Introduction to LiDAR and Its Uses in the Building Enclosure and Beyond

By Robert Hendricks, PhD

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ADVANCEMENTS IN LIGHT detection and ranging (LiDAR) technology have made it a useful tool in the building enclosure (BEC) industry. This article will review some basic LiDAR concepts and current industrial uses of LiDAR, showcase LiDAR's use in the BEC industry, and explore some other interesting applications of LiDAR. Note that this article is by no means a complete accounting of all LiDAR concepts, field practices, or applications; rather, it is written as a general review.

LiDAR is an active remote sensing method that uses light to measure the distance to a target, like a typical laser range finder. This technology was developed from laser altimeters and range finders and adapted to the imaging realm it is commonly found in today.

To measure distance to a target, LiDAR records the two-way travel time of a laser pulse. As the velocity of the laser pulse is known, the distance to the target can be calculated by dividing the travel time in half and multiplying by the velocity. This process is repeated thousands of times a second while changing the direction of the laser pulse, covering the target area. In addition to recording time-of-flight data, the LiDAR device collects information on the pulse phase and return intensity, as well as multiple reflection returns for each pulse. The result is a dataset of points with pulse reflection locations in an x,y,z format with additional data (phase, intensity, etc.) associated with each point. This dataset is often called a "point cloud," as the density of LiDAR data creates a diffused image of the object or area scanned. Modern LiDAR systems also collect high-resolution photography concurrently or associated with laser scans, adding an R,G,B (red, green, blue) color field to each of the points collected.

TYPES OF LiDAR

The various types of LiDAR devices can be classified in several different ways, but fielding method, a common classification, is most relevant for the BEC application. These methods include terrestrial LiDAR and mobile LiDAR.

Terrestrial (also know as "ground-based") LiDAR is collected using a unit that is stationary and typically mounted on a tripod. The LiDAR scans the surroundings in a spherical area around the tripod. The LiDAR is then moved to another position and another scan collected. This process is repeated while ensuring overlap between each of the scan sites. The individual scans are then compiled into a complete image of the site or object. This method is generally used to image objects of various sizes, interior spaces, or smaller exterior areas. Terrestrial LiDAR scanning provides the most precision and can be tied to other databases using ground control points.

Mobile LiDAR relies on moving the LiDAR through the site and the motion of the vehicle provides the method of advancing the scan. With mobile LiDAR, the field of view of the scanner is typically limited, facing one direction (e.g., downward for aerial LiDAR) or along a single or discrete number of planes. As the LiDAR is in motion, there is no need for individual scans to be compiled together to create the model. This method is fielded in large-area imaging and when a suitable vehicle is accessible.

A recent subset of mobile LiDAR is "drone" LiDAR. In this case, an unmanned vehicle or "drone" is used as the mobile LiDAR method of traversing a site. Commonly these drones are aerial, but advancements in robotics have allowed for land-based systems to be employed as well. While innovative, the general collection methods and product are still the same as described previously.

USE OF LiDAR

LiDAR has been used in many industries and fields for several years. This includes the creation of high-resolution digital elevation models for site surveys and environmental planning, construction monitoring, and the creation of

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as-built drawings and models. LiDAR has also been used to create digital twins of objects and spaces for archeological and architectural applications, forensic reconstruction, and the digitization of objects and spaces for video games and other entertainment purposes.

Within the field of BEC, LiDAR can be incorporated into many of the existing investigations and services commonly associated with the industry. As a tool, not a product, it can provide high-quality data while minimizing risk involved in collecting measurements and information. LiDAR is superior to traditional data collection methods in that it provides accurate, high-density data from a standoff distance.

Digital data collected with LiDAR can easily be integrated into geospatial or design software, such as computer-aided design and geographic information system, without loss of fidelity. The data can be shared with other interested parties easily via digital file transfer. This allows a user to "bring the field to the expert instead of the expert to the field." Multiple interested parties can view or work with the same dataset to accomplish the same task or unique tasks.

The LiDAR scan can serve as a measurable historical record, creating a model of the site as it existed at the time of the scan. Users can look back on this record to identify issues or holes in other data sets that might exist. While the LiDAR data may have been collected for a particular reason or to answer a specific question, the completeness of the scanning process (collection of data from the area around the scanner) allows for the data to be used for other purposes, including ones that might not have been realized at the time of the scan. As the previously mentioned information shows, LiDAR has many potential use cases in the BEC field. Some examples are included in the following.

Creation of Line Drawings

Projects may require the use of a general building exterior facade drawing or an interior layout drawing. In some cases, generally with older buildings, these resources do not exist, are of poor quality, or have not been modified to reflect current conditions. LiDAR has been used to provide the point cloud on which a current drawing can be created.

Due to LiDAR's high data density and accuracy, these drawings' accuracy replicates the existing conditions. Further, the standoff distance at which LiDAR can obtain data (tens to hundreds of feet) allows for collection from safe, accessible locations rather than more precarious ones that might be required with manual measurement. This is particularly useful for high-rise buildings.

Surface Modeling

Relative floor elevation (RFE) data has been used to identify depressions or heave in building slabs that could indicate internal or external factors. The density of LiDAR data measurements means that while analog systems might collect 200 data points within a space, the LiDAR will collect 200 million data points in the same space. The density of the LiDAR data point cloud allows for minuscule variations in both elevation and gradient to be observed. This density also eliminates human bias, as all points within the range of the device are collected and incorporated into the cloud.

LiDAR data is collected in a digital format and as a result does not require the analog-to-digital conversion common in other methods. This reduces the overall post-data-collection processing time. Data points from objects not associated with the scan surface can easily be filtered out while preserving the data from the investigation surface. While typical RFEs are collected on horizontal, or nearly horizontal, surfaces, LiDAR collects data from all interior

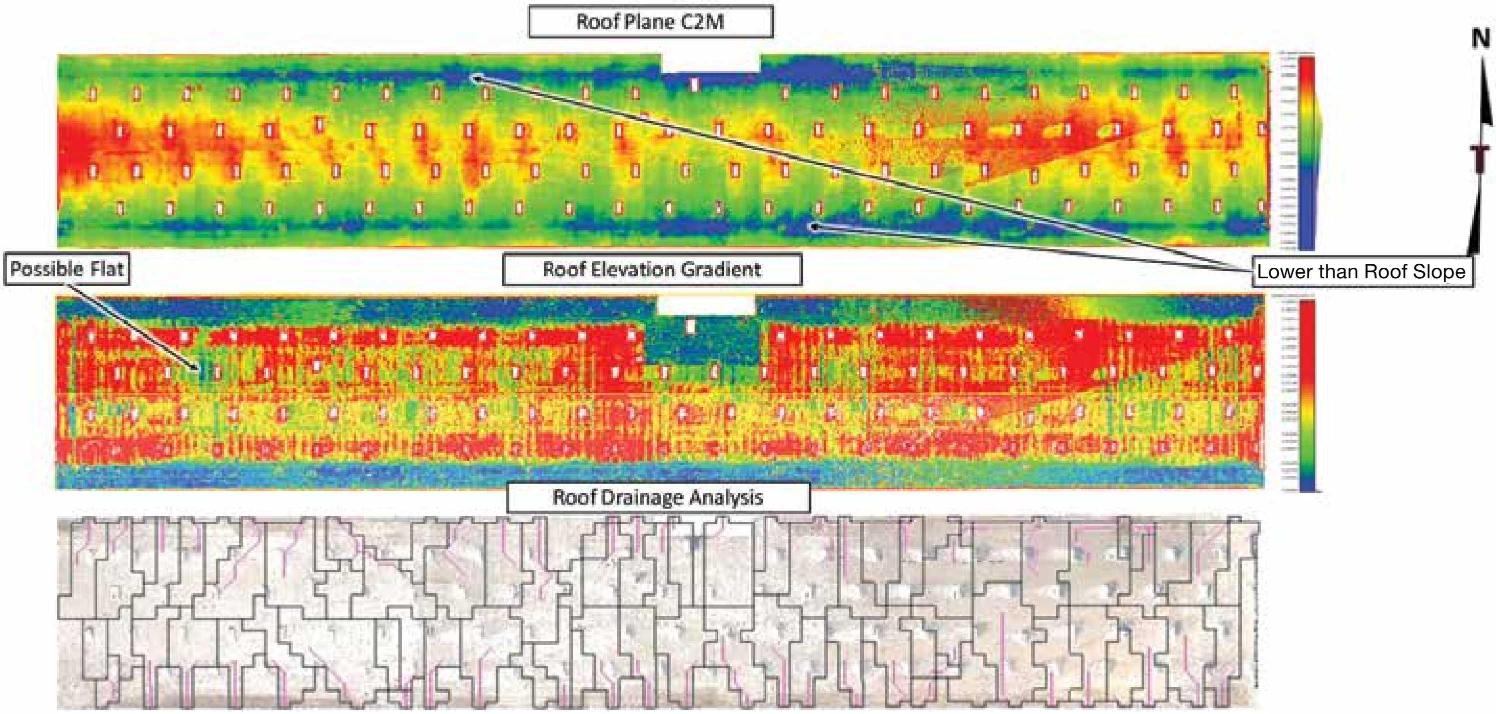

Figure 1. *A collection of roof LiDAR point cloud data classified by spatial components. Top is a cloud-to-mesh (C2M) analysis of the roof using planes fitted to the roof slope (one plane each side, scale is the same). Note that there appears to be variation from the slope concurrent (highlighted in blue) with the location of the wall panels. Middle is an analysis of the roof elevation gradient. A possible "flat spot" is noted in the western part of the roof. Bottom is a drainage-basin analysis conducted from the elevation data and set over the roof image. The basins are shown in black and the possible flow paths in pink.*

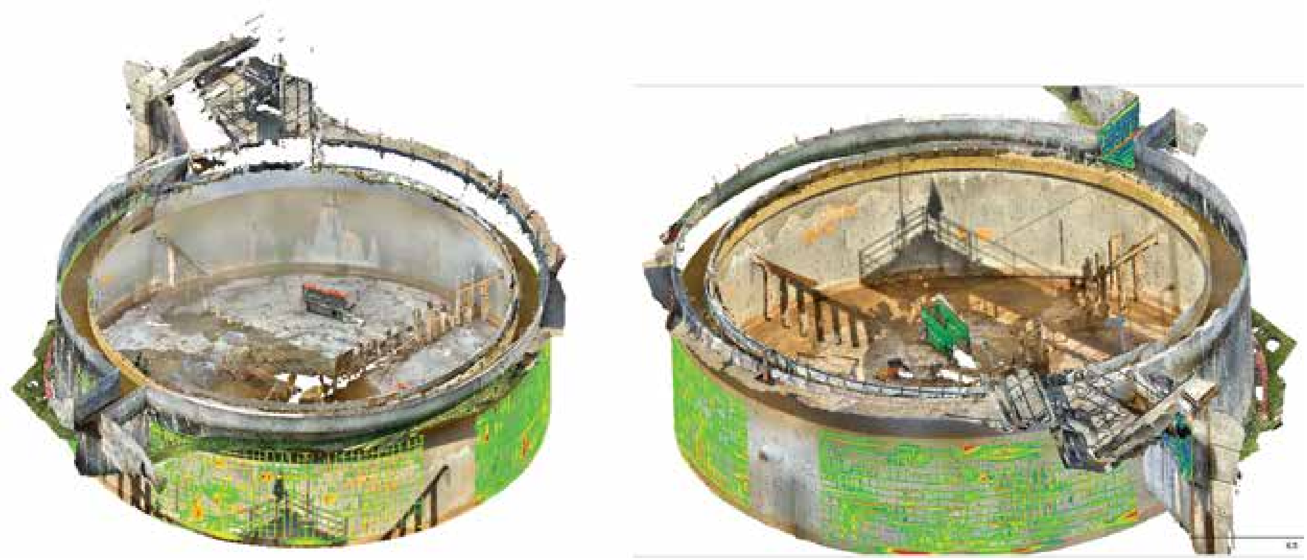

Figure 2. *This project involved using ground-penetrating radar (GPR) and other nondestructive methods to determine the construction and condition of a water tank built in 1941. The investigation focused on the tank walls and the accessible areas of two flumes that feed the tank. Individual GPR scan lines were assembled into three-dimensional GPR models. These models were then exported to the point cloud software. The GPR models of the tank walls are inherently flat and a conversion was designed by the project team to curve the models to fit the tank walls. The flume GPR data did not require this conversion. The figure shows the complete LiDAR and geophysical model exhibiting both the surface features of the tank and the subsurface GPR reflections.*

surfaces within its line of sight. As a result, analysis can be conducted on not just floors (RFEs) but also on walls, ceilings, stairs or risers, sloped surfaces, and cylindrical surfaces (**Fig. 1**)—hence the term "relative surface model" (RSM). This not only expands the services offered but allows for a more complete analysis of the building distress as a whole system.

Further, as the measurement is conducted with a laser, there is no need for the operator to physically reach the floor areas being scanned. This can increase safety (e.g., the operation does not need to go into a hazardous area to collect data but instead can scan from a safe distance) and allows for the collection of data in areas that might otherwise be obscured (under tables or in tight quarters).

Facade Analysis

LiDAR has been used not only to construct the exterior building drawings for facade analysis, as mentioned earlier, but to conduct the analysis itself. The high-resolution data from the scan can be filtered and analyzed to highlight changes in the surface topology where cracks and spalls have occurred. Where positive changes are noted could indicate possible displaced facade. This application allows users to quickly evaluate a building from a safe distance (often from the ground or other buildings in the area) and target specific areas for additional inspection. As many municipalities require regular evaluation of facades, LiDAR is a quick and accurate option for initial inspections.

“4-D” Analysis

The accuracy, precision, and high resolution of LiDAR allow for multiple scans to be seamlessly combined. This accuracy and precision allow for scans of the same space, collected at different times, to be reliably compared to one another, resulting in the ability to track movement of the space over time. LiDAR software can then highlight three-dimensional (3-D) discrepancies between the two clouds, effectively showing changes over time (hence the term “4-D analysis”). This type of analysis can be used in conjunction with the applications mentioned earlier to monitor sites and determine rates of change.

Offset Analysis and Design

The orientations of real-world objects, such as wall panels, window framings, or other building elements, can be compared to those in a 3-D design of a space using LiDAR. By applying a similar process as described earlier, the LiDAR data can be imported and referenced to the digital design model. Where the digital model and LiDAR cloud are offset would indicate a real-world deviation from the design. These errors could be critical to other building elements and functions, including clearance spacing and building efficiency. Multiple scans of the area can be used to show the progress in construction over time.

In a reverse of this process, LiDAR scans of an existing building or space can be directly imported into various design programs and used as a base plan for building renovations or modifications. The LiDAR cloud allows the user to design from the true conditions at the time of the scan and not from other documents (such as original building plans), which may or may not represent the true conditions onsite.

“Reality Capture” and “As-Built Record”

The spatial (x,y,z) and spectral (R,G,B) data collected by a LiDAR scan captures a space or object as it existed at the time of the scan. As such, it can be used as a quantifiable, high-resolution record similar to a site photo. In this case, no analysis of the data is required, but the data is saved if an analysis is needed in the future or if future data needs to be compared to the conditions at the time of the first scan.

This practice method is superior to individual site photos, as the entire space is documented. The scans can then be used to determine measurements for future uses if needed, not just those associated with the initial scanning.

LiDAR also provides an unbiased look into the past of the site, which can be critical for forensic investigations. While site personnel are a great source of information about past conditions, their information can be skewed by on-site exposure and their qualitative descriptions (e.g., “that crack has always been there but now it is bigger”) do not provide the most effective data for an investigation.

Incorporating Other Data

LiDAR data provides information on the surface

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orientations of objects and spaces. However, many investigations and projects involve the need to view subsurface features as well. While LiDAR cannot do this, other investigational techniques, such as geophysical methods, can. Combining surface data from LiDAR and subsurface datasets from other methods creates a single cloud that includes both visible and nonvisible features (**Fig. 2**). This model can be manipulated in 3-D space to provide the best view of both features and cloud-to-cloud calculations can be conducted between datasets to provide enhanced analysis. This technique allows for a more complete view of the site conditions that can aid in the overall investigation or project.

CONCLUSION

This article is not a complete accounting of the applications of LiDAR to the BEC industry, and as technology advances, the applications of LiDAR will be expanded. LiDAR is not a specific service but rather a tool with which to create a more realistic representation of the real world in a digital format that can be shared and viewed easily in a spatial context, to the benefit of the building design and management team. This preservation of existing conditions allows for data that pertains to the health, safety, and welfare of building users to be accessed and analyzed in a detailed, accurate, and spatial context. The spectral and spatial data obtained by LiDAR can be used like any other data obtained; it is simply a fast, more accurate, and more complete method for collecting the data.

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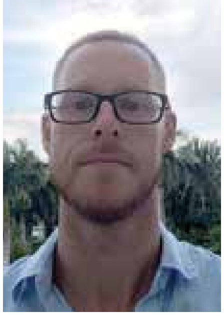

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Robert Hendricks, *PhD, is Terracon's Imaging Task Group Leader and the senior staff geophysicist for the facilities group in Terracon's Dallas office. During the course of his research, Hendricks has made use of multiple geophysical and 3-D modeling technologies, including light detection and ranging, or LiDAR. Since Hendricks joined Terracon in 2017, he has been leading an initiative to integrate LiDAR technology into Terracon's repertoire. He has conducted numerous building enclosure works (both with and without geophysical and LiDAR technologies) as well as a cornucopia of LiDAR-based analysis projects.*

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Foundation grant

Foundation Approves Research Funding on Spandrel Glazing Systems

THE RCI-IIBEC FOUNDATION has approved a grant for research into the thermal performance of spandrel assemblies in glazing systems in collaboration with the Charles Pankow Foundation. This is the second phase of the Pankow Foundation's study of spandrel glazing.

According to the Charles Pankow Foundation grant request, the current state of practice for evaluating spandrel assembly thermal performance is lacking, and the analytical approaches are inconsistent. Right now, building codes and standards are inadequate, leading to variable design execution on projects. While energy codes have become more stringent, spandrel assembly technologies have largely remained the same. Glazed wall systems, including curtainwall and window wall, are facing criticism due to their perceived high levels of embodied carbon content. This spandrel project will study how targeted embodied carbon "investments" (e.g., amount of insulation, insulation type, framing material) can yield meaningful reductions in operational carbon emissions over the life of a building.

"This is a slam dunk for the foundation," said Mike Blanchette, chair of the RCI-IIBEC Foundation. "The two foundations recognize there is a need for improved design guidelines and consistency in calculation methods to identify opportunities to improve materials, details, and systems, and to inform future code provisions."

"The Charles Pankow Foundation is proud to lead this industry-critical research that ultimately will improve building energy performance and reduce carbon emissions," said Rik Kunnath, Charles Pankow Foundation president.

Testing will occur at Oak Ridge National Laboratory, and thermal modeling will be performed by Lawrence Berkeley Laboratory and the engineering team of RDH, Morrison Hershfield, and Simpson Gumpertz & Heger.

Research is expected to be completed by September of 2024. Funding for this project was made possible by the donations to the RCI-IIBEC Foundation's General Fund for Research and Education.

For more information, visit the foundation's website at https://rci-iibecfoundation.org/donate.aspx or contact Foundations Development Officer Rick Gardner at 919-859-0742 or rgardner@iibec.org.