Quantity take-off in traditional and BIM environments:

Comparative analysis of concrete and formworks of building structures

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May 2018

1. Introduction

The construction is, today, an industry on which are required continual processes of update and optimization for better decision-making and search for solutions that can be economic, technically viable and socially empowered.

Recent technological advances have been significantly acting as facilitators of direct and indirect operations and other processes related to the given nature of the industry. They have also taken a big part on changing traditional paper based working methods' support to digital software such as CAD/2D (computer Aided Design bi-dimensional) and, more recently, to parametric and tri-dimensional modulation such as BIM based methods. BIM international implementation is well advanced in countries like the United States of America (USA) and United Kingdom (UK) among others, as in Portugal is only taking its first steps and still in development phases. This technology shows great potential, is wide accepted in the industry and, therefore, it´s important to explore its applicability and share its knowledge.

Traditional methods of quantity surveying are time-costly and error susceptible, due to their manual nature of working methods, which are also depending on the surveyor interpretation, perception and work quality. BIM's capacity of creating, archiving and updating information throughout a project's whole life cycle, shows a relevant potential to participate and accelerate processes of quantity surveying, such as the elaboration of bills of quantities (BOQs) for bidding phases, budgeting, and cost control.

This work pretends to explore the application of BIM methodology up against traditional methods of surveying when are to be determined quantities of concrete and formwork for a structural design of a real case study of a habitational building with approximately 2000 sq. meter. Furthermore, it explores validation of results, errors and limitations of both environments of surveying.

2. Literature Review

2.1. Traditional methods of quantity surveying

It is determined that the action to measure a work is to determine the exact quantity of work to execute on project site and therefore it's very important to understand how quantity surveying is to be executed and structured so its values can provide a solid base to further tasks and project management processes.

Portugal's bibliography on quantity surveying is significantly small. As so, the country does not possess an official document for the matter even though the national industry widely accepts LNEC's document *Curso Sobre Regras de Medição na Construção* (CSRMC) to apply on conflict resolution and agreements on the referred processes of surveying. CSRMC's first publication refers to 1997, elaborated to replace the, at the time ongoing document, *Regras de Medição – Documento de Trabalho*, LNEC's first on quantity surveying, published in 1969 and last revised in 1996.

At an international level, there is a vast range of documents and information regarding quantity surveying. The European ones show most importance on the industry, especially those elaborated by the Royal Institute of Chartered Surveyors coalition, which published documents like the SFCA (Standard Form of Cost Analysis), SMM7 (Standard Methods of Measurement, 7th Edition 1988) and later, responding to the flaws and ambiguities on those, the NRM (New Rules of Measurement, 1st Edition 2012).

Given all the surveying methods and documents currently used in the construction industry, investors, professionals and users find it hard to compare with effectiveness, when using different methods of surveying. The International Construction Measurement Standards coalition (ICMS) took form in 2015, leading the new approach and implementation for international standards on surveying, which objectifies globalization and uniformity of analysis and evaluation of surveys. The series' first document was recently publish as International Construction Measurement Standards: Global Consistency in Presenting Construction Costs (July 2017).

2.2. BIM methodology

Building Information Modelling (BIM) has been emergent technology in the recent years, a paradigm shifter on the construction industry, changing how it operates. BIM's capability of providing digital information, virtually represented as physical and functional characteristics, which can be shared with every entity part of a project, enables decision-making processes to be much more reliable and well oriented throughout its whole life cycle. This capacity then reflects on making management processes also more efficient, cost effective and error free (Song Wu, 2014).

In a consensual manner BIM methodology constitutes a digital representation of a 3D model made of parametric objects rich in information, which can later develop several other dimensions dependent on what studies are supposed to be elaborated on. Figure 1 represents those dimensions with the respective fields of study.

Although BIM technology shows prospects of great potential, its implementation has been rather difficult by the fact that it takes active part on multiple sub sectors of the construction industry, forcing those sectors to buy and gain access to new tools and to learn how to proper work with them.

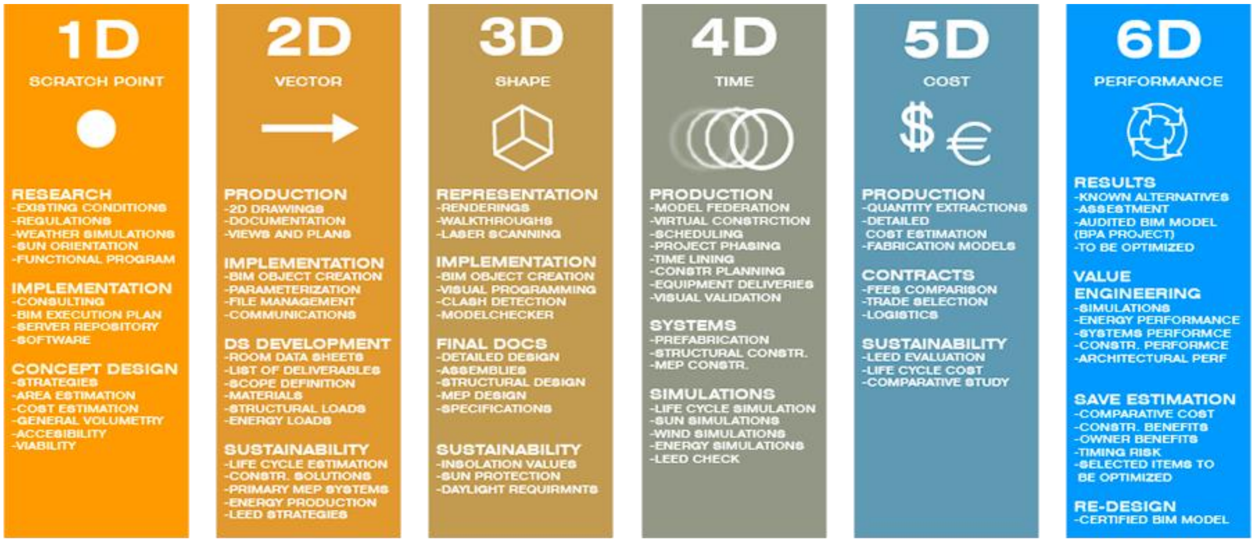


Figure 1 - BIM dimensions and studies

A study elaborated by McGraw-Hill (2015) on entities and professionals who are more dedicated to BIM, concludes that its use is mainly done in conceptual and architectural phases (47%), followed by design teams (38%) and ending with construction companies (24%). Jung and Lee (2015) worldwide study reveals that BIM is essentially well overall implemented in 3D coordination (85%), one of the most recognized advantages of its use, and then followed by cost estimation processes (75%), being these also the most significant uses in Europe and North America. On the other hand, Asia, Middle East and Africa show signs of a stronger approach on architectural themed use.

2.3. Parametric Modulation

The possibility of information modelling objects is a fundamental pillar of BIM methodology (Sampaio, 2018). Objects can contain multiple information of given characteristics such as geometry, material properties, cost, maintenance related aspects, among several others. Opposite to what happens in CAD drawings, BIM´s 3D model associated with geometrical properties allows quantity extraction processes to be automated. These values can be extracted immediately from the model and updated along eventual changes that are made on the project (Jiang, 2011; Kymmell, 2008; RICS, 2014).

The object modulation should be executed considering guideline documents with determined requirements, for a correct validation of results extracted, as are COBIM documents (Common BIM Requirements 2012) developed by BuildingSMART with the objective of user and tool guidance for a correct modulation and high trust levels on sharing a model between construction sectors (COBIM, 2012). The documents are divided between 13 series on which series 5. Structural Design and 7. Quantity take-off are the most interesting to this work due to the project in nature and the pretended analysis to elaborate.

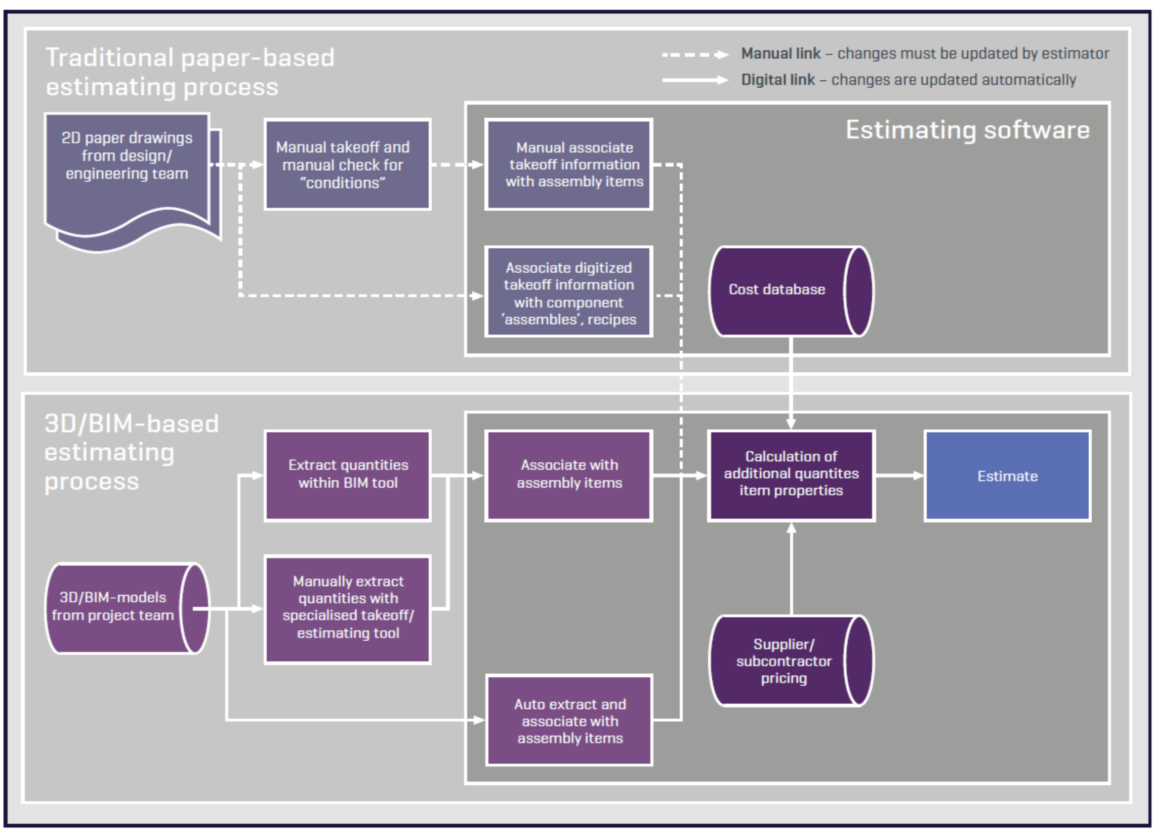
2.4. BIM based quantity estimation

Traditional methods of quantity surveying are based on manual and direct measurements from 2D CAD drawings, which are usually produced by the design project teams. Given the frequent revisions and updates associated with such designs, quantity surveying also requires constant to be revised and updated based the respective documents. Cartlige (2009) refers that this processes are challenging and time consuming to the surveyors, especially when the amount of data is significant. Therefore, surveys could result in inaccurate estimations with low precision (Cartlidge, 2009). These errors often produce budget deviation and poor advice towards the client on project costs (Bylund and Magnusson, 2011), processes which are frequently done with time limits and before project final closure (Aibinu and Pasco, 2008; Yaman and Tas, 2007).

BIM represents a technology that can act on surveying process, turning those more agile and correct. RICS (2014) highly recommends the use of integrated technology processes, as BIM, that are able to significantly contribute to better precision, accuracy and process efficiency on quantity and cost surveying of a project. Design team and surveyors can then be fully synced, making sharing information and conflict resolution easier, concluding on better and well-oriented client advice since early project phases (Raisbeck and Aibinu, 2010).

Figure 2 illustrates the mains steps of BIM based estimated processes when compared with traditional and paper based processes.

Figure 2 - Comparison of BIM based estimation processes with traditional paper-based estimation, adapted from Song Wu, 2014.



3. Method and tools of comparative analysis

The comparative analysis pretends to determine if BIM based quantities are valid and applicable on surveying methods and rules of measurement prior considered on traditional methods of surveying for **concrete** and **formwork** estimations. That objective will be measured by having multi comparison scenarios between two of the previous known and supplied results of traditional based surveys (design and bidding phases) and the BIM environment results extracted on the 3D model.

The proposed comparison scenarios for analyses are as followed:

- Traditional methods of surveying on **design phase** vs **bidding phase**
- Traditional method of surveying on **design phase** vs **BIM** based estimation
- Traditional method of surveying on **bidding phase** vs **BIM** based estimation

The document to serve as base document for comparative analysis is the CSRMC publish by LNEC in 2000 since it was the one verified for both traditional methods of quantity surveying (design and bidding phases).

The present work proposes the use of Revit software from Autodesk as the estimating tool for concrete quantities and Sofistik BIM Tools as the one for estimating formwork quantities. Nota that BIM tools for estimation of quantities are available in the BIM's software market, even though not all are easily reachable due to payment subscriptions.

4. Generation of the 3D model

A correct 3D modulation on BIM environments, that pretends to extract valid and accurate results from its model, is expected to follow guides elaborated from referenced entities based on previous works and developments on BIM technology. The Common BIM requirements 2012, better known as COBIM, is the proposed document to guide the 3Dmodulation process of the present work, being a well-known guide for BIM and the construction industry. As part of gathering important and well oriented guidance information for the modulation process, both series 5. Structural Design and 7. Quantity take-off were studied.

COBIM's series 5. Structural design is a guide oriented for structural analysis of projects and models. The document presents information that allows the design team to correctly model a structure in BIM based processes, describing and detailing actions and processes to be executed. The requirements considered on the present work were: structures to be modelled, definition of stories and sections and numbering and labelling.

COBIM's series 7. Quantity take-off is a guide that provides support on correct bases for quantity extraction and cost estimation for projects. The document itself is not explicit on how to extract those quantities rather than just a guide for understanding the inherent processes and limitation of it. Therefore, the present work considers the chapter of "Quantity take-off related requirements for building information models" and its requirements on: consistency of modelling, levels of details, BIM tools usage, identification of building elements, measurement information and use of software tools and data transfer.

4.1. Initial considerations

Before the modulation process there is a need to define base requirements and considerations on which the model will be constructed. The unit to be considered was the two decimal metric system, in accordance with the CSRMC. 2D CAD drawings with high complexity and more than needed information were cleaned to the referred sections, imported, and adapted on to Revit. Stories and levels were then modeled in Revit.

4.2. Elements to be moduled

There is no explicit requirement that defines the order of elements' types to be modeled once the user has already defined sections and levels of the general model. Nonetheless, modulation should be done according to the planned construction order as referred in COBIM (series 5). In that order, elements were modeled from the bottom to the top of the building, stories by stories or reference levels when necessary. The applied sequence of types of elements modulation was as followed: foundations and foundation beams, pillars, walls, beams, stairs, slabs, roof, reservoir and water pumping structure. The last two were individually modeled for validation purposes, given their survey on traditional methods presented by design and construction companies being separated from the rest of the elements.

Throughout this complex and exhaustive process, new families and types of elements were created to fit non regular geometries, opposed to Revit´s predefined elements for modulation, in order to comply with the proposed level of detail and model consistency (closest to reality as possible). Material types were also implemented on the objects modeled, as surveying by CSRMC also acknowledges separation by different materials and purpose. Additionally, geometric relationships between several elements were also explored along with Revit tools to guaranty a correct modulation process. Table 1 provides an exemplificative list of elements of each object type present on the final 3D model. Figure 4 illustrates final aspect of the 3D model ready for quantity take-off processes.

Table 1 - List of modeled elements (examples by elements of structure)

Element of Structure – Type	Material: Name	Family
Foundation – M1.800.2	Concrete C25/30 XC2 – in situ	M_Foundation-Rectangular
Foundation Beam – VF1 (0,3 x 0,4 m)	Concrete C25/30 XC2 – in situ	M_Concrete-Rectangular beam
Pillar – PC.6 (0,25 x 0,80 m)	Concrete C30/37 XC1 – in situ	M_Concrete-Rectangular-Column
Wall – PAR.C.2	Concrete C30/37 XC1 – in situ	Basic Wall
Beam – V.+3.C.I.1 (0,20 X 0,60 m)	Concrete C30/37 XC1 – in situ	M_Concrete-Rectangular beam
Stairs – EC1	Concrete C30/37 XC1 – in situ	Local modeled stair
Slab – Slab 3,93 m thick. 0,26 m	Concrete C30/37 XC1 – in situ	Floor/ Slab
Roof – Roof thick. 0,21 m	Concrete C30/37 XC1 – in situ	Basic Roof
Hidro. Structure – Wall water p. Structure thick. 0,20 m	Concrete C25/30 XC2 – in situ	Basic Wall
Reservoir – Slab Reservoir thick. 0,20 m	Concrete C25/30 XC2 – in situ	Floor/ Slab

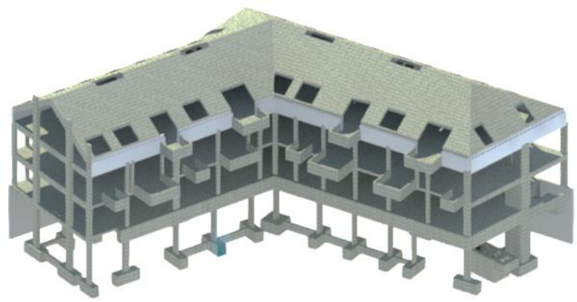


Figure 3 - Perspective of the finished 3D structural model on Revit

4.3. BIM model adaption to CSRMC

Traditional methods of surveying of the case study, as before said, are executed based on the CSRMC document that contains rules and criteria of surveying also which need to be evaluated in the 3D BIM model, so results extracted from it can be validated when put towards their respective comparison quantities on other environments. Therefore, several exemplificative cases of structural elements interceptions verified throughout the 3D modulation were studied by estimating quantities and analysing their validation when facing CSRMC imposed criteria. This process was executed for both concrete and formwork surveys to ensure the model was able to produce valid and comparable results.

5. Results

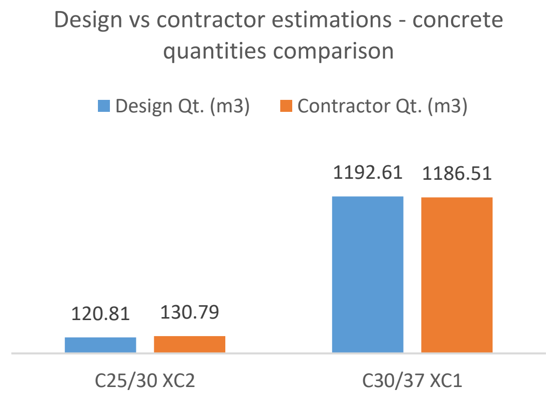
The following results are presented considering CSRMC rules and criteria of measurement, for concrete and formwork quantity surveying.

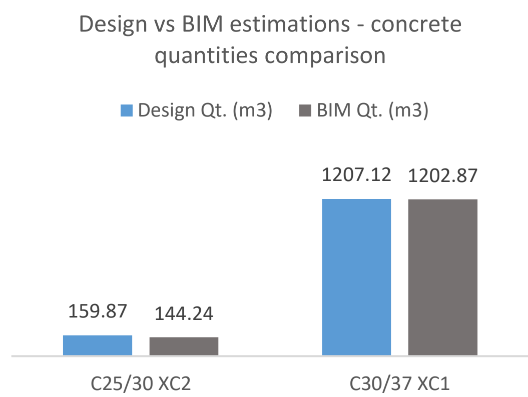
5.1. Concrete volumes and formwork areas quantity estimation

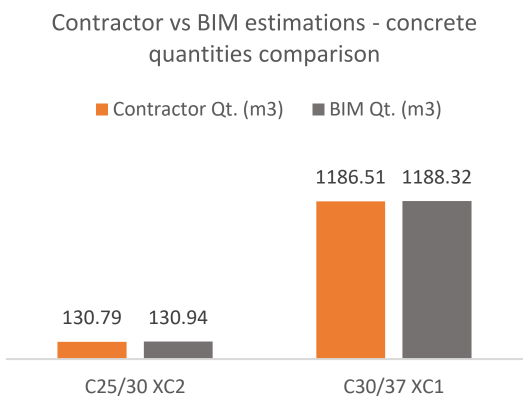
Graphics below present the results obtained when comparing results from traditional and BIM methods of surveying for concrete volumes and formwork areas, by material class and type of finished surface, respectively.

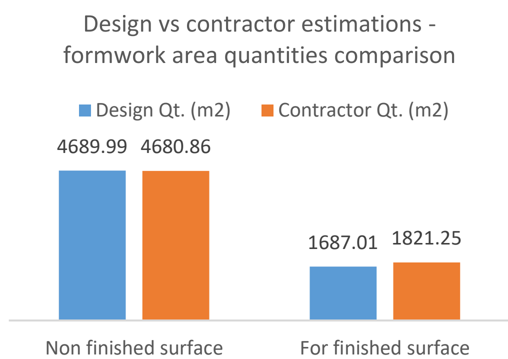
Concrete volume estimations verify their biggest variations when comparing design and contractor surveys with a 6.24% excess of contractor concrete volumes on class C25/30 XC2, and when comparing design and BIM results, providing a 9.83% deficit on BIM quantities of concrete volume of the same class. Every other quantity variation on concrete sits below 1%, and therefore is considered contemptible.

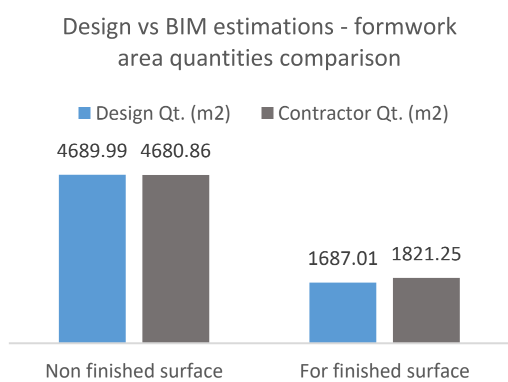
On the other hand, formwork areas estimations verify only one case below 1% variation, when comparing design and contractor results of non-finished surfaces. The biggest variation verifies itself when comparing design and BIM results on finished surfaces, with a 13.53% excess on BIM estimations.

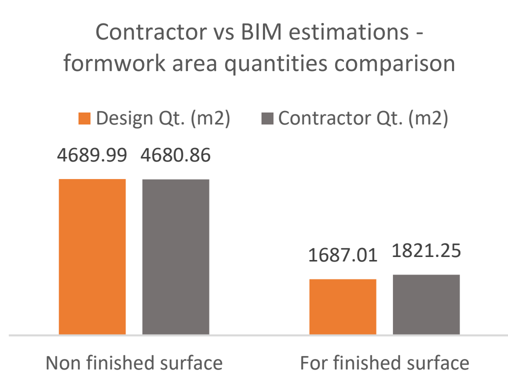












5.2. Discussion

The critical analysis was executed based on the presented results above, related to errors verified throughout the quantity estimation and comparison processes of the tree shown scenarios. **Errors** were defined as incorrect quantity estimation of an indispensable work to be executed on the project and **omissions** as the works that are not present in the project or its BOQ and are part of the contractor remuneration.

The method of exposure for works' errors and omissions consisted on identifying exemplificative cases verified on the estimation and comparison processes. Those are presented on the table 2 with error type, description and detailing.

Table 2 - Identification of errors

Type	Element(s)	Detail description
Error Geometry	M6.600.2	Elements verifies wrong height value on concrete survey, producing an almost 100% deficit of its real volume, on traditional design estimation BOQ.
Error Formwork area	M6.600.1 and M6.600.2	Elements verified wrong accountability of bottom formwork area, on BIM based estimation.
Error Geometry	V0.C.I.1	Element verifies wrong section dimensions which represents, approximately, a 50% deficit in its volume, on traditional contractor estimation BOQ.
Error BOQ Structure	BOQ	Wrong classification for infrastructure and superstructure works, on traditional contractor estimation BOQ Lack of material information and article division on concrete classes and formwork finishes, on traditional contractor estimation BOQ
Omissions BOQ presence	PC17	Element survey was not considered on foundation and -1 level, in both BOQs (design and contractor) of traditional estimation.
Omissions BOQ presence	V.0.C.9'.2	Element survey was not considered on traditional contractor estimation BOQ.

BIM based models, estimations and surveys are no yet perfect and, as so, some limitations and considerations were verified during its modeling and take-off processes. Table 3 describes them by the respective element and how they were, when possible, solved.

Table 3 - BIM surveying method - considerations and limitations

BIM considerations/ limitations	Problem	Explanation /Solution
Formwork Area – Slab of level+1	BIM tools did not allow for quantity take-off	Dividing the element in a share of approximately equal parts using *Divide* tool will solve the problem.
Formwork Area – Stairs and Roof	BIM tools did not allow for quantity take-off	Elements verify high complexity, which according to BIM's forums can explain the problem. No simple solution.
Drawing Inconsistency – Foundation Beam VF1	Design CAD drawings compatibility problem between VF1 beam, M2.800 and N.C.C.2	BIM 3D visualization enables the user to instantly verify the error present on 2D drawings. Problem solved considering inferior beam alignment with M2.800.
Compatibility – Pillars and Roof	Pillar and roof compatibility was not allow to execute by plane reference	The adopted solution consists on creating voids that cut the unwanted part of the pillar in alignment with the roof structure.

6. Conclusions

The elaboration of BIM models showed to be a complex and time costly process for new users. Even so, the tools present themselves has very intuitive to use, which projects an easier adaption to graphic systems older users, that might to still need to receive further instruction on the technologies.

BIM model verified to be possible to adapt to the CSRMC rules and criteria of measurement for both concrete and formwork quantity estimations and surveys, supported by the exemplificative cases studied. Concrete quantity estimations were validated for all elements except the Reservoir and the Water pumping structure, due to their lack of presence in the initial design and as so, in the contractor BOQ. Formwork areas provided by Sofistik BIM tools also validates for most elements of survey, with exception for roof and stairs elements, due to their high complexity of modulation.

It can be concluded that the BIM model in study provides quantities of estimation and information needed to obtain concrete volumes and formwork areas on a design project. Thru its automatic processes, more practical and faster than traditional methods of surveying, it additionally provides the user with easy identification of BOQ's errors and omissions, and therefore contributing for a more accurate and effective survey.

BIM technology shows a great potential for participating in further analysis on quantity estimation processes and take a fully active part on real projects as the one studied on the present work.

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