BIM Quantity Take-offs Analysis for Accurate Estimates of Concrete Volume in Buildings

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Abstract

Precise design of concrete parametric objects for building concrete structures using Building Information Modelling (BIM) provides a new basis for cost estimation and accurate determination of concrete quantities needed in the construction phases. Most BIM software available on the market nowadays offer features, which has the ability to enhance the materials take-off/schedules through acceptable and flexible modifications, as they may occur at the progressive stages of the 3D design model during the pre-construction phases or even more during the building lifecycle. Additionally, the concrete quantities may be assembled based on the concrete type, construction elements, building levels and other criteria. Authors of this manuscript were examining three-dimensional models of structurally different commercial buildings, in order to compare, extract and compute only the quantities of all concrete elements involved in the construction of foundations, columns, framing elements, floors, and walls. The extraction of these quantities is helpful to a construction contractor in determining the cost estimates of all concrete elements and for further analysis on the variances of these quantitates with the final quantities (volumes) which are placed in the buildings during the construction phases. For the three cases selected, the findings revealed a relatively close range of accuracy of positive or negative one to three percent, and therefore it allows generation of savings during procurement process for all stakeholders.

Keywords: Estimating Accuracy, Quantities, Concrete Structures, Variance, BIM

1. Introduction and background for this study

Quantity take-off (QTO) is becoming known as an exhausting work process that requires a long time to be completed. In the traditional way of preparing the estimating sheets and the quantity take-offs in general, both processes need to be done by the same person or at least someone who is using the same procedure because there are different ways of reading 2D plans in order to obtain the materials quantity take-off sheets. Therefore, each construction business has its own method in performing the quantity take-off. In addition, for large projects, the work needs to be divided between the take-off estimator team members, in order to follow the same method of reading these 2D plans.

In the process of obtaining precise quantities, it is critical to avoid recounting or missing elements in assemblies. All these considerations are enough reasons to embrace new technologies which may reduce errors in the QTO work. Many software packages are being used for the quantities take offs and estimating purposes such as On-Center, e-Takeoff, Sage Estimating, Bluebeam Revu, Autodesk Revit, etc. Most of the software is sharing many advantages of saving time and giving certain accuracy for the quantity take-off estimators. In contrast, not all the software is supporting the 3D models' representations and some of the QTO software are required to draw on the plans to obtain the quantity sheets with the values on materials to be used in the jobsite. As a reference, Autodesk Revit Software has the features of providing the quantities take off in association

with the 3D model. The 3D model is created on Autodesk Revit by architectural and/or structural building objects, placed on the basis of the QTO object type required, hence there is no need to redraw 2D plans in order to obtain the quantity take-offs. This approach is new to some estimators who are quite used to extracting quantities only from 3D parametric models.

In the construction industry, there is a demand for precise materials' estimates as they are used for two main reasons. First, these estimates are involved in the bidding process. Second, they are needed to create a valid and as accurate as possible work plan to the Owner, Contractor and potential Subcontractors' jobs working on the respective buildings. It should provide them a fairly good idea about all the materials and how much of them are needed for the project. There is a persistent pressure in the construction market for estimation work to be done faster and as accurate as possible by all construction trades. The QTO accuracy may be inexact when it is sought during different design phases. On one hand, a preliminary version of the QTO helps in providing rough quantities and this could be needed in the early design process. On the other hand, very accurate and detailed QTO sheets are able to be presented when the design is completed, and a contractor is work-ready to proceed.

According to a previous study by Sylvester and Dietrich in 2010 [13], BIM provides a more accurate estimation by visualizing all the construction elements, linking them with the cost databases and reducing human errors, therefore reducing time to acquire a more precise estimate. In many of BIM software markets, the material quantities are automatically adjusted through association of any bi-dimensional changes and/or updates performed to the respective three-dimensional models. For example, the Autodesk Revit users are benefitted to save more time during the pre-construction phases instead of re-computing the quantities of the modified building 3D components in their models. In addition, if known at the time of the actual estimate, the users can attach prices per measuring units and create formulas to compute specific construction element work costs, then adjust the price units in the quantity take-off tables if needed. Other authors' work concludes that while it is possible to adapt the model to extract quantities according to existing specifications for manual-based measurements, the adjustments are not without its consequences in other model applications such as visualization or drawings. Therefore, take-offs specifications should be revised in order to account for BIM's features and accordingly minimizing its limitations [10].

2. Literature Review

Traditionally, the quantity take offs work requires going through every single plan of the 2D drawing sets (architectural, structural, MEP, landscape, fire protection, etc.) to account for all the existing materials and measure every unique instance of certain objects, as first step. For next step, the traditional estimating method requires reviewing the QTO sheets and assuring there is no adding or missing of any building elements,

systems, assemblies, connections or other type of attachments. Unfortunately, these processes consume a lot of time and effort [4].

As there is a demand for QTO's in the construction industry, Elbeltagi [4] also explained the QTO significances and requirements are different for each Owner and also from the Contractor's perspective. The significance of the QTOs perspective is illustrated in the following:

a. From the Owner perspective:
- Provide primary estimates for the project at the different stages,
- Prepare bill of quantities as they are required in the contract documents,
- Issue the contractor payments after estimating the work done.
b. From the Contractor perspective:
- Provide pricing for the different work items,
- Identify the needed resources (Labour, Equipment, etc.),
- Prepare the project schedule,
- Prepare invoices for work done,
- Prepare the subcontractors' payments,
- Review and control of crews' production rates.

All these are contributing to the need for a realistic QTO and BIM software can provide the means to extract efficiently these quantities for construction purposes.

Nowadays, construction projects are more readable as a set of databases more than a drawing set of plans which affects the take-offs and the cost estimating work process [6]. For this purpose, there is a need to work with new software capable of reading the project as a set of databases. As mentioned before, there are many BIM software packages currently available in the market to work within preconstruction estimates.

According to an independent research report by McGraw-Hill Construction [9], in North America, it is shown that the adoption of BIM has increased from 17% to 70% between 2007 to 2012. Furthermore, Autodesk website shared great news during 2013 and commented on one of the previous Smart Market Reports at that time, concluding that "for the first time ever, more contractors (74%) are using BIM than architects (70%)" [1]. This represented a great leap for construction estimates too, especially because during that period of time BIM software was not heavily used in construction estimates or for quantity take off purposes.

The more recent National BIM Report [11] from Great Britain (2018) showed that there is growth in the levels of BIM adoption over recent times. The report analyzes this growth into three distinct categories of adoption, and they are shown in Figure 1, as: aware and currently using BIM, just aware of BIM and neither aware nor using BIM at all. In 2018, there is only 1% of the total companies surveyed which were unaware of BIM

comparing to 43% in 2011. Similarly, the growth of BIM usage went from 13% in 2011 up to 74% during 2018.

According to another study done by Bečvarovská and Matějka (2014), both methods (traditional and BIM-based) were applied to one QTO project; as a result, BIM saved up to 80% of time comparing to the traditional quantity take off methods [2]. Table 1 represents the actual time differences between using BIM and traditional way spent to obtain the QTOs for each of the categories in Table 1.

Other study by Olsen and Taylor (2017) supported the BIM advantage of time-saving in general, besides many other advantages such as the accuracy of the quantity take offs [12]. They explained that the probability of the omissions and errors are decreased when projects involving BIM are more detailed. Figure 2 presents the responses of the survey about defining the advantages of QTO and estimation based on BIM. The visualization and the speed are the top two BIM-based QTO and estimating advantages, according to their findings.

However, this study finds in particular two main disadvantages of BIM-based QTO: the time spent in creating the models and examining them carefully against the design intent, also the complexity of software as being used for the purpose of estimating challenged sometimes by the lack of details (Olsen, D. and Taylor, M., 2017). On a different note, Khosakitchalert et. al. (2019) study proposes a method to improve the accuracy of the extracted quantities of compound elements from BIM models that are incomplete or incorrect by using information from BIM-based clash detection to eliminate excess quantities and add missing quantities [7]. Their method (validated through four case studies) claims that accurate material quantities can be delivered (with a deviation of up to 3%), and therefore time used to edit the BIM models is saved.
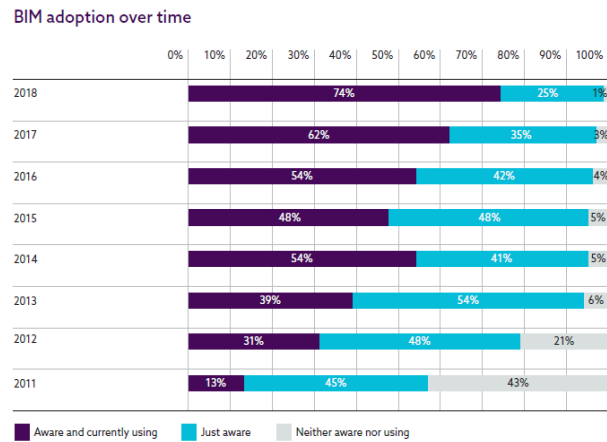

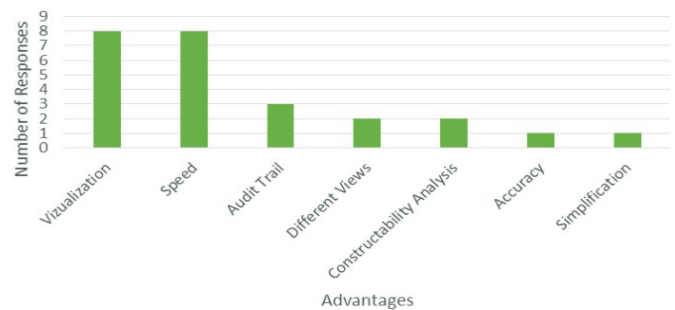**Figure 1. NBS, the National BIM report (adopted from [11] to represent on BIM implementation)**

Figure 2. Advantages of BIM-based QTO [12]

Table 1. Tme Saved using BIM Tool for Quantity Take-Off [2]

Category	Contents	Time (minutes)	
		Manual	**Revit**
Table of rooms	Floor and ceiling composition	40	20
Foundations	Pads, belts, slabs	125	20
Construction phase	Walls, pillars, girders	420	10
Vertical constructions	Masonry, isolation	450	30
Wall surface	Plasters, paints	330	20
Ceiling composition	Ceiling composition	20	15
Floor composition	Floor composition	40	15
Wall composition	Wall composition	100	20
Façade	Façade	240	20
Roof composition	Roof composition	20	5
Balcony composition	Balcony composition	50	15
Groundwork	Excavations, embankments, removal	120	-
Staircases	Staircases	60	-
Other construction and work	Cleaning, shining, covering	70	20
Tables for take-offs		--	130
Total		2085	340

3. Materials used in the study and methodology

Three cases of study were analyzed in conjunction with their concrete-based Autodesk Revit files formats – as-build projects – which were shared by a General Contractor working in the south-east United States (Georgia and Florida mainly) and they were used to perform volumetric concrete quantity take-offs. The following breakdown was considered for each individual project with their concrete elements (Figures 3, 4, and respectively 5):
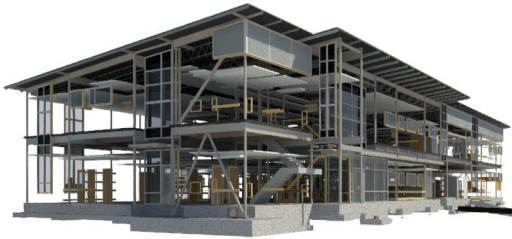

Figure 3. Health Center, Georgia Southern, GA

Figure 4. Grove Station Tower, Miami, FL

Figure 5. Georgia Heights, Athens, GA

Case Study 1: Georgia Southern University Health Center: specifically, foundations, columns, floors, and walls;
Case Study 2: Grove Station Tower (Miami): in this case foundations, columns, framing, floors, and walls;
Case Study 3: Georgia Heights (Athens): specifically, foundations, columns, framing, floors, and walls.

More than a decade ago, earlier adopters and critics reported at that time a number of BIM programs on the market, including Revit Structures, VICO Constructor, Bentley Structures and Tekla Structures having some quantity take-off features and capabilities for concrete volume calculations and

to analyze scenarios in preconstruction phase for concrete work [14]. However, as the BIM software was used for all calculations (Autodesk Revit) in all three case studies, the actual software was employed to compute only the concrete quantities for estimation purposes. It is noted that Autodesk Revit has successfully provided ample opportunities to measure a variety of materials quantities for pre-construction needs. Therefore, it offers several types of schedules and quantity take-offs for building elements and various components (objects) to help in computing the total costs of construction. Autodesk Revit also has other tools for scheduling purposes that are shown in Figure 6, these tools help in the estimation phases or processes. For these particular cases, the scheduling tool used in computations was accessed from the View Tab > Create Panel > click Schedules drop-down > then, choose ⊞Schedule/Quantities.
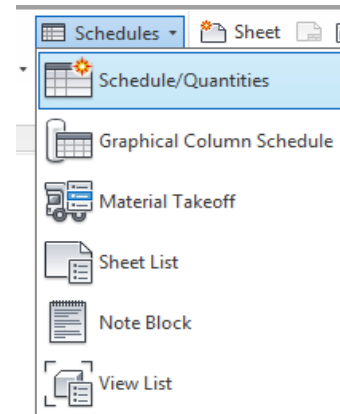

Figure 6. The Schedule/Quantities Revit tool used for computing the QTO structural elements' materials

Using the feature of material take-off in all the concrete structural elements that may have concrete (volumes) among its components from the respective Autodesk Revit models will reveal its quantities as designed in the respective families, including the foundations, columns, framing components, floors, and walls. Because each of these elements has a different structural function in the building, the elements' materials were different too. For example, the columns structural schedule might have a combination of materials such as concrete, steel, and wood. However, for this analysis, the only purpose was to compute the concrete quantities from the different parts of the structure in each Revit file/model of the three respective projects (cases of study). The concrete type and its strength were accounted for separately. Furthermore, the unit costs are going to be different too. This concern is addressed in the chosen BIM software by using the "grouping" feature, based on the concrete/materials type. After this step is finalized, the concrete structural "schedules" are ready to be exported from Autodesk Revit software using Export> Schedule > (*.txt) file feature, as seen in Figure 7. One more step is required in order to obtain the concrete QTO which helps in editing or/deleting the non-

concrete elements from the Excel sheets. This step will be easily applied because all the non-concrete material elements are grouped/gathered and have a sub-heading that indicates the materials type of each group. As a result, the consequent schedule will have concrete material only. In the end, the quantity take-offs will be multiplied with the unit cost/price (CF or CY cost) whenever the final estimation numbers are needed by the Contractor.

Figure 7. Software workflow used for concrete QTO computations

Case Study 1. Georgia Southern University Health Center [for the computational process of this building the following structural elements were considered: foundations, columns, floors, and walls and all of them have different types of materials. The materials quantities take-off schedules are counted separately based on the structural elements of the project. To detail in this case study, the BIM structural elements containing concrete modelled in the 3D design were foundations, columns, floors, and walls. Each one of these structural elements has different types of materials besides the concrete]. Each structure element schedule was exported from BIM software to (*.txt) file extension in the initial process of this computation. Then, all this information was transferred in Microsoft Excel spreadsheets where it was used to edit the output file and remove all the non-concrete materials (Figure 9 and 10). The final concrete structural type elements and its quantities for this specific structure are listed below in each designated category.

Foundations:

1. Concrete cast in place concrete: 772.88 CF (21.88 m^3);
2. Concrete cast in place concrete 3,000 PSI: 7,679.62 CF (217.46 m^3).

Columns:

1. Concrete cast in place concrete 3,000 PSI: 30.52 CF (0.86 m^3).

Floors:

1. Concrete cast in place concrete 3000 PSI: 7,998.13 CF (226.48 m^3);
2. Concrete cast in place concrete 3500 PSI: 9,739.62 CF (275.79 m^3).

Walls: Concrete cast in place concrete 3,000 PSI: 91.84 CF (2.60 m^3).

From these structure elements' materials, it was clear that there were only three types of concrete used for construction of the structure, according to the design information placed in the BIM software. These concrete types quantities are summed up based on their concrete strength. Therefore, the final

computation performed in this case have led to the following quantities:

1. Concrete cast in place concrete: 772.88 CF (7.87 m^3).
2. Concrete cast in place concrete 3000 PSI: 7,679.62+30.52+7,998.13+91.84 = 15,800.11 CF (447.41 m^3).
3. Concrete cast in place concrete 3,500 PSI: 9,739.62 CF (275.79 m^3).

Finally, these results of different types of concrete went through a materials' filtering process using the software filtering tools. These available features within this particular software, including the take-off feature, are unable to manage/edit all grouped family materials and process this data. For this reason, it is sometimes necessary to also use other software. (Monteiro and Martins, 2013). All the structural elements schedules of case study 1 have various types of materials in their assemblies, not only concrete.

Structural Foundations Schedule: it has only two types of the structural material, which are: Concrete cast in place concrete, and Concrete cast in place 3,000 PSI (Figure 9). Obviously, both of these materials are concrete based.

Figure 8. Revit take-off table showing the non-concrete columns materials

Figure 9. Microsoft Excel table illustrating the non-concrete columns materials

Structural Columns Schedule: it has various types of column materials, such as Softwood Lumber, Metal Steel ASTM, and Cast in Place Concrete. The first two types of columns materials are not needed in this quantity estimation because of their specific material as being different than concrete. The only type considered in this quantity calculation is the Cast in Place Concrete for columns.

Structural Floors Schedule: it has only three types of the structural material which are: Metal Roof Deck, Concrete cast

in place concrete 3,000 PSI, and Concrete cast in place concrete 3,500 PSI.

Structural Walls Schedule: Curtain Wall Type, Louver System Type, Sliding Type 11", Exterior Concrete Masonry Units, Gypsum Wall Board, Metal Stud & Rigid Insulation Layer, Metal Stud & Sound Attenuation Layer, Toilet Partition "Plastic", and Concrete cast in place concrete 3000 PSI.

Unfortunately, the authors have not identified at this time a method to delete the non-concrete materials from the actual outputted Revit schedule. In order to place the quantities into a friendly spreadsheet, one more step is needed to output the total quantity of the related concrete element volumes for each building. This step was to export the schedule of obtained quantities into Microsoft Excel sheets and to further modify the material columns in the resulted spreadsheet(s). The structural columns with non-concrete materials were deleted in all the structural elements schedules (Figure 10). The step did not take a long time because the building elements were listed and grouped based on the material type. As a final result, the schedule contained only the structural concrete materials. However, and just as a constructability note, there is no consideration of construction method information to be taken into account when performing generation of quantities for constructability purposes [8].

Case Study 2: Grove Station Tower (Miami). The concrete quantity for this case study is grouped based on the structural elements of the building which are foundations, columns, framing, floors, and walls.

Structural Foundations Schedule:

Concrete cast in place concrete: 36,385.36 CF (1030.32 m^3).

Concrete, cast in place gray: 35,026.25 CF (991.83 m^3).

Columns: Concrete cast in place concrete: 24,056.75 CF (681.2m^3).

Framing: Concrete cast in place concrete: 6,046.38 CF (171.21 m^3).

Floors: Concrete, cast in place gray: 184,409.36 CF (5,221.89 m^3).

Walls: Concrete, cast in place gray: 48,410.33 CF (1,370.83 m^3).

For this structure, there are only two types of concrete as outputted for final calculations:

1. Concrete cast in place concrete:
   36,385.36+24,056.75+6,046.38 = 66,488.49 CF (1882.74 m^3).
2. Concrete cast in place gray:
   35,026.25+184,409.36+48,410.33 = 267,846.94 CF (7584.58 m^3).

In this case, the following classifications for structures were identified.

Structural Foundation Schedule: Concrete cast in place concrete, and Concrete, cast in place gray.

Structural Column Schedule: it has only one type of material which is Concrete cast in place concrete.

Structural Framing Schedule: it has only two types of materials which are Concrete cast in place concrete, and Metal - Steel - ASTM A572.

Structural Floor Schedule: it has only one type of material which is Concrete Cast-in-place gray.

Structural Wall Schedule: Concrete Masonry Units, Concrete Cast-in-Place gray, Metal Stud Layer.

Case Study 3: Georgia Heights (Athens). The concrete quantities for this case study are grouped based on the structural elements modelled, which are foundations, columns, framing, floors, and walls.

Foundations: Concrete cast in place concrete: 54,066.73 CF (1530.99 m^3).

Concrete cast in place gray: 4,721.32 CF (133.69 m^3).

Columns: Concrete cast in place concrete: 23,075.91 CF (653.44 m^3).

Framing: Concrete cast in place concrete: 6,078.58 CF (172.13 m^3).

Floors: Concrete cast in place concrete: 154,809.74 CF (4,383.72 m^3).

Walls: Concrete, normal weight, 4 ksi: 28,287.77 CF (801.02 m^3).

For this structure, there are only three types of concrete outputted in the final calculations:

1. Concrete cast in place concrete: 54,066.73 + 23,075.91 + 6,078.58 + 154,809.74 = 238,030.96 CF (6,740.28 m^3).
2. Concrete, cast in place gray: 4,721.32 CF (133.69 m^3).
3. Concrete, normal weight, 4 ksi: 28,287.77 CF (801.02 m^3).

To synthesize and in order to clearly understand the schedules obtained for all structural elements involved in the three case studies, they are aggregated in the followings:

1. Structural Foundation Schedules: Concrete Cast in Place Concrete, Concrete, Cast-in-Place gray.

2. Structural Column Schedules: Concrete Cast in Place Concrete, Metal - Steel - ASTM A500.

3. Structural Framing Schedules: Concrete Cast in Place Concrete, Metal - Steel - ASTM A500.

4. Structural Floor Schedules: Concrete Cast in Place Concrete.

5. Structural Wall Schedules: Concrete Masonry Units, Concrete, Normal Weight, 4 ksi.

4. Results and Preliminary Discussion

A comparison of the actual concrete quantities which were provided by the General Contractor (in CY) with the concrete quantities obtained virtually from the BIM models (in CF) was performed. These quantities were compared (in the end) based on the same unit provided by the contractor for placing and reporting finished concrete, which was worked out in these buildings (in CY). The following Table 2 below displays the total calculated concrete quantity for each case study comparing them to the reported (actual) total quantities of concrete used by the General Contractor in their construction phases. A discussion follows reflecting on the findings for each case study.

For Case Study 1- the total quantity of the concrete is divided into three parts, based on the concrete strength: 1-cast in place concrete is 772.88 CF (21.89 m^3); 2- cast in place concrete compressive strength is 3000 PSI (20.68 MPa) and the volume is 15,800.11 CF (447.40 m^3); 3- cast in place concrete strength is 3,500 PSI (24.13 MPa) and volume is 9,739.62 CF (275.79 m^3). Accordingly, the total actual quantity for concrete reported by the General Contractor for all structural elements using concrete of various strengths in Case Study 1 were: 1,003 CY (766.85 m^3), meaning foundations, column block outs, and equipment pads: 383CY (292.82 m^3), Slab-On-Grade - Section 1: 190 CY (145.27 m^3) + Section 2: 197 CY (150.62 m^3), and the elevated Slab: 233 CY (178.14 m^3).

Table 2. Comparative results of the three Case Studies for Concrete Quantities

Case studies/ Classification Type	Case study 1: Georgia Southern University Health Center	Case study 2: Grove Station Tower - Miami	Case study 3: GA Heights - Athens
Concrete type 1 and its quantity	Cast in place concrete: 772.88 CF (21.89 m^3)	Cast in place concrete: 66,488.49 CF (1882.74 m^3)	Cast in place concrete: 238,030.96 CF (6740.29 m^3)
Concrete type 2 and its quantity	Cast in place concrete compressive strength 3000 PSI: (20.68 MPa), and the volume: 15,800.11 CF (447.40 m^3)	Cast in place gray: 267,846.94 CF (7,584.58 m^3)	Concrete, cast in place gray: 4,721.32 CF (133.69 m^3)
Concrete type 3 and its quantity	Cast in place concrete strength 3500 PSI (24.13 MPa) and volume: 9,739.62 CF (275.79 m^3)	------------	Concrete, normal weight, 4 ksi (25.57 MPa): 28,287.77 CF (801.02 m^3)
Total quantity from BIM QTO	974.54 CY (745.08 m^3)	12,382.79 CY (9,467.32 m^3)	10,038.52 CY (7,675 m^3)
Total concrete quantities from General Contractor	1,003 CY (766.85 m^3)	12,173 CY (9,306.92 m^3)	10,316.35 CY (7,887.41 m^3)
General Contractor vs. BIM quantities, Error variances results **(< +3%; -2% >)**	**+2.92%**	**-1.72%**	**+2.77%**

For Case Study 2 - the total quantity of the concrete is calculated based on the two different strengths: 1- cast in place concrete is 66,488.49 CF (1,882.74 m3); 2- cast in place gray is 267,846.94 CF (7,584.58 m3). Reported actual/total quantities of concrete from the General Contractor for this case is 12,173 CY (9,306.92 m3).

For Case Study 3 - the total quantity of the concrete has three parts and they are classified based on the concrete type: 1-cast in place concrete: 238,030.96 CF (6,740.29 m3); 2- concrete, cast in place gray: 4,721.32 CF (133.69 m3); 3- concrete, normal weight, 4 ksi (25.57 MPa): 28,287.77 CF (801.02 m3). Total quantity reported by General Contractor in this case after concrete construction phases were completed is: 10,316.35 CY (7,887.41 m3).

Working through the facts as resulted from the totals' comparison, the researchers have found that the error variances for all three case studies are in the range of [- 2.0 to + 3.0] % for the total concrete quantities needed to be used in each case, therefore a comfortable accurate estimate for the type of concrete work from the General Contractor's point of view. The errors generated in these estimates may be caused by several factors and therefore some aspects considered in the extraction of these totals for the quantities which were placed in the respective buildings (when erected) can be reasoned after all. Nevertheless, just by working on this study and considering the time spent to calculate the total quantities of each case study, the authors may empirically imply that the BIM quantity take-off procedure exhibited in this manuscript is an efficient estimation method and therefore may lead to a shorter-time determination needed to compete for real quantities to be priced (and placed as orders) for concrete vendors.

Furthermore and with certainty, the authors are acknowledging that the Level of Details (LoD) and effort the BIM drafters were corroborating into the virtual design and their "constructed" models are critical to the accuracies obtained relative to the parametric-scaled families within the software used (as referred also by Choi et. al. in 2015, [3]).

5. Conclusions and recommendation for further research

The pre-construction quantity take-off (along with the procedural cost estimation) in each of the presented cases are typically involving exhausting work and a great level of attention to details, if performed in a traditional way. However, the BIM quantity take-off as integral method to the procedure represents a great alternative process for extracting the material (in this case volumetric concrete) construction quantities. As a result, BIM quantity take-off generation saves more time and money by providing relatively accurate quantities and therefore an acceptable and accurate cost estimation process for the entire project.

As more details are revealed with their accurate representations for any project in the 3D models, the project quantity take-off and the cost estimation are becoming closer to the factual reality. For example, the concrete details in the presented cases were included in the concrete material descriptions, concrete strength level/type, degree of fire and/or humidity resistance, thermal insulation levels, etc. All these details will have finally an effect on the cost for the quantity unit considered in the estimate.

As limitation for cost estimates, labour costs were not included in the total prices for these case studies, so the sole purpose of calculating concrete material quantities was served as a basis for comparison between quantity take-off/estimated and placed masses of concrete - as volumetric (CY) quantities. Also, as mentioned by other authors [5] in 2017, during the cost estimating phase, the man-hours input from the cost estimator should be lower, as the take-off and parts of the cost estimate can be done automatically and semi-automatically with specialized software tools. The relationship on the labour costs assigned to the quantities needed to be placed is by itself a matter of research and further efficacy on every construction contractor's side.

On a different note, and as a potential further research direction on the presented study, concrete masonry units could be extracted from the completed digital models in each case and be compared with the total quantities used and evidenced by company reports after completion of their masonry work.

Acknowledgements

References

[1] Autodesk News. BIM Adoption expands from 17% in 2007 to over 70% in 2012, according to new McGraw-Hill Construction report. https://adsknews.autodesk.com/stories/bim-adoption-expands-from-17-in-2007-to-over-70-in-2012-according-to-new-mcgraw-hill-construction-re. Published 2013.

2] Bečvarovská, R., Matějka, P. Comparative Analysis of Creating Traditional Quantity Takeoff Method and Using A BIM Tool. Construction Macroeconomics Conference. Retrieved from http://www.conference-

cm.com/podklady/history5/Prispevky/paper_becvarovska.
pdf .2014.

[3]   Choi, J., Kim, H., Kim, I. Open BIM-based quantity take-
off system for schematic estimation of building frame in
early design stage, Journal of Computational Design and
Engineering, 2015; Vol. 2, Issue 1, pp. 16-25.

[4]   Elbeltagi, E. Cost Estimating. Chapter 2: Quantity Take-
off. http://osp.mans.edu.eg/elbeltagi/Cost%20Ch2.pdf ;
Retrieved 26 November 2014.

[5]   Gołaszewska, M., Salamak, M. Challenges in takeoffs and
cost estimating in the BIM technology, based on the
example of a road bridge model. Technical Transactions –
Civil Engineering. 2017; Vol. 4, pp. 71-79.

[6]   Iskdag, U., Underwood J., Aouad G., Trodd N.
Investigating the Role of Building Information Models as
a Part of an Integrated Data Layer: A Fire Response
Management Case. Architectural Engineering and Design
Management. 2006; Vol. 12, pp. 124–142.

[7]   Khosakitchalert, C., Yabuki, N., Fukuda, T. Improving the
accuracy of BIM-based quantity takeoff for compound
elements. Automation in Construction. 2019; Vol. 106,
102891, pp. 1-20.

[8]   Ma, Z., Liu, Z. BIM-based intelligent acquisition of
construction information for cost estimation of building
projects. In: Creative Construction Conference, CC. 2014;
pp. 358-367

[9]   McGraw-Hill Construction. Dodge Data & Analytics.
Smart Market Report: The business value of BIM in North
America. https://www.construction.com/about-
us/press/bim-adoption-expands-from-17-percent-in-2007-
to-over-70-percent-in-2012.asp. 2013.

[10] Monteiro, A., Martins, J. P. A survey on modeling
guidelines for quantity takeoff-oriented BIM-based design,
Automation in Construction. 2013; Vol. 35, Pages 238-
253.

[11] National BIM Report. NBS report. RIBA Enterprises Ltd.,
The Old Post Office, St. Nicholas Street, Newcastle Upon

Tyne NE1 1RH, 2018; pages 1-52.
https://www.thenbs.com/knowledge/the-national-bim-
report-2018

[12] Olsen, D. and Taylor, J. M. Quantity Take-Off Using
Building Information Modeling (BIM), and Its Limiting
Factors. Procedia Engineering. 2017; Vol. 196, pp. 1098 –
1105.

[13] Sylvester, K. E., Dietrich, C. Evaluation of Building
Information Modeling (BIM) Estimating Methods in
Construction Education. In: Proceedings of the 46th ASC
Annual International Conference, Wentworth Institute of
Technology, Boston, MA. 2010; April 7-10.

[14] Wasieleski, R. Concrete and BIM. Two concrete
contractors share their experiences and thoughts on 3D
modeling. Retrieved 26 November 2020,
https://www.forconstructionpros.com/concrete/equipment-
products/article/10117046/concrete-and-bim. 2009.