Research Article

The Application of Laser-Scanning-Based BIM Technology in Large Steel Structure Engineering for Environmental Protection

Chunting Lu,1,2 Li Wang,3 Zheng Yang,1 Xingsheng Liu,2 Xiangwei Zhang,1 and Longhai Wu2

1School of Human Settlements and Civil Engineering, Xi’an Jiaotong University, Xi’an 710049, China
2Installation Engineering Co. Ltd. of CSCEC 7th Division, Zhengzhou 450053, China
3College of Geospatial Information, Information Engineering University, Zhengzhou 450001, China

Correspondence should be addressed to Chunting Lu; luchunting@mjwhedu.cn

Received 30 May 2022; Accepted 30 August 2022; Published 20 September 2022

Academic Editor: Parikshit Narendra Mahalle

Copyright © 2022 Chunting Lu et al. This is an open access article distributed under the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited.

The rise of heteromorphic architecture brings great challenges to engineering design, blanking, construction, completion testing, and maintenance. The 3D laser scanning measurement technology can quickly achieve the “copy” measurement of the target, especially suitable for the digitization of complex structure and the accurate construction of true 3D model and it takes care of other things which are necessary environment point of view. In this paper, we are considering the steel structure inspection and curtain wall blanking in the construction of the Grand Theater in the “Shangqiu Cultural and Art Center” as a case study. First, the laser scanning technology has been introduced to complete the data acquisition of steel structure objects and to screen the other details of the structure. Then, the high-quality point cloud is obtained through multistation splicing, filtering, denoising and smoothing, compression, and simplification. Through field comparison, the point cloud accuracy reached an acceptable level. Though field comparison, it can be seen that the difference between the designed building model combining laser technology and BIM technology is distributed within the range of ±(1–5)mm, and the mean square error is ±3.5 mm, and the deviation of numerical simulation is small, which meets the building requirements. Therefore, this method can effectively detect steel structure, and the BIM model can be updated according to the measured point cloud data. We provide accurate data reference for curtain wall material and installation.

1. Introduction

The architectural design industry has experienced two major changes. The first change is from hand-painted drawings to computer-aided design (CAD), and the second change is from CAD two-dimensional design to three-dimensional design represented by building information modeling (BIM) technology [1, 2]. BIM is an engineering data model based on three-dimensional digital technology and integrating relevant information from construction projects [3]. BIM is the digital expression of facility entities and functional characteristics of engineering projects [4]. BIM technology has been integrated into the whole life cycle of construction to promote the transformation and upgrading of the construction industry with low technology content [5, 6].

In the architectural design stage, the BIM model generally carries out a collaborative design based on the information, drawings, or three-dimensional models provided by civil engineering, electromechanical, and other disciplines involved in the building [7–10]. During construction, the construction process is generally carried out in stages according to a certain sequence, including the earthwork stage, piling stage, masonry stage, structure stage, waterproof stage, and decoration stage [11, 12]. The latter stage of construction needs to be carried out on the basis of the previous stage. Due to the construction deviation, if each stage is still designed and constructed according to the original BIM model, the construction will exceed the preset position, or the facility structure will collide, making it difficult to complete the installation [13, 14]. In particular,
the completion and acceptance of the building requires reconstruction is unqualified, resulting in significant economic losses and even safety accidents with serious consequences [15, 16].

A feasible solution is to measure and detect the construction results after each stage, use the measurement results to update, and adjust the model of the previous stage, so as to keep the model consistent with the actual construction results [17, 18]. Peter et al. studied the application of BIM technology in architecture [19]. Building project results depend on the productivity of human resources, and BIM technology is an effective tool to improve productivity. This study analyzes the impact of BIM on productivity in construction project management. The main purpose of the study is to analyze the application of BIM technology in the construction industry and its impact on productivity. The BIM technology is deeply analyzed in this method, but the laser technology is not used, which results in slow information collection and the installation matching degree does not reach the expectation when BIM technology is applied. Hongwei Ren et al. studied a new method to study the seismic performance of prefabricated shear wall structures [20]. The construction process of prefabricated residential shear wall structures and the vertical components is analyzed. At the same time, BIM technology is applied to prefabricated housing, and the project is modeled by Tekla software, and the model is imported into Naviswork for simulation analysis of four-dimensional construction. The BIM technology application effect of this method is good, but it only analyzes the assembled building, not the large steel structure; so, the practical application scope is small. In this paper, aiming at the construction of a large spherical steel structure project, on the basis of traditional construction technology and in order to solve the abovementioned problems, laser scanning measurement technology is introduced, and BIM technology is combined with laser scanning technology to obtain building information data and improve the performance of BIM technology. The two forms have complementary advantages. Real spatial data of construction results obtained by laser scanning are used for detection, BIM update, curtain wall, and other work to form a complete construction scheme, and the feasibility and effectiveness of this method are verified in the actual project to reduce the frequency of construction repair. The overall research process of this study is as follows:

(1) Introduce the project background and task requirements;
(2) Proposing solutions for better infrastructure and an ecofriendly environment;
(3) Implementation process and results. In the modification part, laser scanning technology and BIM are applied, three-dimensional scanning is used to measure steel structures, point cloud data are processed, digital simulation is compared and analyzed, and the update and application of BIM are analyzed.
(4) Conclusion. Summarize the research content and explain the future research direction.

1.1. Engineering Background and Task Requirements.

Shangqiu Cultural and Art Center has a total planned land area of 8.25 hectares and a total construction area of about 67,000 square meters. Its main functions include group Art Museum, Science and Technology Museum, Grand Theater, underground civil air defense works, supporting public services, and underground parking lot, as shown in Figure 1.

The biggest highlight of the project is the Shangqiu Grand Theater, at the center of the project. The building is spherical, divided into an internal sphere and an external sphere. It adopts all steel structure designs, supplemented by a curtain wall. Figure 2 shows the BIM model of the nested design of internal and external spherical steel structures, in which the external sphere diameter is 58 m and the internal sphere diameter is 44 m.

According to the designed BIM model, the construction party has completed the steel structure installation of the internal sphere and external sphere of the Grand Theater, and the curtain wall installation will be carried out next. Due to the installation error and structural self-weight deformation error, there is a deviation between the actual internal and external spherical steel grid and the designed BIM model. In order to judge whether the manufacturing and installation of the steel grid structure meet the tolerance requirements and to provide an accurate model for curtain wall blanking in the next step, it is required to conduct a detailed measurement of the steel grid structure, detect the construction quality through digital analog comparison, and update the existing BIM model before blanking.

2. Proposed Solutions

By analyzing the task requirements of each stage, the BIM task can be divided into four steps: data acquisition, data processing, digital-analog comparison, and BIM update of completed buildings, to solve the problems existing in the building.

Data acquisition requires the selection of appropriate measurement schemes and equipment to achieve detailed, fast, and high-precision data acquisition of completed buildings [21]. 3D laser scanning measurement technology is a technology to reconstruct the panoramic 3D data and model of the target from complex entities or real scenes, also known as real scene replication technology. 3D laser scanning technology breaks through the traditional single-point measurement method. It has the characteristics of high speed, noncontact, high density, and automation. It has been widely concerned as soon as it appears [22]. It has been successfully applied in many fields, especially suitable for building data acquisition and BIM modeling. In the acquisition stage, it is necessary to consider: the conversion scheme of the measurement coordinate system, the BIM design coordinate system, and the construction coordinate system; selecting an appropriate multistation splicing scheme and appropriate station location; setting reasonable scanning measurement parameters, such as resolution, scanning area, color scanning, etc. The workflow of the data acquisition phase is shown in Figure 3.
The data processing stage mainly completes the multi-station splicing of the point cloud, filtering, denoising, smoothing, and compression simplification, so as to provide a high-quality point cloud for digital analog comparison as shown in Figure 4.

Digital analog comparison compares the obtained physical data of completed buildings with the BIM design model, analyzes the size and location of deviation, and judges whether the construction results at this stage are qualified. The building height is 58 meters and is divided into internal and external spheres. It needs to be collected from multiple angles to obtain its complete point cloud data. Because the internal and external spheres block each other, there are few optional stations, especially at higher positions. Optional stations mainly include: ground, about 3/4 circle around the building (1/4 shelter). There is a connected raceway between the two spheres. There is a concrete step platform below the internal sphere, which is used to install viewing seats in the later stage. There is an external high platform in the east of the external sphere, about 20 meters. There are 5-story ladders in the southeast in contact with the steel structure.

3.1.2. Scanning Measurement Scheme. Station location. The building of Shangqiu Grand Theater adopts all steel structural design and the location of the station needs to be determined during the design. The building height is 58 meters and is divided into internal and external spheres. It needs to be collected from multiple angles to obtain its complete point cloud data. Because the internal and external spheres block each other, there are few optional stations, especially at higher positions. Optional stations mainly include: ground, about 3/4 circle around the building (1/4 shelter). There is a connected raceway between the two spheres. There is a concrete step platform below the internal sphere, which is used to install viewing seats in the later stage. There is an external high platform in the east of the external sphere, about 20 meters. There are 5-story ladders in the southeast in contact with the steel structure.

The free station setting method means that there is no need to place manual signs and set control points, laser scanner alignment and leveling are not required, and stations are set freely during measurement, only to ensure that there is a certain degree of overlap between stations. The free station setting method only needs to ensure a certain degree of overlap between the stations. There are two key points in the splicing of the free station setting method: one is to automatically splice the stations according to the overlapping part by using the ICP algorithm; the other is to carry out the overall adjustment between stations to avoid the error accumulation of sequence adjustment.

Parameter setting. Before applying technology, you need to set parameters. The equipment used is Faro Focus 3D 120,
Figure 3: Data acquisition.

Figure 4: Data processing.
the sampling rate is set to 1/8, the sampling quality is set to 4x, and the sampling time of a single station is 1’58". A total of 120 stations are collected and measured at the construction gap, which takes 3 days.

3.2. Point Cloud Data Processing

3.2.1. Multistation Splicing. Due to the different coordinate systems of different stations and the different coordinates of the same location in the point clouds of different stations, the multistation cloud cannot form a unified point cloud set. It is necessary to determine the conversion parameters between each coordinate system and combine the point clouds obtained by each station into a unified coordinate system so as to obtain a complete point cloud model of the target, that is, multistation splicing [7–9].

According to the compass, tilt compensator, altimeter, and other sensors of the laser scanner, the point cloud can be spliced automatically. Because it is difficult to set up stations and the overlap between individual stations is small, the collected 120 station data are automatically roughly spliced to form multiple clusters, which are called clusters. A cluster to lock is selected, and manually, the position and direction of other clusters are adjusted to make all clusters roughly spliced together.

For the point cloud cluster that completes the initial splicing, the overlapping area of the point cloud is used as a constraint to accurately splice multiple stations as a whole and finally form a complete and unified point cloud in the laser scanning engineering coordinate system, as shown in Figure 6.

3.2.2. Noise Removal and Smoothing by Filtering. Laser scanning is an automatic measurement, resulting in a large amount of environmental data in the point cloud, which is called redundant points, as shown in Figure 5; this redundant point seriously affects the building effect. Therefore, it is necessary to eliminate the redundant points in the laser point cloud data. For the elimination of redundant points, the manual interaction method is the most commonly used and effective method, as shown in Figure 7.

If some points are far away from or near the main point cloud, they are called outliers. Outliers generally appear in clusters. If they appear individually, they are external outliers. Outliers and isolated points are also useless points for the measurement target, and the processing method is to eliminate them. In this project, the weighted average distance method is used for filtering and denoising. For a single site cloud, the weighted average distance filtering method divides the average distance (point spacing) of each point from its adjacent points by the distance from the point to the coordinate origin (survey site), which is equivalent to reducing the point spacing of all points to the point spacing at the unit distance (the distance from the survey site is 1.0); then, according to the statistical knowledge, the points are statistically analyzed according to the normalized average.
distance, and the points outside the confidence interval are removed as outliers (See Figure 8).

Due to the existence of measurement error, the measurement results deviate from the correct position, showing the characteristics of local burr and unsmooth [10]. It cannot be deleted directly but can be adjusted locally. For a point $P_s$ in the point cloud, if $P_s$ is not isolated from the point cloud surface where it is located (nonoutlier) but the existence of $P_s$ affects the smoothness of the local surface, $P_s$ is called a random noise point. The bilateral filter [11] with an additional normal vector including angle and prediction distance constraint constructed by Li Mingli et al. is used for smoothing, and the processing effect is shown in Figure 9.

3.2.3. Compression Simplification. The huge point cloud brings challenges to computer storage, processing, rendering, and transmission. The operation of reducing the amount of effective point cloud data is called point cloud simplification. According to the criteria on which point cloud simplification is based, it can be divided into the direct simplification method, voxel simplification method, and simplification method considering characteristics [12]. The point cloud simplification method based on the octree structure has the advantages of high speed and uniform sampling. The volume bounding box is used to constrain the point cloud; then, the minimum bounding box is decomposed into several small squares of equal size (uniform octree) by octree. In each bounding box, the point closest to the center of the bounding box is selected to replace the point in the whole bounding box, so as to realize the compression and simplification of the point cloud. The compression ratio can be constrained according to the side length of the small square. The longer the side length is, the higher the compression ratio is and the more sparse the point cloud is. Figure 10 shows the sampling effect with a side length of 5 cm.

The site comparison is carried out with the construction party. 10 places are selected at different heights and directions. The measured value of steel tape is used as a reference for comparison. The difference is distributed in the range of $\pm (1\text{–}5) \text{ mm}$ and the mean square error is $\pm 3.5 \text{ mm}$.

3.3. Digital Analog Comparison Analysis

3.3.1. Coordinate Conversion. In order to provide a more intuitive detection effect for the construction party, the digital-analog comparison analysis is selected in the construction coordinate system. In order to convert the laser scanning engineering coordinate system and BIM design coordinate system into the construction coordinate system, artificial signs are arranged at the center of the inner surface of the circular steel drum (4 inner and 4 external spheres) of 8 steel grid frames during field data collection; then, two control points under the construction coordinate system are selected, the station is set by using the total station; then, the construction coordinates of the sign center are measured. According to the laser scanning engineering coordinates and BIM design coordinates of the mark points, the transformation of the two coordinate systems is completed, so as to realize the coordinate system I, as shown in Figure 11.
3.3.2. Comparative Analysis. The comparison analysis can be based on the comparison between the point cloud and point clouds, the comparison between point clouds and 3D models, or the comparison between models. In this project, the BIM model is used as the benchmark to directly compare the measured point cloud data with the BIM model data.

To analyze the deviation between each measuring point and the design model, two analysis methods of normal deviation and shortest distance deviation can be used at one time. The normal distance analysis method is as follows: for a point in the point cloud, the neighborhood KNN of the point is obtained by using the nearest neighbor search algorithm based on octree; then, the normal direction of the point is obtained by principal component analysis to calculate the distance from the point along the normal direction to the model as the actual deviation value. The shortest distance analysis method is as follows: for a point in the point cloud, to directly find the nearest distance between it and the model as the deviation.

The nearest distance analysis method is used to analyze the internal and external spheres with 20 mm and 50 mm chromatographic scales, respectively, and the test report is generated according to the analysis results. The results are shown in Figure 12.

3.4. BIM Update and Application. After passing the test, the designed BIM model shall be updated and modified according to the measured data; the reason for applying this step is that it can reduce the construction errors and further improve the construction quality.

A BIM model is built based on the measured point cloud. There are three modeling methods: manual modeling, semi-automatic modeling, and automatic modeling [6].

Manual modeling realizes manual modeling according to modeling software. First, the processed high-quality point cloud data are imported into BIM modeling software and then modeled according to the measured data. Commonly used software includes Revit, Bentley, Rhino, 3DS MAX, etc. The manual modeling method is intuitive, simple, and easy to implement, but the degree of automation is low, and the model accuracy depends on experience. Semiautomatic modeling refers to manually selecting the point data of regular objects such as planes, balls, and cylinder, and then fitting the high precision spatial geometric information of feature objects through algorithms, such as plane equations, central point coordinates, axes, dimensions, etc. The fully automatic modeling method completely relies on computers and algorithms to realize the construction of the BIM model. This method is still in the experimental stage and is only suitable for some simple rules.

Using the semiautomatic modeling method, a new BIM model is constructed according to the measured point cloud. The blanking of curtain wall installation according to the updated accurate BIM model can avoid the problem of installation mismatch. A curtain wall adopts a combined curtain wall, which is composed of glass material, metal material, and stone material. The curtain wall type has good visual effect, energy conservation, and environmental protection, is the cause of the curtain wall itself weight is lighter, alleviates the pressure of the main structure and foundation, and reduce the engineering cost, improving the aseismic performance of building, and use less material, curtain wall component replacement and maintenance convenience, low maintenance cost, and high artistic quality. The curtain wall discharging process is the retest reference line and the elevation line. After the retest is correct, the keel position and curtain wall position are determined according to the keel position and axis steel line position displayed in the BIM model. According to the position of the wiring, find the embedded parts and from the structure to achieve the first vertical frame, then the horizontal frame, after the vertical frame positioning in the horizontal frame. Curtain wall pendant, that is, glass material, adopts segmental installation, which is connected with keel steel through bolts to fix the glass, so as to complete the curtain wall falling. The blanking design effect of the curtain wall is shown in Figures 13-14.
4. Conclusion

In order to improve the construction inspection and blanking accuracy of large steel structure buildings and reduce the degree of installation mismatch, the application method of laser scanning and BIM technology in large steel structure engineering is proposed. This method takes the large-scale steel structure construction project of Shangqiu Culture and Art Center as the research object and uses a three-dimensional laser scanner to collect detailed point cloud data inside and outside the steel structure. We compare the BIM design model and complete the structural design and inspection, update the BIM model according to the point cloud, and accurately cut the curtain wall design. The scheme can better complete the construction inspection and BIM update tasks with a mean square error of ±3.5 mm and a low deviation, which meets the building requirements. The data provided by the updated BIM model are more accurate and applicable to other similar projects. This method mainly combines laser scanning technology and BIM technology, which improves work efficiency, makes the building model more accurate, and provides more effective reference data for staff. The scheme still needs to be improved: there are many manual intervention parts in point cloud data processing, which are inefficient, and the processing results are closely related to the experience of technicians; the construction of an accurate BIM model based on point cloud mainly depends on the existing modeling software, which is generally in semiautomatic mode, and it is necessary to explore fully automatic modeling methods. At the same time, the increase in greenhouse gases has become a global problem. Therefore, the follow-up research will focus on reducing carbon emissions and reducing greenhouse gas emissions to improve the idea of construction technology and promote the development of the green building industry.

Data Availability

All the data pertaining to this article are available in the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

Authors’ Contributions

All the authors have contributed to the conceptual idea, proposed methodology, and drafting of the paper equally as the individual responsibilities allocated to each one. The weightage of contributions is decided mutually, and the authorship is given in an order from first to fifth in this manuscript.

References

[1] Y. Li, P. Li, Y. Li et al., “Research on key technologies of construction management of large swivel bridge based on BIM technology—a case study of dade swivel bridge,” IOP Conference Series: Earth and Environmental Science, vol. 568, no. 1, pp. 012052–21062, 2020.
[2] C. Hu, L. Kong, and F. Lv, “Application of 3D laser scanning technology in engineering field,” E3S Web of Conferences, vol. 233, no. 04, pp. 04014–04020, 2021.
[3] W. B. Wang, “Stability analysis of cross-section of double-row large-diameter pipeline based on BIM technology,” International Journal of Industrial and Systems Engineering, vol. 39, no. 2, pp. 162–153, 2021.
[4] G. Sha, H. Wang, G. Men, R. Guo, and Y. Feng, “Application research on information integration technology of bridge BIM model based on 2-D EBS coding system,” Journal of Physics: Conference Series, vol. 1904, no. 1, pp. 012031–12121, 2021.
[5] Y. Xiao and J. Bhola, “Design and optimization of prefabricated building system based on BIM technology,” International Journal of Systems Assurance Engineering and Management, vol. 14, no. 2, pp. 36–41, 2021.
[6] J. Zhang, L. Yang, Z. Tian et al., “Large-scale screening of antifungal peptides based on quantitative structure–activity Relationship,” ACS Medicinal Chemistry Letters, vol. 14, no. 35, pp. 63–72, 2021.
[7] M. Strach and P. Grabias, “Application of laser scanning technology for structure gauge measurement,” *Open Geosciences*, vol. 12, no. 1, pp. 1653–1665, 2020.

[8] B. Tian, N. Wang, Q. Jiang, L. Tian, L. Hu, and Z. Zhang, *Journal of Materials Science: Materials in Medicine*, vol. 32, no. 6, pp. 63–69, 2021.

[9] B. Shu, Z. Xiao, L. Hong et al., “Review on the application of bamboo-based materials in construction engineering,” *Journal of Renewable Materials*, vol. 8, no. 10, pp. 1215–1242, 2020.

[10] L. J. W. Mei, “Application of BIM technology in design and construction of high-rise prefabricated steel structure green residential building,” *Forest Chemicals Review*, vol. 3, no. 01, pp. 712–720, 2021.

[11] M. Hasan, “Sustainable design of machine components: a critical review of carbide/steel laminate composite,” in *Proceedings of the 2021 International Conference on Science & Contemporary Technologies (ICSCT)*, pp. 1–6, Dhaka, Bangladesh, August 2021.

[12] G. Wei, “Application of BIM technology combined with artificial intelligence in construction management: artificial intelligence in construction management,” *Stavebníobzor - Civil Engineering Journal*, vol. 30, no. 2, pp. 96–104, 2021.

[13] J. Deng, “Simulation Application of Building Construction Management Based on BIM Technology,” in *Proceedings of the 2020 IEEE 2nd Int. Conf. on Civil Aviation Safety and Information Technology (ICCASIT)*, pp. 590–593, Weihai, China, October 2020.

[14] L. Jiang, S. R. Sakhare, and M. Kaur, “Impact of industrial 4.0 on environment along with correlation between economic growth and carbon emissions,” *Int J SystAssurEngManag*, vol. 13, no. S1, pp. 415–423, 2021.

[15] M. Kaur and S. Kadam, “Bio-inspired workflow scheduling on HPC platforms,” *Tehnički Glasnik*, vol. 15, no. 1, pp. 60–68, 2021.

[16] A. Jadhav, M. Kaur, and F. Akter, “Evolution of software development effort and cost estimation techniques: five decades study using automated text mining approach,” *Mathematical Problems in Engineering*, vol. 2022, Article ID 5782587, 17 pages, 2022.

[17] M. Kaur, S. Kadam, and N. Hannoon, “Multi-level parallel scheduling of dependent-tasks using graph-partitioning and hybrid approaches over edge-cloud,” *Soft Computing*, vol. 26, no. 11, pp. 5347–5362, 2022.

[18] W. Zhang and M. Kaur, “A novel QACS automatic extraction algorithm for extracting information in blockchain-based systems,” *IETE Journal of Research*, pp. 1–13, 2022.

[19] P. Mesáros, T. Mandičák, and A. Behunova, “Use of BIM technology and impact on productivity in construction project management,” *Wireless Networks*, vol. 28, no. 2, pp. 855–862, 2020.

[20] H. Ren and J. Chen, “The application of BIM technology in the research on seismic performance of shear wall structure of prefabricated residential buildings,” *International Journal of Critical Infrastructures*, vol. 18, no. 1, pp. 32–44, 2022.

[21] B. Mareschal, M. Kaur, V. Kharat, and S. S Sakhare, “Convergence of smart technologies for digital transformation,” *Tehnički glasnik*, vol. 15, p. 1, 2021.

[22] S. G. Maxineasa, D. N. Isopescu, I. R. Baciu, and M. L. Lupu, “Environmental performances of a cubic modular steel structure: a solution for a sustainable development in the construction sector,” *Sustainability*, vol. 13, no. 21, p. 12062, 2021.