Construction Engineering Requirements for Integrating Laser Scanning Technology and Building Information Modeling

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Abstract: Laser scanning for rapid spatial data acquisition is an established technology in the architecture, engineering, and construction (AEC) sector with a wide range of applications. An understanding of the wide variation of technical requirements and considerations associated with these applications is critical to decision making about laser-scanning implementation on projects. Furthermore, significant industry transformations in the use of building information modeling present extraordinary opportunities for AEC professionals to employ the use of laser scanning in the context of holistic, collaborative workflows grounded in three-dimensional model-based design. This report analyzes the construction engineering requirements of laser scanning technology for applications across all phases of the project life cycle and proposes a multidisciplinary framework to integrate applications of laser scanning technology with the fundamentals of three-dimensional model-based design. **DOI: 10.1061/(ASCE)CO.1943-7862.0000322.** *© 2011 American Society of Civil Engineers.*

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Introduction

Research Objectives

Laser-scanning technology has numerous applications within the architecture, engineering, and construction (AEC) sector. As more projects implement workflows based on building information modeling (BIM), it is useful to determine how laser-scanning technology can be applied to support a three-dimensional (3D) model-based design workflow by rapidly acquiring 3D data representing the built environment. Industry reports indicate that BIM approaches, among other benefits, can improve life cycle management of facilities (McGraw-Hill Construction 2009). Furthermore, combining laser scanning with BIM can yield significant advantages over traditional approaches by facilitating design and construction activities on the basis of accurate, fully representative existing conditions captured with laser scanners. This approach of integrating as-built and as-designed data sets enhances the efficiency of information management and results in improved reliability of the project model (Goedert and Meadati 2008). In addition, the approach facilitates integration of the design and construction phases, which can present significant opportunities for advancing implementation of technology on construction projects (Nam and Tatum 1992). The presented research seeks to accomplish the following objectives:

- Summarize types of 3D range imaging and discuss technical requirements and processes for the acquisition, interpretation, and application of range data;
- Identify and categorize current and potential applications and specify phases of implementation in the construction project life cycle; and
- Propose 3D model-based design workflows and present a framework for application of laser scanning technology.

Three-Dimensional Model-Based Design

The National Institute of Building Sciences defines building information modeling as a "digital representation of physical and functional characteristics of a facility," that is, a shared knowledge resource for facility information that facilitates decision making throughout the project life cycle (National Institute of Building Sciences 2007). Recent industry transformations toward the implementation of BIM workflows have been far reaching and widespread, presenting extraordinary opportunities for technological innovation and process structuring to improve construction efficiency. Adoption has been rapid, with nearly half of AEC professionals implementing BIM, an increase of 75% in the past two years (McGraw-Hill Construction 2009). The shift toward standardization of BIM processes is an important factor to consider for laser-scanning implementation because field data acquisition technologies can potentially play a central role in updating 3D models frequently based on reliable data sources to monitor and manage project information (Hajian and Becerik-Gerber 2009). The combination of these two technologies has important implications for analyzing and comparing as-built and as-designed data throughout the project.

Laser Scanning for Construction Projects

Three-dimensional (3D) imaging systems are instruments that rapidly perform thousands of measurements per second of 3D coordinate positions of objects within a region of interest [U.S. General

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Services Administration (GSA) 2009], serving as a digital representation of existing site conditions. Several terms for 3D reflectorless imaging systems exist:

- *3D laser scanner* refers to terrestrial (stationary), mobile (vehicle-mounted), or aerial (aircraft-mounted) scanning devices that emit a laser to determine distance measurements through pulsed time-of-flight (TOF) or phase-based imaging (GSA 2009);
- *Laser detection and ranging (LADAR)* is a term for 3D laser scanning systems that obtain multiple distance measurements within a scene in the form of a point cloud (NIST 2006), a term commonly used for government-supported detection-related systems (Teizer and Kahlmann 2007);
- *Light detection and ranging (LiDAR)* is a term for aerial 3D laser scanning systems that are typically mounted on helicopters or airplanes equipped with inertial global positioning system (GPS) navigation systems that monitor aircraft orientation, roll, pitch, and yaw (Schaefer et al. 2005, Kraus and Pfeifer 2001); and
- *Flash LADAR*, also referred to as a 3D video range camera, describes a broad-field illumination source (NIST 2006) that uses a single light pulse to illuminate areas for real-time data capture in dynamic scenes (Teizer and Kahlmann 2007).

These systems are generally capable of capturing data related to distance (range), intensity, and color, and can be integrated with photography/video, inertial management units (IMUs), and GPSs. Laser-scanning workflows for these systems can be broadly described in three major steps: acquisition, interpretation, and application. The following sections will discuss the technical requirements for each phase of the laser-scanning process and will explicitly identify the relevant inputs and outputs of the process.

Point Cloud Data Acquisition

Scope Definition

Before any activity takes place in the field, it is important for practitioners to develop a strategy for data acquisition, beginning with the formal definition of the scope of field activities (see Fig. 1). A goal-oriented approach should be emphasized because the end use of the acquired data explicitly governs the goals of the laser-scanning survey. The decomposition of survey goals is integral to the effective data collection on site (Tang et al. 2007), and it drives decisions for all downstream activities. Corporate or agency requirements such as programming guidelines and procedures will also influence the scope definition and should be formally outlined in the contractual documents with laser-scanning subcontractors.

Planning

The survey goals defined in the scope definition should be combined with measurement and inspection goals to begin identifying equipment specifications. The selection process should begin by first identifying whether aerial, mobile, or terrestrial scanning is appropriate on the basis of the precision and accuracy required to achieve survey goals. Equipment selection criteria include the range accuracy, useful range, field of view, resolution, scanning speed, and georeferencing and registration methodologies used for combining multiple scans within a common coordinate system (Hiremagalur et al. 2007). Practitioners must also determine if additional data types must be collected, such as photo or video of the site. Because of the massive amount of output data resulting from capturing dense point clouds, these supplemental data sets can be helpful during interpretation of data, and several commercially available systems have this functionality built into the scanner (Leica Geosystems 2010).

Field Operations

Field conditions and target-object-surface properties can heavily influence the accuracy of the acquired data. Performance-influencing variables in the field include the beam width, the angle of incidence for scans, and the object characteristics such as color and reflectance (Hiremagalur et al. 2007). Site conditions such as high winds can influence the precision of scanned data (Jaselskis et al. 2005), and these field conditions combined with systemic errors can result in accuracy variances in the field from the technical manufacturer's specifications for scanned objects (Kiziltas et al. 2007). Consideration of target-object placement and careful planning of scanner and target positions can reduce poor precision results because of mixed pixels and other systemic problems (Mills and Barber 2004), but it is good practice to capture multiple scans from different positions to validate uncertain field conditions if present. Multiple scans must then be registered, which describes the process of establishing all scans acquired from different field positions in a common coordinate system. This is accomplished manually using the placement of reference targets in the scanner's field of view (Kiziltas et al. 2007). Registering both 3D computer-aided design (CAD) models and 3D laser scans in a common coordinate frame can provide an integrated

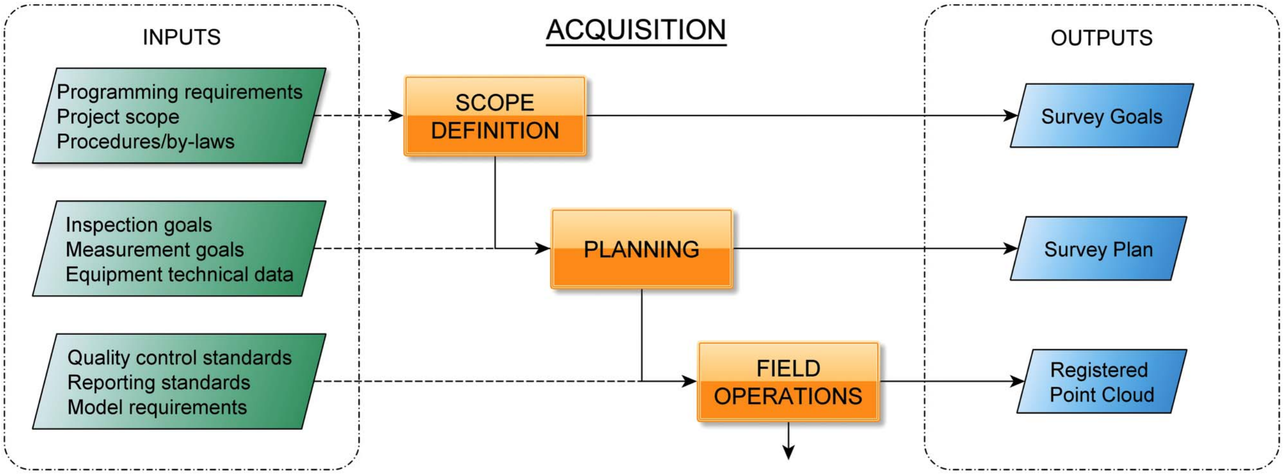


Fig. 1. Process map for laser-scanning data acquisition

data query tool for analyzing objects (Bosche et al. 2009) and is an essential step for establishing a system for 3D analysis throughout the project life cycle.

Data Interpretation and Object Recognition

Quality Control

After the point cloud has been registered, it is important to begin by filtering out noise and other unwanted points in the cloud (see Fig. 2). Unstructured, dense point clouds that result from field operations can be difficult to work with because there is no distinction between objects or areas of the site and the data set may be too detailed for many types of analysis. A system of quality control should be introduced to filter unwanted points manually or on the basis of criteria such as right of way, field of view, or other project guidelines. This process, which can be a combination of manual and automated methodologies, eliminates erroneous readings and unwanted points such as vegetation, stockpiles, equipment, vehicles, or other objects that are not needed to accomplish survey goals, resulting in a filtered point cloud.

Classification

Numerous methods have been introduced to automate extraction of geometric features from point clouds to identify and classify different objects within the cloud. These methods include the automated elimination of vegetation and buildings for creating digital surface models (Axelsson 2000; Kraus and Pfeifer 2001) and iterative extraction of planar surfaces and parametrized shapes (Vosselman et al. 2006), functions now available in many off-the-shelf commercial software systems. Whether accomplished manually using constraints analysis (such as elevation or shape files) or automatically with software or programming tools, the optional classification process categorizes points on the basis of user input and creates "layers" of points similar to computer-aided design and drafting (CADD) conventions. This allows users to more easily accomplish survey goals by isolating key areas of the site for analysis.

Mesh and Surface Modeling

Although many types of analysis are possible with classified point clouds, it is often more useful to create 3D surface models that represent the scan data. This process involves creating triangular irregular networks (TINs) or meshes using the coordinates of the points as vertices to define a surface. Approaches have been used to identify objects and automatically create surface models using geometric primitives (Chen and Chen 2008; Vosselman et al. 2006), which fit known planar objects to scan data and create a representative surface. Generated surfaces can be directly compared to BIM models to evaluate as-built versus as-planned conditions, and can be integrated with site monitoring procedures to assess and visualize construction progress (Shih et al. 2004).

Applications of Point Cloud Data

Categories of Application

This report classifies the myriad applications of laser scanning for construction projects into four major categories in order of the level of detail: rapid urban-scale modeling and mapping, infrastructure asset management, construction site monitoring, and structural analysis and inspection (see Fig. 3). The key metric for establishing this system of classification is the accuracy and precision (i.e., "range uncertainty") required to achieve survey goals established in the scope-definition phase of the laser-scanning process. This in turn drives the approximate distance to the target objects and the corresponding point density of the resulting point cloud. Note that 3D surface models are not mandatory for all applications—classified, filtered, and even simply registered point clouds may provide the necessary information to accomplish the goals of the application depending on the application requirements, which should also be specified during scope definition.

Rapid Urban-Scale Modeling

One of the key advantages to laser scanners is the ability to rapidly acquire range data for large geographic areas, a capability that presents numerous opportunities for large-scale data acquisition and management. An understanding of the 3D characteristics of metropolitan areas, including both terrain features and the built environment, is useful for better understanding and managing urban development decisions from the programming phase through to facility management. City-scale project analyses must rely on known characteristics of individual urban structures, which often consist of a variety of as-built plans in printed and digital format with unknown quality. For large urban areas, it is not feasible to assess these individual records, and aggregation of the information would be by necessity a manual process. To address these issues,

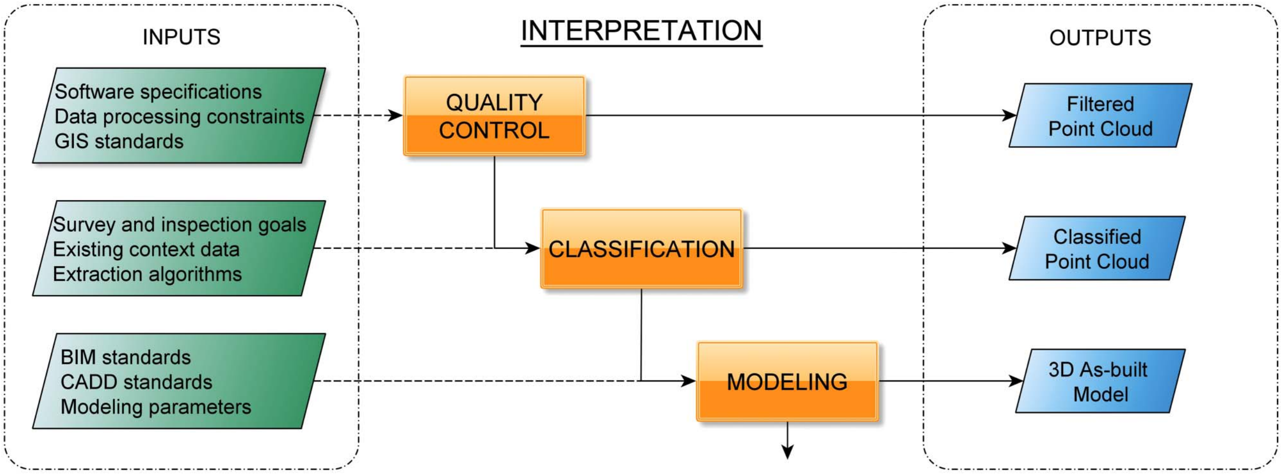
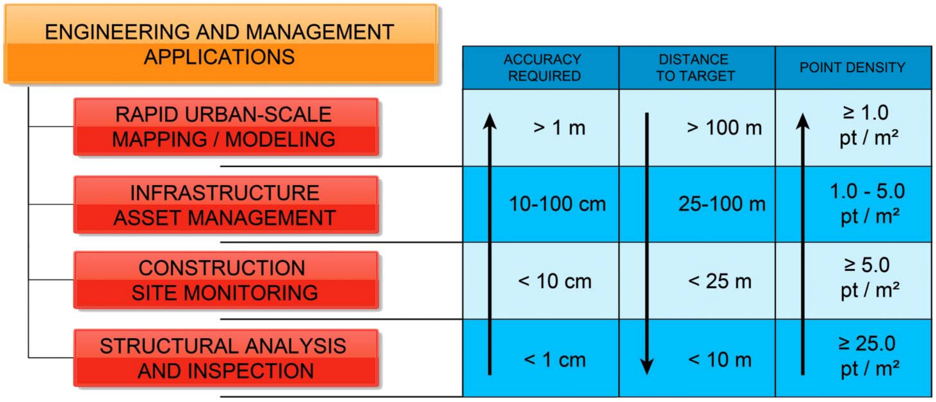


Fig. 2. Process map for laser-scanning data interpretation



ENGINEERING AND MANAGEMENT APPLICATIONS	ACCURACY REQUIRED	DISTANCE TO TARGET	POINT DENSITY
RAPID URBAN-SCALE MAPPING / MODELING	> 1 m	> 100 m	≥ 1.0 pt / m²
INFRASTRUCTURE ASSET MANAGEMENT	10-100 cm	25-100 m	1.0 - 5.0 pt / m²
CONSTRUCTION SITE MONITORING	< 10 cm	< 25 m	≥ 5.0 pt / m²
STRUCTURAL ANALYSIS AND INSPECTION	< 1 cm	< 10 m	≥ 25.0 pt / m²

Fig. 3. Classification and metrics for laser-scanning applications

a number of approaches have emerged to automatically generate digital surface models (DSMs) of cities from point clouds acquired with aerial LiDAR that represent the built environment. The resulting 3D city models have virtually endless applications for programming and permitting activities, integration with facility management systems, urban planning, and maintenance of public facilities.

Urban-scale modeling and mapping applications typically begin with aerial LiDAR data capture because of the scale of the target area, but may be supplemented with additional technologies to identify more detailed features of the environment. To address complex requirements for level of detail, acquired aerial and mobile scans can be registered together, surfaced, and combined with aerial imagery to create texture-mapped city models, which accomplishes the complete regional coverage needed and the detail required for walkthroughs (Fruh and Zakhor 2003). Practitioners should be careful to identify key areas in the flight-optimization plan at which sudden elevation changes and beam divergence can cause poor edge detection and mixed pixels (Vosselman and Dijkman 2001; Kiziltas et al. 2007). These problems can be reduced by optimizing flight paths at an approach angle of about 45° to the urban gird (Hinks et al. 2009) and combining known information such as building break lines to eliminate spatial discontinuities (Zhou et al. 2004). The surface characteristics of the target object should also be considered to avoid errors owing to high surface reflectance or light and weather conditions in the area.

Infrastructure Asset Management

Because of the massive value of infrastructure assets such as capital and private facilities, water and power infrastructure, and road networks, significant benefits can be realized from better recording and managing of the built environment. Budget, personnel, and resource constraints often force public agencies into a reactive approach to maintenance and replacement of deficient assets. Proactive planning and improved management procedures can provide significant advances in acquiring information about existing assets, which is often disparate and incomplete. Significant losses have been noted because of the difficulty in obtaining information about existing assets, such that over US$5.4 billion is wasted per year on operations and maintenance engineers verifying the accuracy of existing information and transferring information related to existing U.S. capital facilities (Gallaher et al. 2004). Existing studies imply that understanding and recording details about infrastructure assets can lead to improved management, operations, and maintenance, which reduces efficiency losses and associated labor costs.

An important goal of infrastructure asset management applications is to understand the maintenance and replacement needs of existing assets, which is primarily applicable to public agencies and large corporations. For larger assets such as road networks and land holdings, digital surface and terrain models can be extracted from aerial LiDAR data to assess infrastructure conditions (Priestnall et al. 2000; Axelsson 2000; Fruh and Zakhor 2003) and compare terrain models with the built environment. This regional data can be analyzed to help enable agencies determine the likelihood of damage risks and to assess damages for restoration and rehabilitation efforts (Priestnall et al. 2000), such as risks associated with highway slopes (Duffell and Rudrum 2005; Kemeny et al. 2008), dam slopes (Schaefer et al. 2005), and coastal bluffs (Collins and Sitar 2005) that are susceptible to instability or failure because of changing geological conditions. For highway infrastructure assets, maintenance plans can be generated on a metropolitan or regional scale by establishing a framework for analyzing mobile and aerial scan data. This framework can be integrated into existing management systems, such as hazard and deficiency rating databases, inspection results, and historical resource records (Kemeny et al. 2008; Duffell and Rudrum 2005; Hughes and Louden 2005) to monitor maintenance and replacement needs.

Construction Site Monitoring

Infrastructure construction sites are complex, dynamic, and dangerous places. The construction industry has the highest number of fatalities of any industry, accounting for over 18% of all fatal occupational injuries (U.S. Dept. of Labor 2010). This statistic implies that increased safety is of paramount concern on construction sites and improved monitoring of construction activity can improve planning and dynamic response, which will lead to better awareness and prevention. Formal records and visualizations of site activity over time will likely lead to improved planning on future projects and enhanced comparisons between as-built and as-designed data sets during the project life cycle. Progress monitoring also appears to have potential for improving assessments of completed work and performing in-progress inspections because of rapid acquisition rates and improvements to worker safety in comparison with traditional surveys (Jaselskis et al. 2005).

The dynamic nature of construction sites leads to unique technical requirements for scan applications. A frequent, complete, and accurate assessment of the site conditions and an understanding of scope–schedule relationships to on-site activity are crucial elements of a proactive quality control strategy (Akinci et al. 2006). For high-level assessments of progress, terrestrial scanners capturing dense point clouds can be used to perform object identification and comparison with construction schedule activities. For BIM projects that maintain a four-dimensional (4D) computer model of the planned activities on site, sequenced scans taken at different times on site can be used to compare the planned activities with the actual progress in the field (Shih and Wang 2004; Shih et al. 2004). To facilitate a comprehensive understanding of the site, it is important to establish the scope of the monitored area and place reference targets in positions visible from each scan location (Shih and Wang 2004). Successful applications of a series of terrestrial laser scans have also been demonstrated for calculating volumes of materials (Hashash et al. 2006) and assessing adjacent deformations and ground movements over time (Finno and Hashash 2006; Laefer et al. 2006).

For highly active work sites and for survey goals requiring very rapid capture rates, flash LADAR technology (i.e., 3D range cameras) can be used to capture a low-resolution range and intensity image in near-real-time when terrestrial scanning is not feasible (Lytle et al. 2005; Teizer and Kahlmann 2007). By combining a flash LADAR approach with digital photo capture and close-range photogrammetry, practitioners can create photo documentation of site activity (El-Omari and Moselhi 2008; Bohn and Teizer 2009), which may be applicable for training, billing, and additional managerial tasks. This technology also shows potential for obstacle detection and avoidance systems (Teizer et al. 2007), which may improve equipment efficiencies and worker safety when applied to autonomous heavy-equipment operation (Son et al. 2008). These technological approaches can provide additional benefit when integrated with project management systems, which can synthesize project goals and assist in driving decisions such as equipment selection, scan locations, and analysis frameworks.

Structural Analysis and Inspection

Assessments of structural integrity provide useful information about construction quality, maintenance needs, and potential safety risks. Whether these assessments are part of an asset-management strategy or whether the performance of individual structures or components is of interest, laser scanning technology provides a useful means to inspect and analyze structures in the built environment. In the United States alone, there are nearly 150,000 bridge structures that have been classified as structurally deficient or functionally obsolete, representing almost 25% of all bridges in the country (Federal Highway Administration 2010). Studies suggest that laser-scanning technology can provide benefits for understanding the detailed condition of bridges and other structures by analyzing 3D point clouds and representative surface models of structures (Fuchs et al. 2004; Jaselskis et al. 2005; Gordon and Lichti 2007; Walters et al. 2008; Thayer and Hallmark 2009), which can be used to develop a systematic approach to maintenance and replacement. Structural-analysis applications, aside from point comparisons, may require the use of 3D surface models to accomplish survey and inspection goals. Three-dimensional surface models on the basis of dense point-cloud data are inherently much more accurate than the single-point accuracy of traditional surveys, as the error of the model is equal to the range uncertainty of the scanner divided by the number of points in the cloud, according to least-squares adjustment theory (Kiziltas et al. 2007). Field personnel can achieve very high-accuracy surface models even for larger structures by carefully planning control points for registration and operating the scanners at the lowest possible range, which maximizes point density and reduces mixed pixels. Characteristics such as length, width, height, area, volumes, and alignments are examples of component attributes that should be explicitly identified in survey goals (Tang and Akinci 2009).

Terrestrial laser scanning can support identification of component position and camber/deflection for structures and can validate design and regulatory compliance in the field through analysis of point clouds. To accomplish this, the selection of optimal scanner configuration on the basis of current site conditions is important to reduce field time and data-processing requirements (Akinci et al. 2006). Scanner configurations should be optimized by defining a line-of-sight field of view for scanner positions that can accomplish one or more surveying goals within a single scan, which may require significant planning for highly dynamic sites. For scans of structures, field personnel must avoid a condition called "naive scanner saturation," which describes the acquisition of numerous unstructured point clouds without properly considering inspection objectives, which may yield insufficient data to extract surveying goals for structures (Gordon et al. 2003). Field personnel should be careful to evaluate data quality for scans near the maximum range of the scanner because the relatively low point density at these distances may not be sufficient to accomplish survey goals (Kiziltas et al. 2007). Identifying these and other systematic errors induced by mechanical movements of the scanner and its inherent measurement accuracy is an important aspect of developing a survey plan for field operations (Olsen et al. 2010). Overall, the volume of measurements acquired by terrestrial scanning is adequate for most structures, and the analysis can be performed with minimal setup time and traffic impact when compared to traditional methods (Fuchs et al. 2004).

Workflows and Processes

Life Cycle Approach

The scope of applications and associated technical requirements for 3D range imaging warrants a life-cycle approach to implementation that prioritizes accurate information transfer across project phases and among project team members. This approach supports the use of building information models developed as part of a 3D model-based design process and encourages interparty collaboration. Industry practitioners rated improved multiparty communication and understanding as the most important benefit of BIM (McGraw-Hill Construction 2009), a goal that can be supported by integrated as-built and as-designed data. An integrated life-cycle approach for BIM projects using laser scanning has potential for improving decision making throughout the project by supporting the structured transfer of information to downstream activities in the project schedule. A formal review process should be introduced between each major phase of the project to validate project objectives and review planned processes. The process map in Fig. 4 shows these integrated BIM and laser-scanning support processes for each phase of the project life cycle and should be referenced throughout this section.

Scanning equipment can be cost prohibitive when compared to traditional survey methods, but additional life-cycle value is realized by the complimentary uses of acquired point-cloud data (Duffell and Rudrum 2005) and the additional range, intensity, color, and photo/video data provided by the scanner that is not available from total stations. Laser scanning can also reduce or eliminate nonvalue adding activities through improved field efficiencies and corresponding management processes with missing communication loops (Kiziltas et al. 2007). Furthermore, cost and schedule savings can often be realized simply through integration of engineering and construction planning because of high dependencies across disciplines (Tatum 1984). One way to integrate planning activities for design and construction is through

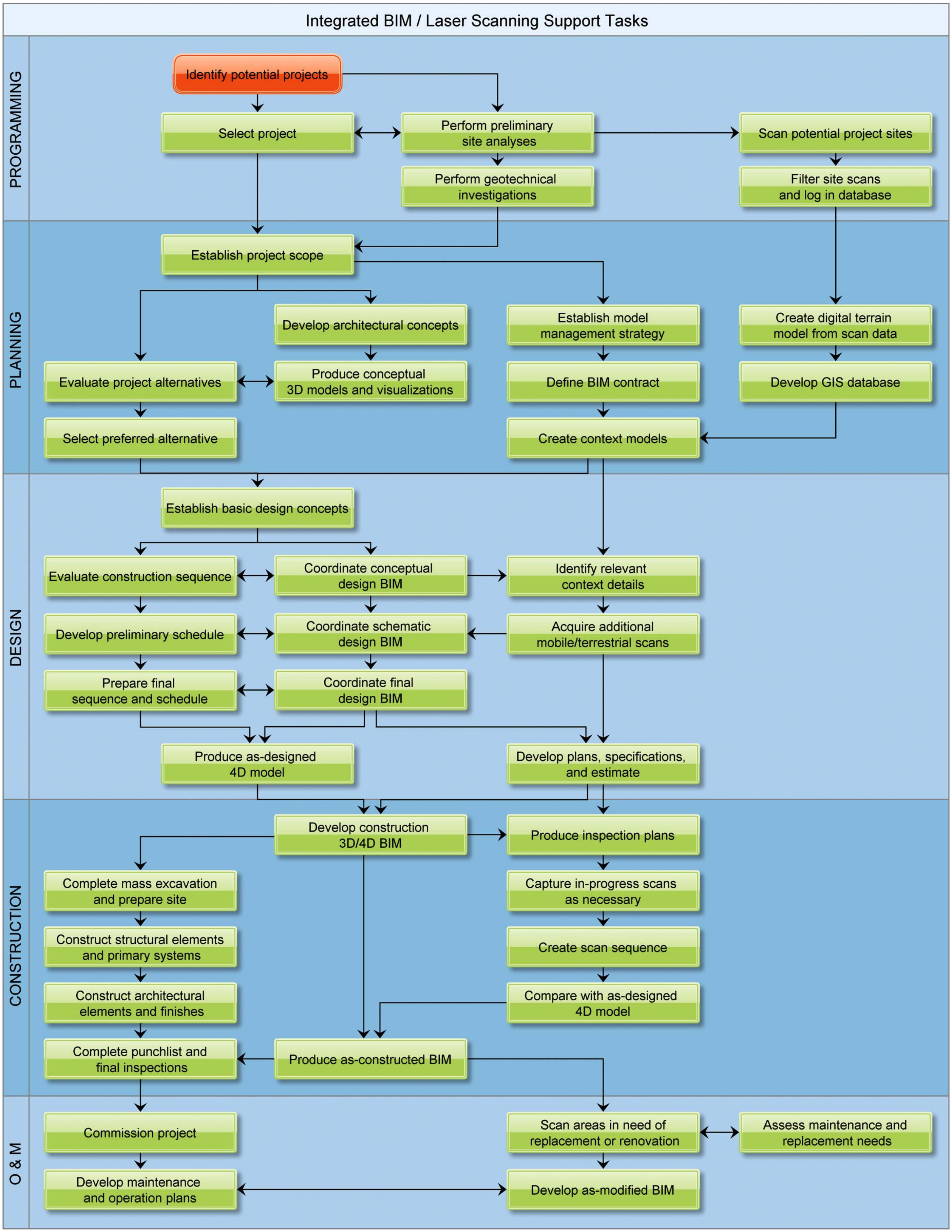


Fig. 4. Integrated BIM and laser-scanning process map

the integration of semantically rich as-built information items such as components with a 3D model-based design (Akinci and Huber 2009), which enables advanced analysis requiring information from both as-built and as-designed data sets such as progress tracking, productivity tracking, and construction quality control (Bosche et al. 2009). Successful construction innovation has been linked to a high degree of interaction between design and production functions even in the absence of contractual agreements (Nam and Tatum 1992), so a system of data integration is important to the success of any holistic laser scanning implementation strategy supported by BIM processes.

Programming Phase

A primary objective during the programming phase of projects is to understand which projects should receive funding in the context of long-term development plans. Improved decision making can be facilitated by scanning potential project sites to help clients and owners define the program, an activity that is part of preliminary site analyses and geotechnical investigations. Scanning can be used during programming directly to determine organizational needs, such as using detailed structural assessments and site surveys to identify areas in need of maintenance or replacement. At an operational level, programming activities should include development of an asset management strategy using scans with a corresponding database that logs and organizes scans of potential sites for later reference during project planning. In urban areas, access to a detailed record of 3D terrain and built environment conditions could allow more informed programming and permitting decisions for new projects. Programming activities should also focus on developing organizational standards and practices for BIM, including the specifications for 3D model production, data exchange formats for information transfer, and integrated contractual agreements. Laser scanning equipment specifications, field operational procedures, and postprocessing file formats and software packages should be included in these standards.

Planning Phase

After selection of projects, the project-planning stage begins with evaluating project alternatives through development of scope, cost, and schedule requirements. In the context of these programming requirements, a model management strategy specific to the project should be clearly identified and formalized in contractual documents that dictate the BIM development process. It is important to select the appropriate spatial data collection technique for any given set of application requirements (Zhu and Brilakis 2009), which should be articulated based on project-specific needs and considerations in the BIM contract. During alternatives selection, contextual digital terrain models (DTMs) and digital surface models (DSMs) should be developed to assist in the selection process. This information will also serve as the baseline 3D environment for development of BIM design concepts when integrated into the project geographic information system (GIS) database. This information can be used to develop representative 3D visualizations of the site in combination with early design concepts, which have proven valuable for communicating project goals and improving technical understanding of projects (Garrick et al. 2005).

Design Phase

Ideally, building information models should be developed directly from the as-built conditions, factoring in 3D representations of the site characteristics in the design of the facility or transportation asset. These existing conditions, represented in a classified point cloud or a 3D surface model, are direct inputs to the conceptual design model development and continue to be used throughout schematic and final design. During the design phase, the design is developed in coordination with the high-accuracy data acquired from the built environment by importing surface DTM representations of surrounding terrain, adjacent facilities, and 3D surface models of existing roadways, bridges, tunnels, or other contract interfaces. In addition to site-level scans, supplemental detailed scans of key interfaces identified in conceptual designs can be registered with the site scans and used to represent potentially problematic areas with high accuracy. Design professionals can then develop design objectives in coordination with validated as-built records, which reduces field coordination issues and risks associated with unknown or misunderstood site conditions. Four-dimensional models should be applied where feasible to assess issues with construction sequence and design constructability. Ultimately, this information refines the final design BIM, which is the central repository from which plans, specifications, and the estimate are produced for construction.

Construction Phase

During construction, the primary applications of laser scanning are for validating consistency between construction quality and the design drawings, and monitoring activities on site. Contractors should refine the final design BIM during construction, factoring in design changes and improvements, relevant resource data, and additional design detail required to generate 3D integrated shop drawings (ISDs) from the model. Reliable data acquisition sources are required to update BIM models frequently on the basis of changes in the field (Hajian and Becerik-Gerber 2009), so field personnel should determine what activities will be monitored by either terrestrial scanners or flash LADAR and identify speed and accuracy requirements for progress assessments. The frequency of acquired scans should be determined with the data formats and analysis tools needed to achieve inspection and measurement goals for the project. Contractual documents should specify modes of data interoperability between the design and construction stage, which can lead to improved object identification and comparison with schedule activities (Shih et al. 2004). The writer's experience with 4D modeling on transportation infrastructure projects indicates that significant value can be gained by validating as-designed 4D simulations with as-built point-cloud records, a procedure that can be performed in a single interface using available commercial software (Autodesk 2012). At substantial completion, the project should be scanned to record final conditions in coordination with the final as-built record BIM, and then transferred to building operators to assist in facility management.

Operations and Maintenance Phase

The lack of a facility model to manage operations after construction has long been a problem for operations and maintenance personnel (Korman and Tatum 2006), so proper management of laser-scanning data throughout the life cycle can provide advantages by accurately representing as-built conditions. After project commissioning, the validated as-built BIM and as-built point-cloud data can be integrated with building automation systems to improve operations. Furthermore, facility managers can use the BIM to develop maintenance and operation plans and to generate safety and security procedures. Principally, the scans and any representative models will serve as a repository for as-built conditions that are easily accessible to operations and maintenance personnel and can be used for subsequent renovation and rehabilitation as needed. Scans acquired after construction can also be used to assess structural integrity and identify maintenance and replacement needs for renovation projects.

Conclusion

This report presented and categorized numerous applications of different 3D range imaging technologies for construction projects and identified the relevant processes and technical requirements for implementation. A life cycle approach using building-information modeling and laser scanning was proposed to demonstrate the applicability of laser scanning for integrated 3D model-based design projects. Key considerations and construction engineering activities were then identified for each phase of the project life cycle based on the writer's research and experience. The research presented indicates that numerous laser-scanning applications exist for all project phases and significant potential benefits can be realized by integrating accurate context data capture with a structured BIM approach to engineering design.

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