IMPLEMENTATION OF POINT CLOUD AND BIM TECHNOLOGIES IN A CONSTRUCTION WORKFLOW

A case study of a building project in Yuecheng District, China

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Abstract. In recent years, there has been a surge of retrofitting and building projects in rural China, to elevate the living standards in local areas. However, with the conventional use of surveying and inspection instruments, the amount of construction errors account to substantial waste of materials, time and labour. The issue is magnified in the current context that emphasises on efficient utilisation of resources. The emergence of laser scanning and BIM technologies is evident with scanning equipment and software being more accessible. This paper explores the use of the two technologies, to be integrated into the a construction workflow. The research includes a self-conducted site survey, data collection, data processing and analyses. The processed point cloud data is extracted and compared to the as-designed BIM model, to analyse and assess the construction errors in various scales. The result displays a significant portion of the building being out of tolerance and its causes. A theoretical framework is proposed to integrate point cloud and BIM technologies, not only to document and assess the overall building dimensional accuracy, but also to minimise construction errors and waste, ensuring a responsible consumption and production of building materials.

Keywords. BIM; Laser Scanning; Point Cloud; Construction Workflow; Cast-in-situ Concrete Structure; Tolerance Compliance; SDG 12.

1. Introduction

Architectural design in rural China has played a significant role in recent years, as part of the rural revitalisation strategy, leading to a significant increase of construction projects. Concurrently, digital technologies such as BIM have been utilised more widely in the context of information revolution. Their role to improve the sustainability of architecture and its construction process has been continually explored. It is noted by the International Energy Agency (IEA, 2019, p. 9) that the building and construction sector is responsible for '39% of energy and process-related carbon dioxide (CO2) emissions in 2018, 11% of which resulted from manufacturing building materials and products such as steel, cement and glass'. Furthermore, construction quality control remains a problem that additional costs of removal and replacement of defective concrete elements could account to 12% of a project's contractual value (Puri et al., 2018). This issue is magnified with construction in rural China (Ru et al., 2020): 1) Safety; 2) Quality; 3) Lack of technical drawings; 4) Lack of geological survey; 5) Lack of training and basic building knowledge for rural construction workers.

Conventionally, the role of dimensional accuracy in construction is ensured by the contractors, surveyors or inspectors, with the use of tape measures, theodolite, total stations, etc. In the context of reconsidering the global carbon impact, for Sustainable Development Goal 12 in particular, it is vital to minimise waste generation through reducing additional building materials and preventing construction errors. With the emergence of laser scanning technologies that captures the complete point cloud scan of the entire surrounding, its potential to be integrated into the construction workflow and assist with the current issue is questioned.

2. Literature Review

Point cloud technologies not only are able to conduct more accurate surveys, architectural elements unreachable can now also be scanned, modelled and analysed. The current application of point cloud and building information modelling (BIM) technologies is explored across the AEC industry. Methods have been implemented for the generation of 3D elements from point cloud data to BIM models, as Tamke et al. (2014) investigated the approach to automatically extract semantic spatial information of point cloud from interior building scans and Rodríguez-Moreno et al. (2018) proposed a method of modelling heritage architecture from point cloud. Laefer and Truong-Hong (2016) proposed a method to identify automatically steel structural members from laser point cloud scans and generate the geometry compatible for BIM models. Advantages and effectiveness have been shown by incorporating point cloud and BIM for tracking construction progress (Kim et al., 2020), despite the labour intensity of converting point cloud to BIM (Qu & Sun 2015). Methods have also been proposed for assessment of structural elements for compliance in a surface level (Puri et al., 2018).

3. Research Objective

This paper seeks to further extend the use of the two technologies, to be integrated into the workflow of a construction. It questions the limitations of current surveying and construction methods, especially for building projects in rural China. This paper aims to provide a framework for incorporating BIM and point cloud scanning technologies into future projects in similar context, scale and type, addressing the Sustainable Development Goal 12 of responsible consumption and production.

4. Methodology

A case study is conducted to explore the use of BIM and point cloud technologies in a building project. The investigated building is located in Anqiaotou village in Yuecheng District, Zhejiang Province, China. The building is a two-storey concrete structure with masonry walls (Figure 1&2). Its floor area is approximately 380sqm. A BIM model is built in Autodesk Revit, including the disciplines of architecture (Figure 3) and structural engineering (Figure 4) according to the final design intentions.

Figure 1. Image of the investigated building during construction (left);
Figure 2. Image of the investigated building after construction (right)

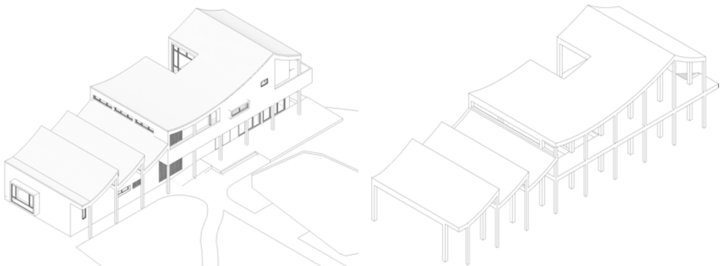

Figure 3. Architectural model of the investigated building in BIM (left);
Figure 4. Structural model of the investigated building in BIM (right)

A set of point cloud data is collected with a 3D laser scanner, Leica BLK360, during its construction, after the concrete structure and part of the masonry walls were built. The accuracy of the scanner is specified to be 4mm at 7m and 7mm at 20m. The point cloud scans are automatically registered using point cloud processing software, Trimble Realworks, forming the complete point cloud models of the surveyed building (Figure 5). The overall cloud-to-cloud error from the registration is 5.95mm. The two numbers of error would be considered for the surface analysis. As the analysis is focused on the concrete structure of the building, the components of the cast-in-situ concrete, including columns, floor slab, beams and roofs are extracted from the point cloud model (Figure 6).


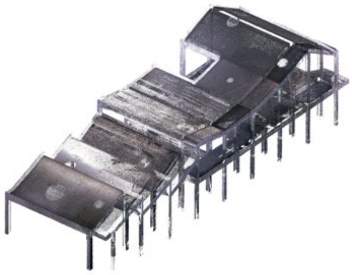

Figure 5. Registered point cloud of the building (left);
Figure 6. Extracted structural point cloud model (right)

Geomagic Control X, a quality control and inspection software, mainly used in the manufacturing industry, is implemented to align the point cloud and its respective structural part in the BIM model. As the entire building is a new construction, there is no reference point, therefore an effective way to compare the overall building geometry is to apply the software's automatic alignment with the least-squares method.

Surface analyses are carried in both 3D and 2D. Comparisons are made with the national standards for construction tolerance in China, GB50204-2015 'Code for quality acceptance of concrete structure construction' (Ministry of Housing and Urban-Rural Development of the People's Republic of China, 2015). The dimensional tolerance for various components is summarised in Table 1.

Table 1. Summary of tolerance for relevant components

Component	Tolerance (mm)
Axis location of columns, walls and beams	8
Floor level	±10
Cross sectional dimensions of columns, slabs, walls and beams	+10, -5

Using the method of worst-case analysis, the errors from the laser scanner and point cloud registration are accounted with summation. After the overall building is compared and analysed, the process is repeated for smaller components to draw further observations and conclusions.

5. Result and Analysis

5.1. OVERALL BUILDING

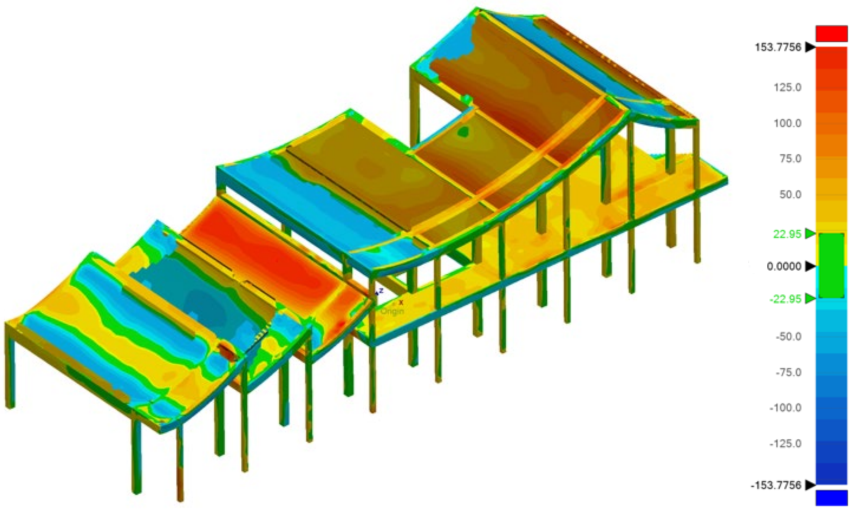

Figure 7. 3D comparison result

Taking the largest tolerance from Table 1, an overall tolerance of 10mm is used for analysing the entire building. Combining with the errors of the scanning equipment and point cloud registration, the sum equals 22.95mm for the assessment of the overall building. As shown in Figure 7, a range of deviation is detected, from -145mm to 208mm. Only 29.77% of the building is within tolerance. As the surfaces within tolerance is shown in green, it can be seen visually that columns generally stay within the tolerance. Most major deviations are observed from the floor and roof slabs.

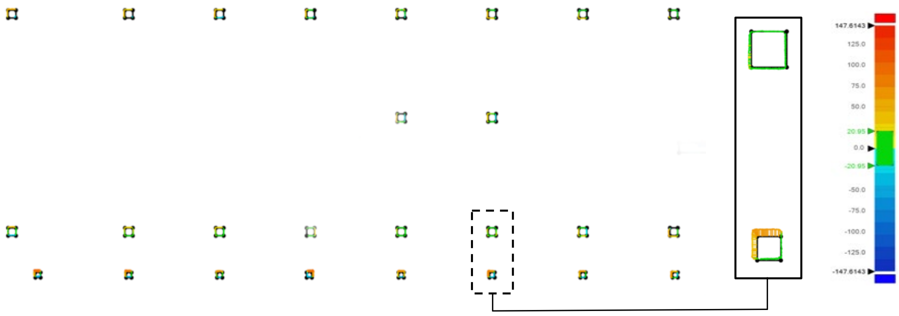

Figure 8. 2D comparison in plan (left); Figure 9. Close-up view on two of the columns (right)

An analysis in plan is made at the centre level between the ground and first floor levels as shown in Figure 8. Referring to Table 1, the location of the columns is taken as 8mm, therefore tolerance is added with other errors to 20.95mm. As observed from the 3D comparison, the columns have a larger portion being within tolerance, 46.86%. Furthermore, Figure 9 displays a close-up of two of the columns. The top one is shown to be in the correct cross-sectional size. The bottom column has two sides deviated outwards by 40-60mm, while the other two sides shown to be correct, indicating the structural member size difference between the as-built and as-designed dimensions.

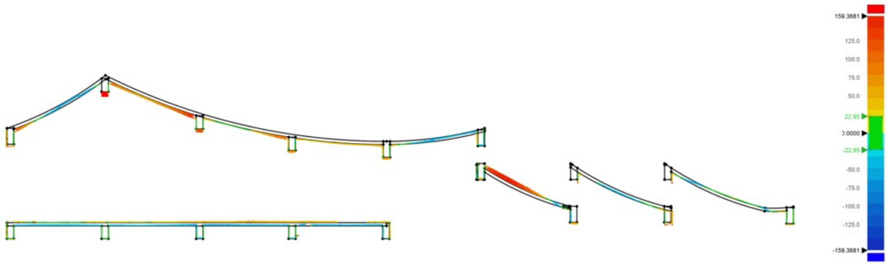

Figure 10. 2D comparison in long section

The deviation of roof slabs is more clearly shown in section (Figure 10). As the tolerance is set to be the same as for the overall building, 22.95mm, the portion of the section being within tolerance is 24.51%. It is evident that there is a significant deviation of the built roof slabs, with the maximum being 180mm away. Comparing the top and bottom surfaces, the entire floor slab is also observed to be elevated by approximately 50mm. Both the roof and floor slabs are explored individually. It can also be seen that the sides of floor and roof beams mostly stay within tolerance.

5.2. FLOOR SLAB

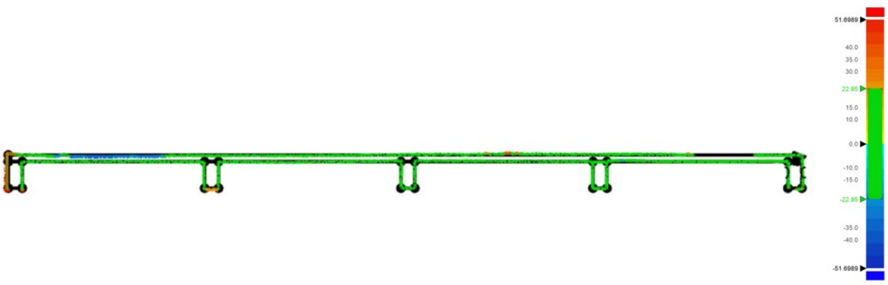

Figure 11. 2D comparison in long section of the slab in the first floor

The first-floor slab is further extracted to be individually compared to its respective point cloud model. The comparison displays a much higher alignment between the two, having 87.11% being within the tolerance of 22.95mm. There are spots showing unevenness of the slab. The reason is possibly due to pieces of occlusion during construction.

5.3. ROOF SLAB

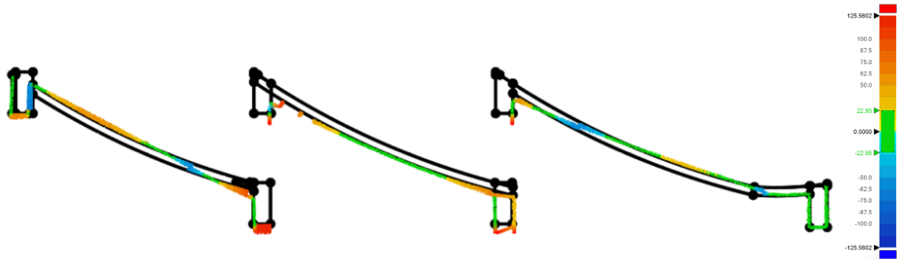

Figure 12. 2D comparison in long section for the first-floor slab

As observed from the overall building analysis, the roof slabs have a significant difference from its as-designed form, despite being aligned independently. The deviation ranges between -67mm to 166mm. Furthermore, the deviation is too high that the wrong surface of the roof is compared for some parts, therefore the true deviation would be larger. From Figure 12, it can be observed that the built roof form has been straightened, hence creating such deviation from the curved roof as designed.

6. Discussion

Table 2. Summary of analysis results

Component	Within Tolerance	Deviation Range
Entire building	29.77%	-145mm to 208mm
Columns - plan	46.86%	-147mm to 134mm
Entire building - section	24.51%	-124mm to 180mm
Floor slab - section	87.11%	-37mm to 68mm
Roof slab - section	46.82%	-67mm to 166mm

From the overall analysis, it is observed that even as a worst-case analysis, only 29.77% is within the allowable tolerance. If tolerance compliance is strictly enforced, a significant amount work would be required to be demolished and rebuilt, leading to a great amount of construction waste.

From the separate analyses, further general observations are drawn visually. For example, a structural member size difference can be indicated with two adjacent sides deviating outwards while the other two sides stay correct in position. The dimensions in the construction are relatively more accurate in the horizontal plane, as observed from the horizontal locations of the beams and columns. In comparison, the elements in the vertical plane such as roof slabs are more difficult to control. It is also noted that elements with curved surfaces require additional attention.

The analyses reveal several limitations of conventional surveying and modelling techniques used in the project. The analyses in various scales display that with the use of instruments such as tape measures and theodolites, the local dimensions of each component can generally be maintained within construction tolerance. However, as human errors accumulate, it creates a big portion being out of tolerance. It displays the significance of overall building dimensions that can be captured accurately by a laser scanner.

Before the construction continues, it is important to identify the crucial dimensions, forms and levels. In this case, the masonry walls are enclosed by the concrete structural frame. Without the awareness, errors would be carried on and magnified to the later stages of the construction process, such as prefabricated elements and fixed cabinets.

7. Conclusion

The case study displays a method to comprehensively assess the construction quality of a building in terms of dimensional tolerance compliance. Apart from analysing the overall building, the components of a building can also be extracted to be analysed separately to investigate the cause for each unexpected result. As the number of studies accumulate, the common spots of possible errors would become more apparent. The architect or the site inspector would be able to pay more attention to the common points before construction. In this case, it would be the curved roof form and the height of vertical elements. The case study reveals the importance of maintaining dimensional accuracy to minimise additional materials and works.

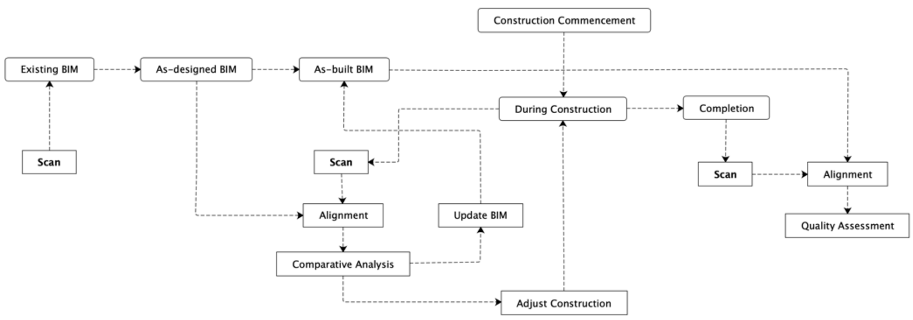

Figure 13. Construction workflow integrated with point cloud and BIM technologies

A theoretical framework (Figure 13) is proposed for implementing point cloud and BIM technologies into projects in similar scale and contexts. The framework is advised to be utilised in three stages (before, during and after construction), to have a more informed design decision-making, to prevent inaccuracy and to improve construction quality. Before construction, especially for projects with existing building parts, a scan is advised to record and reconstruct the existing building model. The scan during construction is vital to determine the as-built condition, to determine if there should whether be a redesign or reconstruction if there is any part with significant error. There can be multiple scans during construction, such as main structure, external walls, fixed furniture, etc. The scan after construction assists to document and provides a way of assessment of the construction quality of the project.

The proposed workflow allows architects to extend their roles, as the designer of the building, to discover and communicate the construction issues. In addition, it extends the responsibility of the construction team to maintain their accuracy as the constructed buildings are now able to be documented objectively. As the critical components can be identified, the additional costs of construction waste and labour can be reduced, ultimately leading to a more efficient and sustainable construction workflow.

8. Future Works

For cast in-situ concrete structure, as opposed to structure such as steel frames, there is an issue of using formwork that the final form of the concrete structure is unknown until the concrete is poured, cured and its formwork is taken off. When an intolerable error or deviation is discovered, it would require a significant amount of costs, material and labour to demolish and rebuild the parts. With a known consistent thickness of the formwork material, it presents the potential of predicting and modelling the external surfaces of the formwork, then be compared to the point cloud scan of the formworks before pouring the concrete.

As the technologies of point cloud scanning become more advanced and affordable, it is anticipated that the tool-set will be able to be implemented into the construction process in realtime. In addition, due to the lower accuracy level of aerial-based scanning with drones, the study was focused on terrestrial point cloud scans. As the accuracy of drone-based scanning improves over time, it would also be beneficial to be integrated into the process.

Acknowledgements

This work is supported by the General Program of National Natural Science Foundation of China (52078265), "Research on the Building Information Theory and BIM-based Integrated Mechanism for Existing Building Retrofitting".

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