Unique Lift System Enables Installation and Servicing of Large Telescope Mirrors

The Large Synoptic Survey Telescope (LSST), under construction atop 8,737-foot El Peñón peak in northern Chile, is a partnership project of the National Science Foundation (NSF) and the Department of Energy (DOE). The goal of the LSST, scheduled to be fully operational in 2022, is to conduct a ten-year survey that will deliver a 200-petabyte set of images and data addressing some of the most pressing questions about the structure and evolution of the universe and the objects within it. The LSST will conduct a deep survey over an enormous area of sky and do it with a frequency that enables images of every part of the visible sky to be obtained every few nights. This mode will continue for ten years to achieve astronomical catalogs thousands of times larger than have been previously compiled.

EVERYTHING ABOUT THE LSST IS BIG

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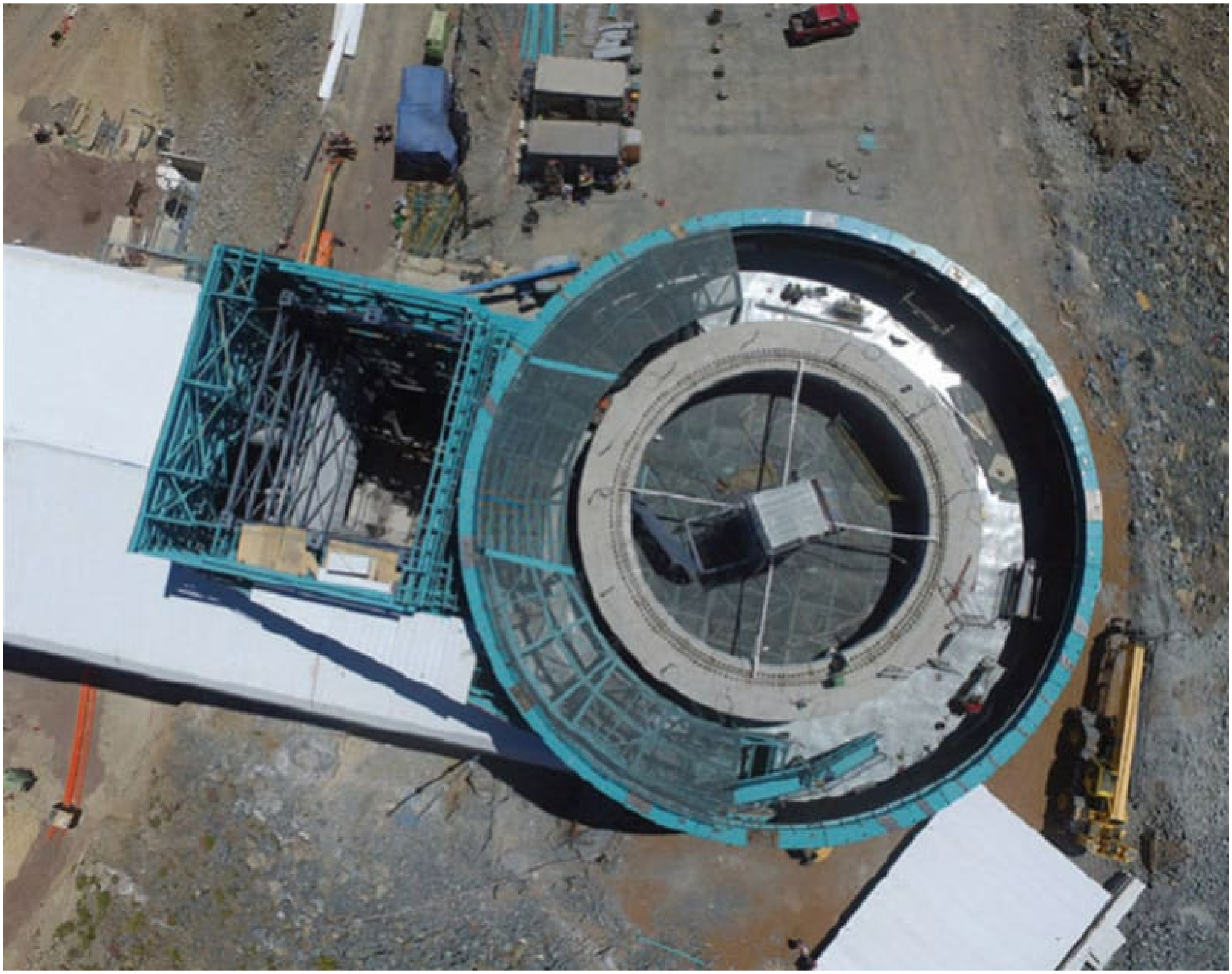
The LSST, when completed, will be the world's most powerful survey telescope. It is a wide-field survey reflecting telescope, with an 8.4-meter primary mirror. It is unique among large telescopes because of its very wide field of view of 3.5 degrees, covering a 64-cm-diameter flat focal plane. It uses a novel three-mirror design that delivers sharp images feeding a 3.2-gigapixel CCD imaging camera — the largest digital camera ever constructed.

The camera will take a 15-second exposure of the night sky every 20 seconds — 800 panoramic images every night. This is equivalent to taking roughly 800,000 images with an eight-megapixel digital camera, but of much higher quality — more than 200,000 exposures per year of raw image data. In a ten-year survey, the LSST will produce a deep, time-dependent, multi-color movie of the sky.

Initial computer requirements are estimated at 100 teraflops of computing power (one teraflop is a measure of computing speed equivalent to one trillion floating point operations per second). The camera contains more than three billion pixels of solid-state detectors. More than 30 terabytes of data must be processed and stored each night in producing the largest non-proprietary data set in the world.

By digitally imaging the sky for a decade, the LSST will produce a petabyte-scale database enabling new paradigms of knowledge to address the most pressing questions in astronomy and physics that are driving advances in big data science and computing.



Aerial view of the telescope dome enclosure and lift structure being built.

DESIGN LIMITATIONS FOR A MIRROR LIFT SYSTEM

Modern optical and infrared astronomical telescopes generally utilize large mirrors that require periodic recoating of their reflective surfaces to maintain the high-resolution imaging demanded by their scientific missions. The need to recoat these large mirrors requires stripping off the old coating and placing them in specialized coating chambers, generally located away from the telescope due to their size and utility requirements.

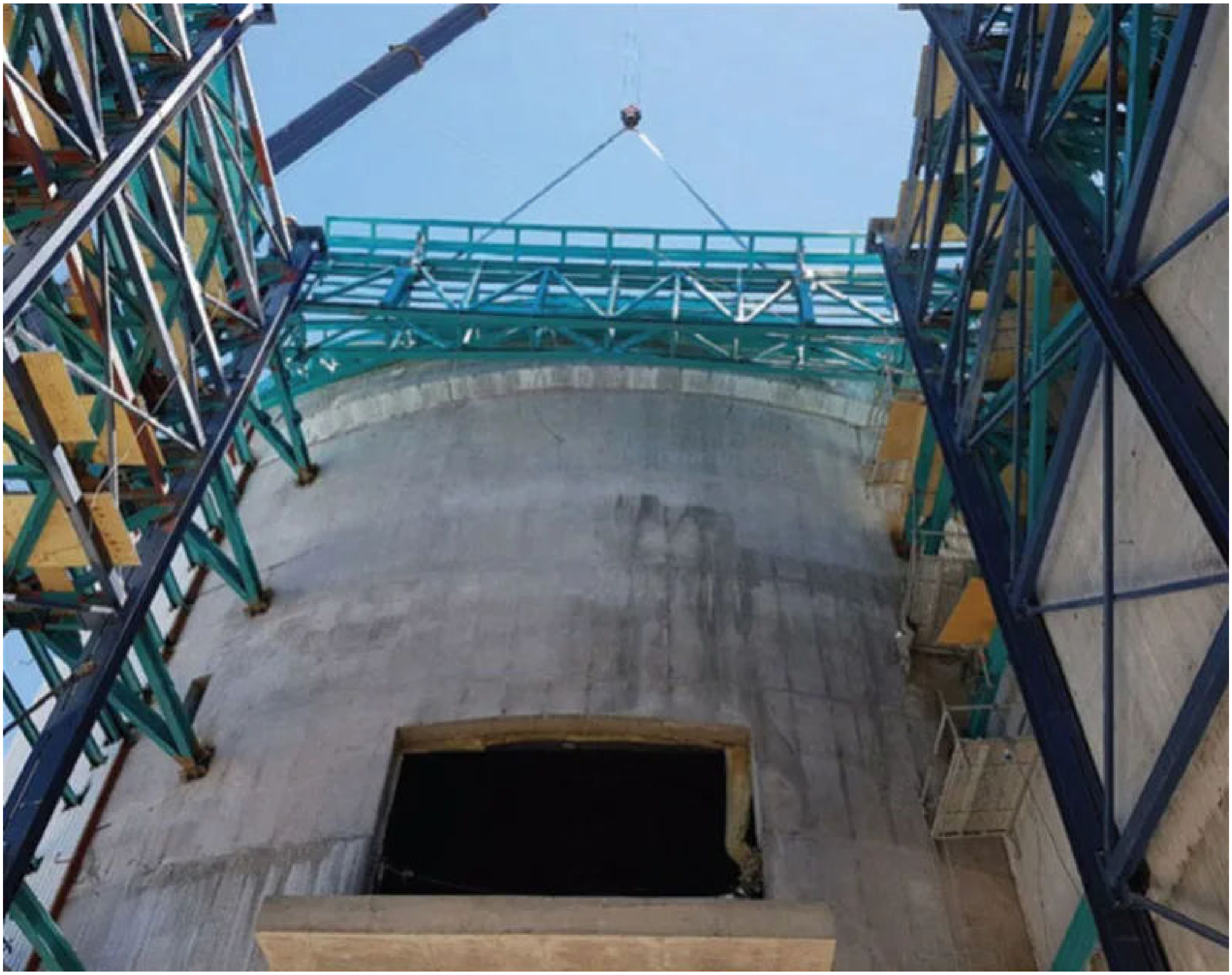
The methods devised to safely transfer these very large, heavy, and extremely critical optics from the telescope to the coating plant vary widely for different telescope facilities. Cranes mounted on domes conveying the mirrors through floor hatches, custom screw-post lifts within the enclosures, special trucks with jacking beds to lift and transport the mirrors, and even bringing the coating plant to the telescope have all been utilized at telescopes designed and built in recent decades. The wide support pier for the LSST telescope, however, did not allow space for lifts or hatches to be located within the telescope chamber that would be large enough to convey the primary mirror assembly, which is 27 feet in diameter and weighs in excess of 93 tons.

Adding to the design challenge, the mirror transporting method would be required to operate within a seismically active zone, safely absorbing seismic loads of up to 8.0 on the Richter scale, as well as resist 100-mph wind loads present on the mountaintop. Further, because the site's elevation is at 8,737 feet above sea level, the system would need to be factory pre-constructed and tested, disassembled for shipping within containers, and reassembled onsite at the LSST facility.

ENGINEERING CHALLENGE

The use of a vertical reciprocating conveyor (VCR) was identified as a likely viable option for the LSST mirror transporting system, although there were no known precedents for using a VRC to transfer large telescope mirrors. In 2010, LSST engaged Pflow Industries, which offers complete vertical lifting solutions, to conduct an engineering analysis for the design of a VRC solution for the lift.

"Designing a building to support the lift, and simultaneously resist the wind and seismic forces, proved to be difficult," said Jeffrey Barr, LSST Project Architect. "It was decided early on to incorporate the lift structure into the building design through collaboration between Pflow structural engineers and the Chilean structural engineers designing the facility."



The 80' vertical lift system is designed as a permanent and integral structural component of the telescope facility.

The Pflow solution envisioned was a permanently installed lift outside of the telescope dome enclosure, but integrated within the building structure itself that would rise up to the level of the dome and receive the payload of the mirror assembly through a back entry door. During normal telescope observing operation, all elements of the LSST lift and shaft would need to retract below the dome to stay out of the way of its rotation and out of the observing field of view of the telescope. This meant that the lift would need to raise the shaft roof when deployed to its upper position to receive the mirror from the telescope and deliver it back after recoating. The 80-foot-high lift would also need to be extremely reliable and flexibly designed to transport other large loads to various levels of the observatory facilities.

“During the design process, Pflow engineers worked closely with the LSST team,” said Mark Webster, Vice President of Engineering at Pflow. “We began with a set of approximate static equivalent loads based on the initial seismic and wind parameters, and designed an initial structural bracing scheme using finite element analysis (FEA) that would adequately support the lift during seismic and wind events. This information was shared with the Chilean engineering team along with SolidWorks models of the lift structure. After nine months of design review meetings, ongoing analysis, and exchange of structural analysis results, a final collaborative FEA model of the combined building and lift structure was created, and final structural modifications made based on the results."

The entire lift system incorporates approximately 160,000 pounds of fabricated steel.

INNOVATIVE LIFT DESIGN

Pflow engineers leveraged and extended existing well-proven industrial technology for this new specialized application. Many features have been incorporated to protect the mirror assembly during transport, and all critical lifting components have redundancy to minimize the chance of a catastrophic failure. Key specifications and innovative features were designed into the LSST mirror assembly lift.

1. The entire LSST lift system incorporates approximately 160,000 pounds of fabricated steel.
2. The lifting carriage consists of a 35 × 35-foot platform. Beneath it is an 11-foot-tall structure for support of the platform.
3. The lifting system was designed such that the failure of any single lift system component would not result in a loss of control of the load. Twelve lifting chains, powered by a pair of 60-HP gear drives weighing 6,500 pounds each, are incorporated with a combined tensile strength of 974 tons.
4. "Roller chain drives inherently have some vibration due to the chordal action of the chain as it is driven by the sprocket," added Webster. "The normal velocity of a lifting platform driven by a roller chain drive is not linear, but sinusoidal. A new chain drive arrangement (patent-pending)

was engineered to eliminate this chordal action, resulting in a linear carriage velocity and ensuring smooth platform velocity."

5. Two redundant motor/gear-reducer/ brake assemblies are provided and synchronized via shafts and couplings. Although the two motors and reducers share the load during normal operation, a single brake has adequate torque to support the entire load independent from the other.

6. The lift platform needed to be locked at each level to allow for the smooth transfer of the mirror aboard a wheeled cart riding on rails. Alignment of the rails was critical, and any motion of the platform needed to be eliminated. The Pflow solution was to provide carriage-mounted powered locks that automatically extend when the platform is at any floor level. "The control system automatically extends the locks and smoothly sets the platform onto the locks, relieving the tension from the lifting chains," continued Webster. "To accomplish this smoothly, a variable frequency drive is employed that slows the travel velocity to a low speed to minimize the impact when setting down onto the locks."

7. A guide system, located near the bottom of the carriage structure, allows the carriage to extend above guide columns and lift the 20,000-pound observatory roof section 15 feet vertically.

8. Due to the potential for seismic and wind events, the moveable roof section is mechanically locked to the building structure when in the normal lowered position. When the lift platform is raised to the roof level, another set of mechanical locks attaches the roof to the specially designed lifting structure at the top of the lifting carriage. It is important that the roof section is never left unlatched and unprotected from the potential of wind damage. A special lock system was developed that locks the roof section to the lifting carriage structure prior to unlatching the roof from the building structure. Only after signals are exchanged verifying that the platform locks are engaged are the building locks allowed to disengage and the roof raised.

Testing the 35 x 35 x 11' lift carriage assembly at Pflow facilities.

LSST CONSTRUCTION PROJECT

The LSST construction project is funded by the NSF and the DOE. The NSF supports construction of the telescope and site facility, data management system, and education and public outreach components of LSST, as well as the project management and system engineering efforts. DOE is providing the camera and related instrumentation. Both agencies expect to support post-construction operation of the observatory. Site and facility design, engineering, and construction are under the direction of, and managed by, the LSST architectural and design team, working in affiliation with an onsite Chilean engineering group.

As early as 2005, construction of the telescope's 8.4-meter-diameter primary mirror — the most critical and time-consuming part of a large telescope's construction — was underway at the University of Arizona's Richard F. Caris Mirror Lab. The following year, the site for the LSST telescope was selected at the El Peñón peak alongside the existing Gemini South telescope and Southern Astrophysical Research telescopes. The site is inland and approximately 60 miles by road from the support town of La Serena, where the LSST base facility is located.

Site excavation began in March 2011, followed by start of construction of the telescope facility in January 2015. Three years later, the facility has now been substantially completed. The vertical reciprocating conveyor is in the process of being fully completed and tested.

Engineering first light is anticipated in 2019, science first light in 2021, and full operations for a ten-year survey commences in January 2022.