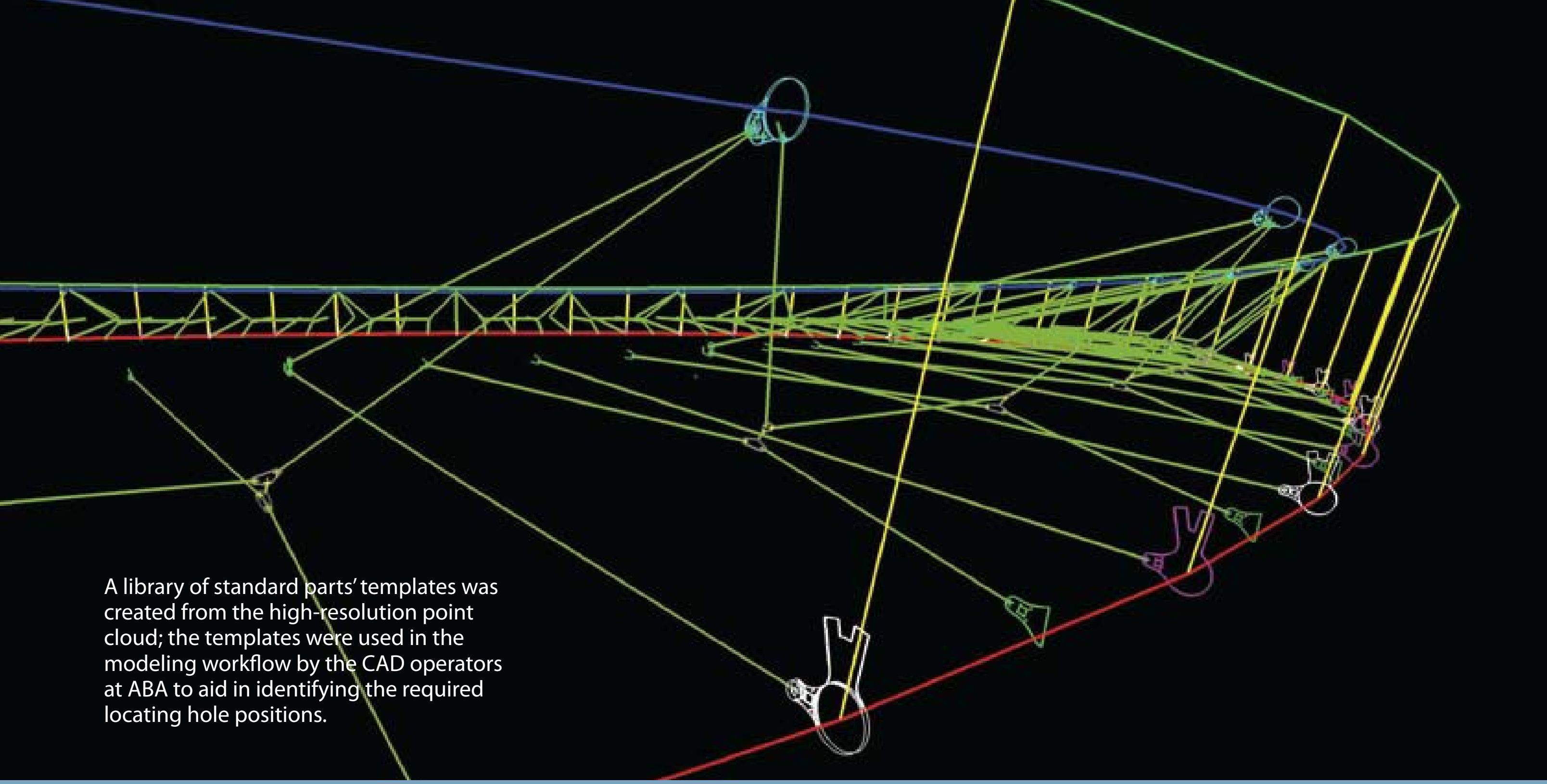
The location of the scans had been carefully chosen so that the steelwork requiring monitoring and the previously placed control targets were within the scanners' field of view. The targets were acquired using software that finely scans a user-defined area or point and fits a vertex to the center of the black and white target.

Ambient air temperatures in shade and in sunlight and the steel surface temperature were all recorded at the time of each scan. Speed of operation, therefore, was essential to the data capture process, minimizing expansion and contraction effects brought about by possible temperature variations. The Team Stadium surveyors observed the targets and provided coordinates on the site grid to ABA, which was able to complete the whole survey in under four hours.

Office Work

ABA used Leica Geosytem's Cyclone software suite for processing point cloud data and downloading it once they returned to the office. The scans were then fully imported before being compiled into a single database.

Using Cyclone's registration module, the targets in each individual scan, which had been acquired in the field, were double-checked to ensure they were labelled correctly. Where it had not been possible to acquire a target in the field, the target was now fitted manually. A registration was



A library of standard parts' templates was created from the high-resolution point cloud; the templates were used in the modeling workflow by the CAD operators at ABA to aid in identifying the required locating hole positions.

then created using the supplied control file for the targets and applying cloud-to-cloud constraints. The registered point cloud was unified into one final point cloud, as it is more efficient to work on one point cloud than 28 individuals.

The importing, unification, and general processing of point cloud data can be time consuming for essentially a push-button exercise. Therefore, ABA tried to work efficiently by using hi-spec machines and runningnumber-crunching processes overnight, leaving CAD operators free for the data extraction and processing during the day. Only then could steelwork-monitoring data be extracted.

Where differences existed between prediction and as-built, the most effective demonstration to the designer was to simply switch on the point cloud in the modeled dataset.

Team Stadium required center line positions for the three truss chords (bottom, top inner, and top lower) and the truss-lacing outer radials along with specific locating hole positions. For each steelwork component, the relevant area of point cloud was taken from the main model and worked on in a new model space. The center line positions were taken from cylinders modeled to the point cloud using Cyclone.

To model the cylindrical steel parts from the millions of points in the cloud, typically there need to be points representing at least one third of the circumference of a cylinder to yield an accurate fit. ABA found fits within 1 mm of the theoretical design diameters of the steelwork. To give some idea of scale, the diameter of the truss chord bottom is 3' 6".

The locating hole positions were clearly visible in the high point density scans. Once again, an area of the point cloud was worked on in a new model space, and the holes were located with the aid of parts templates, which the team had constructed to aid the fitting process.

By the time of the final monitoring exercise, a total of three and one-third miles of cables had been fabricated and rigged between the top and bottom truss chords and the inner tension ring, adding another 450 tons to the structure. From ABA's survey, they were able to establish precisely the center line and catenary of each of these cables.

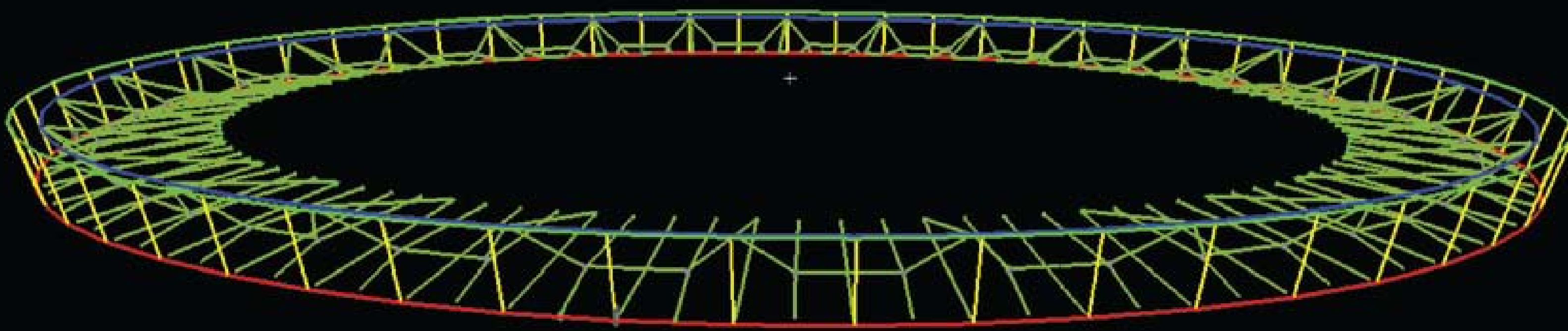
Team Stadium compared the gathered as-built information to their design models and checked that the as-built steelwork was performing as expected within their design tolerances. Afterwards, they could make any adjustments to the steelwork or cabling in the next construction stage that were necessary prior to arrival on site.

ABA was able to scan the complete upper tier of the Olympic Stadium using its three scanners in a matter of hours. Using a time-of-flight scanner would have taken considerably longer to achieve the same density of points and would have raised the specter of temperature-dependant distortion. With a refined workflow, ABA was able to register the data and supply the monitoring information within two weeks of each site visit.

The rapid generation of the 3D wireframe model for the stadium enabled the design and contruction teams to proceed with confidence. This modeling was an essential part of the team effort, which completed the stadium on schedule.

Where Team Stadium had any queries, ABA was able to refer to the point cloud and draw out any additional information that was required without further site visits.

Where differences existed between prediction and as-built, the most effective demonstration to the designer was to simply switch on the point cloud in the modeled dataset. The modeled objects were then combined with the original point cloud, and any issue of doubt was instantly removed. The "capture all"



This wireframe model contains all center lines for steel components, cables, and locating hole positions. The linework was created in Cyclone and exported to AutoCad as a final deliverable.

nature of laser scanning is one of the key benefits that ABA customers have increasingly appreciated over the years.

Not everything in life is predictable. Models can simulate future events to increasingly accurate degrees, but there is still a need to temper the purely algorithmic with the effects on real-world conditions and results. In the surveying sector, it's appreciated that, in the real world, engineering construction does not often match design for many reasons—and why as-built surveys and measuring the unpredictable are important.

ALAN BARROW is the owner of ABA Surveying, Inc. in Guildford, United Kingdom.