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Construction Quality Assessment using 3D as-built Models Generated with Project Tango

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Abstract

Assessing the quality of construction for compliance with the design intent has been a challenging task in the AEC (Architecture, Engineering, and Construction) industry. As modern design methods using Building Information Modeling (BIM) techniques have been increasingly adopted by the AEC industry, construction quality assessment using BIM has become a challenging new task for practitioners. In the past few years, 3D as-built models for construction quality assessment have been developed using data acquisition techniques like 3D laser scanning and photogrammetry. However, certain limitations like non-affordability, requiring expertise to operate, and dependence on time-consuming processes are restricting their usage for construction quality control purposes. The main objective of this work is to study the applicability of using a new, affordable, easy to use, and faster modeling technology (Project Tango) to produce 3D as-built models for facilitating the construction quality control process. For this purpose, a construction project was chosen as a case study and three different scenarios (including interior and exterior environments) were modelled using Project Tango. A post-processing method was developed to prepare the scanned as-built models for comparison with the design BIM. The accuracy level of these as-built models were also evaluated using dimension accuracy analysis. The prepared as-built models and the design BIM were then integrated and adjusted in the Autodesk Navisworks environment to perform the quality control assessment. This assessment process includes object completeness testing and spatial deviation analyses. This research thus highlights both the advantages and limitations of Project Tango and shows that such technologies have a great potential for construction quality assessments.

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1. Introduction

With the increase in use of computational methods, such as Building Information Modeling (BIM), designers are able to develop more complex architectural concepts. As a results, the construction quality assessment (CQA) of such projects has evolved to an even more challenging process with higher levels of complexity. This is due to the difficulty in identifying various quality issues while comparing the design with the built environment. It can also lead to situations with increased project and construction costs affecting both the project owners and the contracting firms. Traditional CQA methods that are based on periodic site visits by the consultants and validation of the finished product by comparing with the 2D design drawings are often time consuming, laborious, and prone to human errors [1,2] and therefore, alternative solutions are required.

BIM usage in design and construction phases is being used for identifying design coordination issues through clash detection and for identifying construction schedule feasibility issues through 4D analysis. However, there is still a great potential in using BIM for CQA. One typical obstacle in this regard is the difficulty in comparing the design models directly with the as-built conditions on site. This issue can be addressed by developing 3D as-built models that are reflective of the current construction conditions and comparing the design and as-built model using suitable tools. Currently, there are two data capturing and modelling techniques–3D laser scanning and photogrammetry–that are predominantly being researched and used by various professionals in the industry. However, both these techniques have certain limitations like non-affordability, requiring expertise to use, and reliance on time-intensive intermediate steps that are still curbing their usage on a broader scale. Therefore, there is a demand to find alternative techniques to address these limitations.

This study aims to test the applicability of Project Tango as a potential solution for the above described research demand. A methodology is developed to assist in performing the CQA under different conditions based on a sample case study. A review of the current technologies and their comparison with Project Tango in various aspects is discussed in the following section. The construction project chosen as a case study for this work is then presented. This is followed by a brief discussion of the methodology used for generating the as-built models The steps involved in performing the dimensional accuracy testing and the deviation analysis are then presented. Finally, a summary of the analysis results and the lessons learned from this study is outlined.

2. Research Background

2.1. 3D Laser Scanning

Laser scanners generate a 3D point cloud by using a time-of-flight technique for recording the coordinate data of points across large areas, which are then used to generate a 3D as-built model [3,4,5]. The ability to collect huge amounts of data in a short time makes this a suitable option for large scale and infrastructure projects. Typically, there are three steps involved to get a 3D geometric model from the scanned 3D point cloud:

1. Data collection, where laser scanners are used to generate point cloud models from different locations.
2. Data post-processing, where the model assembly and noise reduction steps are performed.
3. Geometric modelling of the refined point cloud to create a 3D model.

Research has also focused on the automatic generation of BIM from the 3D point cloud, especially for facility management and energy analysis purposes. Laser scanning technique for CQA has been employed in several research studies through methods for automatically comparing the as-built model with the design model [1,2,6]. However, such methodologies are often costly and involve a steep learning curve which makes them unsuitable for small and medium sized contracting companies [7,8,9].

2.2. Photogrammetry

Photogrammetry is an image-based technology which addresses some limitations of laser scanning such as

portability and cost. The captured images are processed extensively using a method called triangulation to produce a 3D point cloud. The point cloud is then used for generating 3D models with the help of semi-automated tools available in several Scan-to-BIM artifacts tools such as RealWorks or EdgeWise3D [4]. This method generates 3D point clouds from 2D images and often involves several post-processing stages, some of which are quite time-consuming [10,11]. Also, the use of semi-automated tools for generating the 3D geometric model from the point cloud requires intensive manual input from users, thus making them more susceptible to human interpretation errors [4,12].

3. Project Case Study

The case study for this work is based on the AYO Smart Home project which aims to provide affordable housing for low-income sector, while maintaining high levels of liveability and energy efficiency. For this purpose, a pilot home is built on UBC campus and the construction phase of this home is used for testing. Periodic site visits were conducted at different instances during the time of construction to capture construction of different components of the project. Three different model cases were chosen for performing the CQA tests:
1. Foundation system: To validate the usage of Tango in exterior environments
2. Interior hall: Validate the usage in interior environments
3. One of the interior rooms

4. Methodology

4.1. Data Collection with Google Project Tango

Project Tango technology is a development-stage project by Google that uses a mobile tablet device for generating spatial models of surrounding areas. It uses advanced vision, depth sensor, and image processing tools. The depth sensor assists in recording the spatial environment and creates 3D as-built models directly. The depth sensor relies on reading the reflected infrared lights using the device's infrared camera. Thus, it is necessary to test the device's applicability in both outdoor, indoor scenarios and assess the model accuracy

Fig. 1: Project Tango device used in this study

Project Tango relies on various device applications that assist in developing the requiring as-built models. Two mobile applications were found to be useful for model-generation purposes: (1) Tango Constructor; (2) Room Scanner [13]. Tango Constructor generates a 3D meshed object directly that can then be exported to .obj format [13] whereas Room Scanner generates a 3D point cloud with a storage limit of up to 500,000 points. The data acquisition limitations, file storage format, and post processing software availability for the exported files from these applications were studied to identify the most suitable data collection tools.

4.2. Post-Processing

If a 3D point cloud is generated using Project Tango instead of a 3D meshed object, geometric modeling of the 3D point cloud must be done. Semi-automated mesh generation techniques available in software like Realworks were used for this purpose. The resulting meshed model was then imported into Meshlab where different noise reduction techniques like vertex removal and filtering methods were used for reducing the noise level [14]. Once the refined model was generated, it was then exported into .DXF format that is readable by Navisworks Manage.

4.3. Data Analysis

a) Object Completeness Testing: In this step, the as-built and design models were appended in Navisworks to identify any missing objects from either of the models. In order to identify the missing objects, color coding and transparency techniques are used. This test helped in identifying events like design changes during construction.

b) Dimensional accuracy analysis: This step involved measuring the dimensions of various objects in the three different models to establish the accuracy level of the 3D models developed using Tango. Previous work done by Ankit Bhatla et al. [15] provided a guide for developing the methodology to perform this analysis. Establishing the accuracy levels of the generated 3D models is essential for one to rely on this method. Length and depths of various components like foundation sides and beams were measured in this step and then compared with the measured values on-site. The absolute difference was then evaluated the check the deviation between the recorded and real values. The measures were performed using the "Measure" function in Navisworks Manage.

c) Spatial Deviation analysis: The analysis steps is based on work done by Tang et al. [16] where the deviations were identified through color coding. This analysis helped in identifying deviations in location of components.
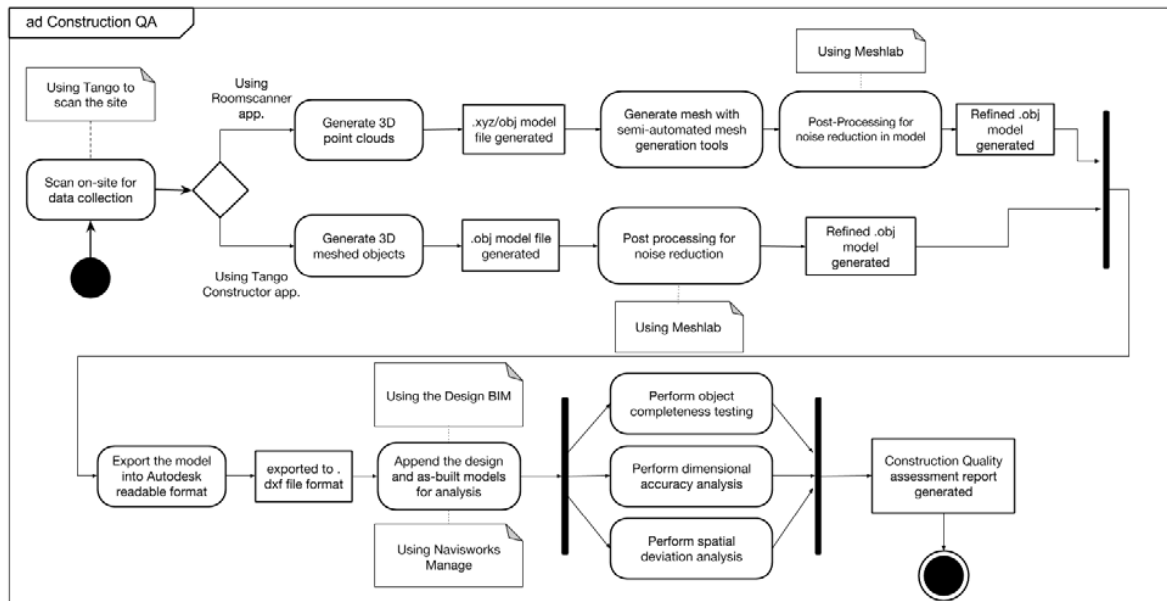

Fig. 2: CQA with Project Tango in UML activity notation

5. Performing the CQA for the case study with Project Tango

As stated, the CQA in this work was studied in three different scenarios. Hence, three as-built models were generated according to the methodology described in Section 2. Due to the storage limit of 500,000 points present in RoomScanner, it was decided to use the Tango Constructor application for this work [13]. This section discusses quality assessment and the results in more detail.

5.1. Quality Assessment of the Foundation

a) Dimensional Accuracy Analysis: This particular case was chosen to test the suitability of using Tango in exterior conditions. In order to generate the model, the site was scanned during evening times or before sunset, since that is when the amount of surrounding infrared light is minimum. The generated as-built model is shown in Fig. 3 (a). The dimensional accuracy analysis was performed by comparing the dimensions of various selected components in the as-built model with on-site measured values. The components selected are indicated with a number as shown in the design BIM in Fig. 3(b). Table 1 shows the results of accuracy analysis for this case.
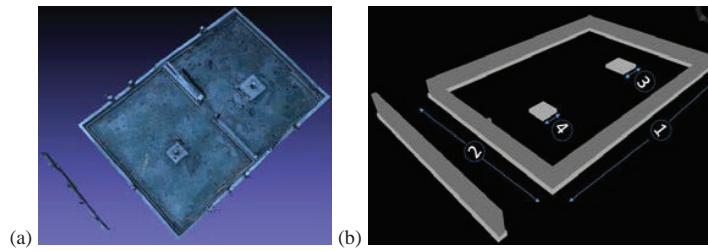
(a)   (b)

Fig. 3: (a) As-Built Model generated using Tango in exterior conditions; (b) Virtual Model developed from design drawings highlighting the selected components for dimensional accuracy testing;

Table 1: Dimensional accuracy analysis of the foundation 3D as built model

Component IDs in Fig. 3(b)	Measured dimensions from site (m)	Dimension value from as-built model (m)	Absolute Difference (Δ)
1	12.2	12	0.2
2	8.5	8.35	0.15
3	1.2	1.15	0.05
4	0.9	0.85	0.05
PONY WALL (Depth)	0.48	0.475	0.005
TOP OF FOOTING (Depth)	0.3	0.275	0.025
BOTTOM OF FOOTING (Depth)	0.2	0.18	0.02

The analysis showed that in this experiment, the 3D model developed using Tango in exterior conditions showed errors that were low in terms of absolute errors (0.005 m to 0.05 m for objects less than 2 m). Still, the largest absolute error (0.20 m for component 1) was enough to limit its potential for quality control purposes.

b) Object Completeness Testing and Spatial Deviation Analysis: In order to identify the missing objects and deviations present in the as-built conditions, the design model was appended with the as-built one in Navisworks Manage. Spatial Deviation was not observed, but some objects were recorded to be missing from the design model. The missing objects are identified and highlighted in Fig. 4. It was observed that the as-built model contains additional footing components that were not modelled in the design model. This is due to design changes that occurred in later stages that were missing from the initial designs. This ability to identify design changes between the final construction and the earlier designs was found to be a useful feature of the technique.
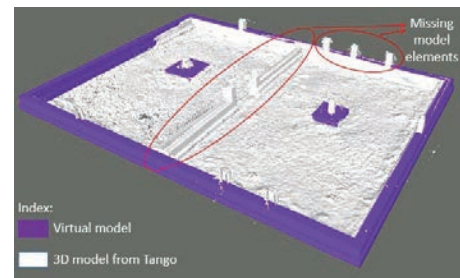

Fig. 4: Deviations identified between the virtual and as-built 3D models.

5.2. Quality Assessment of the Interior Hall

a) Dimensional Accuracy Analysis: This case was chosen to test the suitability of Tango in interior environments. It is observed that one of the major issues that the modeler faces when scanning interior environments is the noise from unnecessary objects in the interiors. This sometimes make the post-processing stage quite difficult leading to more time being spent here. The generated as-built model is represented in Fig. 5(a) and the components selected for accuracy analysis are numbered and shown in Fig. 5(b). The results were similar to the first case, with some of the component measurements being quite accurate, but the worst cases (e.g., a deviation of 0.35 m for an 8 m component) being large enough to limit the potential for quality assurance use. The results are presented in Table 2.

Table 2: Dimensional accuracy analysis of the interior hall 3D as built model

Component IDs in Fig. 5(b)	Measured dimensions from site (m)	Dimension value from as-built model (m)	Absolute Diff. (Δ)
1	8	7.65	0.35
2	5.72	5.65	0.07
3 (Depth of beam)	0.25	0.235	0.015

b) Object Completeness Testing and Spatial Deviation Analysis: The object completeness test showed that there are no missing objects either in the design or as-built model, but the deviation analysis showed some discrepancies. One such discrepancy is the mismatch of the hall dimensions recorded in the as-built model with that of on-site measured value (Fig. 6(a)). Also, deviation analysis showed that the actual location of windows is not matching with that of intended location. There is a significant offset observed that are highlighted in Fig. 6(b). As with the case shown previously in Fig. 4, this is suspected to arise from inconsistencies between the initial the final design.
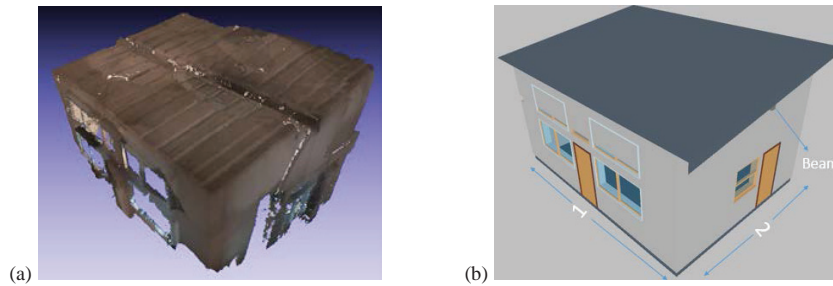

(a)   (b)

Fig. 5: (a) As-Built model generated via Tango; (b) Virtual Model highlighting the selecting components for accuracy testing;
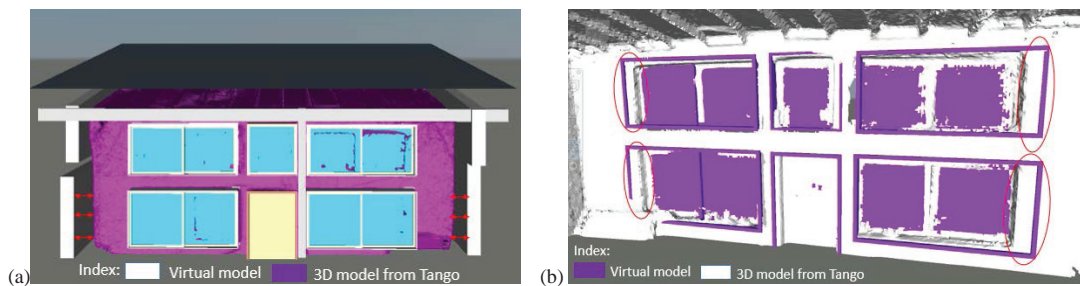

(a)   (b)

Fig. 6: (a) Deviation in the hall dimensions; (b) Deviations in the windows placement.

5.3. Quality Assessment of the Interior Room

a) Dimensional Accuracy Analysis: An additional case was considered to test the Project Tango device for suitability in interior environments (). The dimension evaluation again showed that the 3D model generated was fairly accurate with a low absolute error values (0.05 m to 0.06 m for objects less than 4 m).
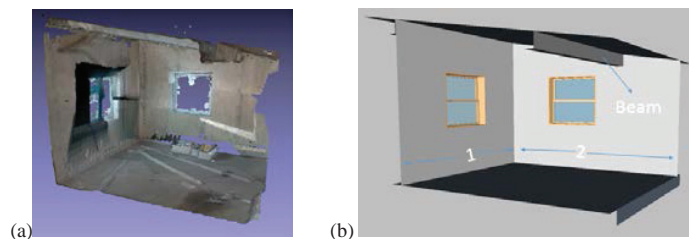

(a)   (b)

Fig. 7: (a) As-Built Model generated using Tango; (b) Virtual Model developed from design drawings.

b) Object Completeness Testing and Spatial Deviation Analysis: Missing objects were identified in the design model from the completeness test. It was observed that the as-built model also has lateral beams in the roof which are missing from the initial design. This can be attributed to the lower LOD of the developed design BIM model. The spatial deviation analysis again showed an offset in the window location similar to the one observed in the above case. Both the deviations are identified in Fig. 8.
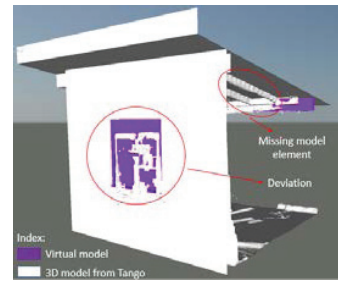

Fig. 8: Deviation analysis showing the offset in window location and missing model elements in the virtual model

5.4. Discussion

The results of the performed CQA for the scenarios above, highlight that the device's use of reflected IR light made depth perception difficult in certain cases, such as modeling black surfaces and window regions. Furthermore, the results show that the accuracy of the as-built models created with the Project Tango device were generally accurate with few instances of higher absolute dimension errors. This limits the potential for the current approach to be used in quality control due to the importance and need for highly accurate as-built models [17]. The Project Tango device sometimes failed to record elements of smaller dimension accurately. Major disparities are found in certain windows location, and object completeness testing identified several missing objects from the initial design model, thus assisting the team in recognizing the design changes that occurred during the construction phase.

In addition, based on the experience from this work, an analysis is conducted in order to provide a better overview about the advantages and weak points of the Project Tango in comparison with the two other common techniques. Detailed results of this analysis are summarized in Table 3 which is developed based on different related works [3,10,15]. This table includes three following categories: (1) cost involved; (2) data acquisition accuracy; and (3) user convenience. The analysis showed the possibility of Project Tango being a viable option for generating the as-built models depending on project requirements. For projects with a budget constraint or small scale projects where it is not necessary to develop highly accurate models, this analysis highlights that Project Tango has potential to serves as an alternative to 3D laser scanning. In addition, Project Tango seems to be suitable solution in projects where it is intended to quickly generate models without special expertise instead of opting for Photogrammetry. Also it is worth mentioning that the traditional 3D laser scanning and Photogrammetry are well calibrated and established processes which makes their usage justifiable in works that requires certifications. Further works needs to be done for Project Tango to be used as a common technique by working professionals and this paper is a first step in that direction.

6. Conclusion

In this work, Project Tango was studied as an alternative to the current existing as-built modeling techniques. Its suitability to both exterior and interior environment conditions was tested and proved through three different cases. It showed that Project Tango has potential to be used, particularly on small size and low budget projects. The object completeness analysis proved that Project Tango can be used in identifying missing objects. Dimensional accuracy analysis showed that the model generated using Tango was nearly accurate with absolute errors of up to 0.35m being reported. This level of dimensional accuracy may limit its potential for quality control applications. Also sufficient care is to be taken while developing the model. Furthermore, the spatial deviation analysis helped in identifying some deviations in objects size and their location. Although the resulting models were very usable, most of the modeling process was still manual. Thus there is a demand for developing automated methods to address this issue and to reduce the potential human errors in stages like data collection, post-processing, and quality assessment.

Table 3. Comparison of different techniques used for as built model generation.

Category	Parameters	3D Laser Scanning	Photogrammetry	Project Tango
Costs involved	*1. Equipment costs*	Highly costly in the range of $50K-$150K.	Affordable in the range of 500-1000$	Affordable with a price tag of 500$
	2. Software support and costs	Need expensive proprietary software	Need software like Autodesk 123D.	Need open source software like Meshlab
User convenience	*1. Post processing time requirement*	Huge amounts of time required.	Time required is more than that of laser scanning.	Time required is less.
	2. Mobility	Not very mobile.	Highly mobile.	Highly mobile.
	3. Learning curve	Very steep learning curve	Minimal learning curve	Minimal learning curve
Device accuracy and suitability	*1. Acquisition Accuracy, range*	High accuracy and range to the extent of millimeter	High accuracy but loses focus for large distance	Moderate accuracy compared to other two
	2. Weather conditions	Not affected by weather conditions much	Highly affected by weather like cloudy situations	Highly affected by weather like sunlight.

Acknowledgement

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