CIVIL & ENVIRONMENTAL ENGINEERING | RESEARCH ARTICLE

As built case studies for BIM as conflicts detection and documentation tool

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Abstract: As built documentation provide critical information that is needed during and afterward the construction. This process serve as a foundation upon which all changes, modifications or otherwise, made during the construction so that it can quickly obtain information about any design change. After construction, it serve as ready information source about what was actually built. Conflicts of the design documents with as built is crucial aspect of construction projects in order to prevent excessive cost of delays and work correction during operation and maintenance or renovation phases. Traditional documentation method sometime fails to serve in managing the development, rehabilitation and renovation of existing buildings. The lack of appropriate documents, change orders and as built-drawing for existing buildings are very common. These obstacles can be solved by the collaboration of all stakeholders at different phases of the project life cycle to insert, extract, update or amend related information. Since Building Information Modelling (BIM) has the potential to create a single model that offers visualization, clash detection, construction phases, and materials and testing together, this research will utilize the ability of BIM through case studies to address the conflicts detection through the project life-cycle. The results illustrates the main conflicts that had detected between the existing buildings and the available construction documents. The results of the two case studies prove that BIM model was very correlated to as-built in term of quantities take off and in the final shop drawing.

ABOUT THE AUTHORS
The experimental work of this research was implemented in Iraq, as a country suffer from a security problems includes but not limited to civilian war. In last decade many heritage and old building were destroyed in this country, with no possibility to rebuild them due to the missing documents for these buildings. In Diyala province, the central library and festivals hall considered as largest and most important buildings. This work aim to investigate the possibility of using of BIM to re-document and 3D-visualizing of these buildings, besides the providing of as-built modelling and quantities take off. This work is a part of a promising project to sustain and protect the heritage wealth in Iraq.

PUBLIC INTEREST STATEMENT
• The conflicts of design documents with as-built data was investigated as crucial aspect of construction projects.
• Building Information Modelling (BIM) has the potential to create a single model that offers visualization, clash detection, construction phases, and materials and testing together.
• This research was utilized the ability of BIM through case studies to address the conflicts detection through the project life-cycle.
• The results of the two case studies prove that BIM model was highly correlated to as-built in term of quantities take off and in the final shop drawing.
• These indications refer to high accuracy of BIM as a powerful tool for the re-documentation of existing building and their conflicts detection.
• BIM can be used efficiently in heritage wealth and old buildings protection by providing the 3D visualization and documentation for these sites.

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of quantities take off (coefficient was 95.8 and 99.8%) and in the final shop drawing. Also, the root mean square error was very little for BIM model (RMSE was 7.17 and 6.65) compared with traditional process for the quantities estimation compared with traditional process (RMSE was 43.75 and 47.33). These indications refer to high accuracy of BIM as a powerful tool for the re-documentation of existing building and their conflicts detection.

Subjects: Computer Graphics & Visualization; Engineering & Technology; Engineering Management; Civil, Environmental and Geotechnical Engineering; Design

Keywords: building information modelling; clash detection; project lifecycle; BIM visualization

1. Introduction

Many challenges occur in managing of the existing buildings through their lifecycle, often due to a lack of related technical information. The rework is a major factor that contributes in unnecessary excessive time and cost. It was found that the direct costs of the rework ranging from 3 to 23% of the contract value (Love, Irani, & Edwards, 2004). Improving the productivity in the construction industry at task, project, and industry levels would have an extensive benefit that will cover further than the industrial sector (Nepal & Staub-French, 2016).

Empirical evidence revels that the use of automation and integration technologies improves construction productivity (Abd & Abd, 2012; Eastman, Eastman, Teicholz, & Sacks, 2008). Every increase in productivity increases cost with the duration. Construction methods with its main factors; time, cost and productivity will give the project manager or the site engineer a chance for taking the accurate decision in suitable time. In other words, successful project with successful construction management (Abd, Abd, Zain, & Ismail, 2008; Babic & Rebolj, 2016).

One of the problems in the architectural engineering and construction (AEC) sector are that there are so many different professionals working on different parts of the project (structure, services, design, distribution ... etc.) following a fragmented method of management. Each of these parts must be based on a common “idea” and follow the same criteria of others, they are key part of information that, all together, allow the possibility to create the project. If information is not accurate and exactly enough, the next stages will be affected by it (Abd & Abd, 2014; Tauriainen, Puttonen, & Saari, 2015). Therefore the lack of appropriate documents, change orders and as a built-drawing for existing buildings is very common.

The fundamental hypothesis of BIM is collaboration by different stakeholders at different phases of the life cycle of a facility to insert, extract, update or amend information in the BIM to support and express the roles of that stakeholder (Smith, 2009). Within the construction industry it was found that the traditional process has been described as one of data waste, meanwhile; the ability to guide BIM users in the real world can still be largely improved (Chong, Lee, & Wang, 2017; Wu, Xu, Mao, & Li, 2017). This research aims to detect conflicts between schemes and reality to configure a document based on the reality by using BIM because current documentation methods do not lend themselves toward managing the continuous changes to buildings, two case studies were used that represented the central library and the multi-purpose hall in the University of Diyala.

The reason for choosing these projects was many documents not available for these buildings (missing documents). These projects were assigned to more than one contractor due to security incidents in Diyala Governorate at construction period (2002–2015). Also the project design has a lot of details (slabs, beams, columns, concrete wall, finishing floor, staircases and truss, etc.). This research was utilized Autodesk Revit software (version 2015) as BIM tool.
The experimental work was implemented in Iraq, which suffer from a security problems includes but not limited to civilian war. In last decade many heritage and old building were destroyed in this country, with no possibility to rebuild them due to the missing documents for these buildings. In Diyala province, the central library and festivals hall considered as largest and most important buildings. This work aim to investigate the use of BIM to document and 3D-visualizing these buildings, besides the providing of as-built modelling and quantities take off. This work is a part of a promising project to sustain and protect the heritage wealth in Iraq.

2. Sustainability and building performance using BIM

Building Information Modelling (BIM) was witnesses an enormous attention in academic and industrial environment. Beside the technical benefits of developed process, BIM also integrates an innovative platform to improve construction productivity and sustainability along the project life cycle. The three essential elements; social, economic, and environmental, contribute to the sustainability and become a metrics to measure the sustainability level on projects (Elmualim & Gilder, 2014; Khan, Dewan, & Chowdhury, 2016). BIM can improve social sustainability in two main areas. First, BIM provides a better facility design for a society’s comfort of living. BIM enables owners to review the design and give feedback through the visualization of a three-dimensional (3D) building information model before the facility is constructed. Second, BIM transforms conventional practice, which is often highly fragmented, to a better collaborative effort that strengthens the working relationship among project participants. In a BIM platform, team members have to share their own viewpoints of information with other members to form a reliable basis of decision-making to construct a facility. In terms of economic sustainability, a BIM-based cost-estimating system was created to automate the bill of quantities production. Many researchers provided a detailed review of green BIM to magnify the environmental sustainability throughout the building life cycle (Plebankiewicz, Zima, & Skibniewski, 2015; Wong & Zhou, 2015).

Habibi (2017) proposed a framework to explore the performance of existing building in Ferrara (Italy). The core step in this framework was to establish and determine consumed energy and environmental performance for the case studies. A simulation of building performance adopted to assess these parameters. Architectural data (e.g. location data, building geometry, and materials) had been used as a BIM framework to promote collaborative design progress, optimization, and contribution to advanced simulation in building performance and energy efficiency. The important conclusion presented that the future vision of BIM tools should focus beyond visualization and coordination.

The results of Park, Chen, and Cho (2017) work indicated that the addition of map knowledge from a BIM model showed the capability of correcting improbable movements in construction industry. Moreover, the knowledge-based decision-making process demonstrated its capability to make positive interaction by reducing the positioning errors by significant rate.

The promising development of BIM utilization in the construction industry introduces alot of opportunities for professionals to data exchange and use. Practical BIMs can especially create great potentials for downstream information users (Zadeh, Wang, Cavka, Staub-French, & Pottinger, 2017).

3. Experimental works

3.1. Case study 1

This project is one of the main buildings in Diyala University campus and its function is a multipurpose hall. It has a total area of 2,500 m² while the construction area of 2,380 m². The project was assigned to local company with estimated cost of (700,000,000 Iraqi Dinars, note that 1.0 $
US = 1160 ID). The work was started on 10 November 2002. The construction work was stopped at 2003 (Gulf war III). The project was re-announced for bidding and assigned to another local company with estimated cost of (1,600,000,000 ID). The work was restarted on 3 March 2005 and the project was stopped in 2006 due to security events in Diyala Governorate, the project was assigned for the third time to a new local company with estimated cost of (1,894,193,000 ID) in 2012. The other information about this building can be summarized as follows:

- The type of contract was a unit price contract.
- The building includes (25) rooms and other facilities for different purposes.
- The building height reaches to (17.4 m) and consists of three floors.
- Ground floor: Contains different ground levels (0.9, 1.2, 1.8, 2.1, 2.35, and 3.1 m) and high up to level (5.5 m).
- First floor: begins from level (5.5) and ends of level (9.2).
- Second floor: begins from level (9.2) and ends of level (12.9).
- The main hall starts from the ground floor at level 1.2 and ends at level 17.4,
- All slabs were of concrete except the slab of the main hall, which is of steel truss.

3.1.1. The conflicts of as-built with project documents
The ground floor has different levels and there were no strips from level to level as shown in Figure 1(a), when this floor represented by BIM according to the schemes, it is found that there is a difference between two levels (1 m) lack of the stairs as shown in Figure 1(b) while the building has stairs on the level 0.9–1.8 as shown in Figure 1(c); therefore, these stairs were introduced using the BIM model as shown Figure 1(d).

The architecture and structural schemes were not provided for a big part (slab and beams) in the first floor as shown in Figure 2(a). When this part represented in BIM model, it appeared as shown in Figure 2(b), also it was found that this part of the slab and beams in the real building were implemented by repeating the details of the slab and the beams of the ground floor as shown in Figure 2(c); therefore this part was modelled accordingly in the BIM model as shown in Figure 2(d).

When representing the second floor, conflicts founds between the walls, slab and the beams according the schemes as explained in Figure 3(a) and (b) of the second floor, also it was found in the real building; the wall was implemented according to the beam and the slab as shown in Figure 3(c); therefore, the wall was modelled accordingly in the BIM model as shown in Figure 3(d).

3.1.2. BIM accuracy
Considering the main articles in the construction activities for the case study-1; it was found that the accuracy of the quantities take off using BIM technique had an error rate of 6.646% for the main fourteen activities. Meanwhile the traditional estimation method was of error rate of 43.749% for the same activities. Table 1 show the BIM, traditional estimation, and the actual quantities as built and their comparison.

Figure 4 draw the correlation between the BIM measures and each of traditional estimation and as built measures. It was clear that there is a high correlation between BIM and as build measures than traditional estimation (95.8 vs. 91.1% respectively). This is a second proof that reflects the high accuracy of BIM measures compared with traditional estimation. Figure 4 illustrates the formula for each fit line for the two methods.
Figure 1. Introducing the stairs for the ground floor.

Figure 2. The conflicts on the first floor between (the architecture and structural schemes) of the multi-purpose.
3.2. Case study 2

This project is one of the main buildings in Diyala University campus and its function is a central library. It has a total area of 3,000 m² while the construction area of 2,800 m². The project was assigned to the local company. The work was started in 2002. The construction work was stopped at 2003 (Gulf war III), the project was assigned again to the Secretariat Implementation, the work was restarted in 2005 and the project was stopped in 2006 due to security events in Diyala Governorate. The project was assigned for the third time to a new local company with estimated cost of (3,274,732,000 ID) in 2012. The other information about the building can be summarized as follows:

- The type of contract was a unit price contract.
- The building includes (36) rooms and other facilities for different purposes.
- The building height reaches to (28.4 m) and consists of five floors.
- Ground floor: begins from level (0.9) and ends of level (5.9).
- First floor: begins from level (5.9) and ends of level (10.5).
- Second floor: begins from level (10.5) and ends of level (15).
- Third floor: begins from level (15) and ends of level (19.1).
- Fourth floor: begins from level (19.1) and ends of level (23.3).
- All slabs were of concrete.
3.2.1. The conflicts of as-built with project documents

There was lack of documents of the first floor (beams, slabs). Furthermore, when interviewing with one of the engineers that implemented the building, found that the height of the beams in the missing documents was 70 cm, but they were implemented at 90 cm due to columns that were previously implemented less than the height of the slab (90 cm instead of the 70 cm), these beams were introduced using BIM as shown in Figure 5(a) and slab as shown in Figure 5(b).

In the architectural schemes it was found that the front wall is arch ends with straight wall, but in the structural schemes, the beam and slab are arch as shown in Figure 6(a), when representing them by BIM the conflict was clear between the wall with the beams and slab as shown in Figure 6(b). In the as built, the front wall was implemented each shape of arch to the end without straight wall as shown in Figure 6(c) therefore, the wall was modelled accordingly in the BIM model as shown in Figure 6(d).
In Architecture scheme the slab that surrounds the dome, which is in the form of a circle at level 14.6 as shown in Figure 7(a), but the other slabs at level 15. When the slab represented using BIM, the conflicts found between the walls and beams with slabs as shown in Figure 7(b), also it was found that this slab in the real building was a change in the design of the slab in level 14.6 was not in the form of a circle as shown in the Figure 7(c) because the slab conflict with beams (the Architectural and the Structural schemes); therefore, the slab was modeled accordingly in the BIM model as shown in Figure 7(d).

3.2.2. BIM accuracy
For the main seventeen articles in the construction activities for the case study-II; it was found that the accuracy of the quantities take off using BIM technique have an error rate of 7.17% for the main activities. Meanwhile the traditional estimation method was of error rate of 47.33% for the same activities. Table 2 show the BIM, traditional estimation, and the actual quantities as build and their comparison. Again this is a clear evidence for the good precision of BIM accuracy.

Figure 8 elaborates the correlation coefficients of BIM measures with each of traditional estimation and as built measures. The high correlation between BIM and as built measures was very clear.
compared to traditional estimation (99.77 vs. 92.34% respectively). This is another proof that reflects the high accuracy of BIM measures compared with traditional estimation. Figure 8 illustrates the formula for each fit line for the two methods.

Table 2. Comparison of BIM, traditional estimation, and as build quantities for case study-II

| No. | Item                  | BIM          | Estimation vs. BIM | As Built vs. BIM |
|-----|-----------------------|--------------|--------------------|------------------|
|     |                       | Quantity     | Quantity           | Error (%)        | Sqr-error       | Quantity | Error (%) | Sqr-error |
| 1   | Foundation (m³)       | 1,482.612    | 1,424.000          | 3.95             | 15.63           | 1,572.980| 6.10      | 37.15     |
| 2   | Columns (m³)          | 235.399      | 248.852            | −5.71            | 32.66           | 248.852  | 5.71      | 32.66     |
| 3   | Beams (m³)            | 531.220      | 420.000            | 20.94            | 438.35          | 535.000  | 0.71      | 0.51      |
| 4   | Domes (m³)            | 146.283      | 100.000            | 31.64            | 1,001.05        | 146.500  | 0.15      | 0.02      |
| 5   | Slabs (m³)            | 877.267      | 914.720            | −4.27            | 18.23           | 878.720  | 0.17      | 0.03      |
| 6   | Stair (m³)            | 13.619       | 23.330             | −71.30           | 5,084.37        | 14.830   | 8.89      | 79.07     |
| 7   | Under D.P.C 24 cm (m³)| 278.334      | 327.320            | −17.60           | 309.75          | 319.320  | 14.73     | 216.84    |
| 8   | Brick above D.P.C 24 cm (m³) | 1,300.109 | 1,321.900         | −1.68            | 2.81            | 1,315.900| 1.21      | 1.48      |
| 9   | Brick above D.P.C 12 cm (m³) | 154.121  | 250.000            | −62.21           | 3,870.11        | 161.000  | 4.46      | 19.92     |
| 10  | Concrete wall (m³)    | 82.126       | 80.830             | 1.58             | 2.49            | 87.830   | 6.95      | 48.24     |
| 11  | Floor of the hall (m²) | 2,039.800    | 2,750.000          | −34.82           | 1,212.23        | 2,070.000| 1.48      | 2.19      |
| 12  | Floor of the inner corridors (m²) | 1,737.600 | 1,800.000         | −3.59            | 12.90           | 1,800.000| 3.59      | 12.90     |
| 13  | Floor of the external corridors (m²) | 894.262    | 1,150.000          | −28.60           | 817.83          | 940.000  | 5.11      | 26.16     |
| 14  | Floor of roof (m²)    | 1,339.919    | 1,600.000          | −19.41           | 376.76          | 1,270.000| −5.22     | 27.23     |
| 15  | Concrete of D.P.C (m) | 461.431      | 1,166.670          | −152.84          | 23,359.26       | 524.670  | 13.70     | 187.83    |
| 16  | Concrete under the tile (m³) | 2,725.663 | 3,729.500         | −36.83           | 1,356.38        | 3,077.000| 12.89     | 166.15    |
| 17  | Package stone (m²)    | 5,765.665    | 5,000.000          | 13.28            | 176.35          | 6,000.000| 4.06      | 16.52     |

| Mean square error (%) | 2,240.42 | 51.46 |
| Root mean square error (%) | 47.33 | 7.17 |
Comparing with the results of previous researchers, this work also presented the development and validation of a retrofit strategy on detailed building elements through BIM-based building visualization analysis as discussed by Habibi (2017). Meanwhile, in terms of sustainability aspect, BIM standards and guidelines should include elements of relational contracting in the project delivery system, especially for public involvement and other downstream project stakeholders in order to be used in refurbishment and demolition aspects (Chong et al., 2017). The knowledge gained in this study is that the inclusion of BIM as error tracing tool proved to have a large impact on accuracy of project documents, thus, it considered a vital component in reducing drift in building information management, and this was exactly concluded by Park et al. (2017).

4. Conclusion
This research explores through case studies the ability of BIM as a tool for improvement of knowledge management in the constructed projects. The results prove the capability of detecting many conflicts occurs between the as built and the design construction documents. Through the use of this tool; it was possible to avoid or minimize change orders to the minimum for the construction project and to provide quantities take off, 2D, 3D, simulation and multi cross-sectional details for the project. Most of the conflicts were found in the concrete work and finishing items for the case studies. BIM have been proved to be powerful tool for existing building re-documentation and conflict detection, also to reduce the change orders for new or continued projects. The results illustrates the main conflicts that had detected between the existing buildings and the available construction documents. The results of the two case studies prove that BIM model was of high correlation coefficient with as built in term of quantities take off (correlation coefficient was 95.8 and 99.8%) and in the final shop drawing compared with the traditional estimation method (correlation coefficient was 91.2 and 92.3%). Also, the root mean square error was very little for BIM model (RMSE was 7.17 and 6.65) compared with traditional process for the quantities estimation compared with traditional process (RMSE was 43.75 and 47.33). These results reflect the high accuracy of BIM and its ability to be used as a powerful tool for the re-documentation of existing building and their conflicts detection. Also, BIM can be used efficiently in heritage wealth protection by providing the 3D visualization and documentation for these sites.

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