BIM-based approach for quantity take-off to facilitate progress payments: the case of high-rise building projects in Vietnam

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Abstract:

Building Information Modelling (BIM) has been widely applied in construction projects due to its ability to organise, interrogate and manipulate large amount of information. In BIM-enabled projects, selected datasets are embedded in the BIM model for data exploitation. BIM quantity take-off (QTO) for contract progress payment is time-consuming, tedious and error-prone process, only with a modest degree of automation. This paper aims to provide an integrated approach for quantity take-off for progress payments. There are four major challenges: (i) new types of information required to be embedded into the BIM model, (ii) changes and updates of information requirements as projects progresses, (iii) low interoperability between BIM model and estimation software (independent software or spreadsheet), and (iv) potentiality of low productivity and accuracy in data entry. The methodology adopted is based on a qualitative deductive research approach and expert consensus through Delphi technique. The proposed framework addressed all the challenges by accommodating the BIM-based information management process and project phases. It emphasises the role of a pre-project information delivery plan for creating BIM objects and developing BIM libraries, which previous studies tend to neglect. The framework also provides a guide for the involvement of different project team members in BIM authoring and data entry to ensure higher productivity and error reduction. Though having some limitations, this paper provided a new approach to facilitate the BIM-based QTO for progress payments, with specific examples from high-rise building projects in Vietnam, which can be expanded to other sectors of the construction industry.

Keywords:

Building Information Modelling

Quantity take-off

High-rise buildings

Progress payment

Vietnam

1 Introduction

In Vietnam, as well as most other countries worldwide, the construction industry (CI) provides significant contribution to the national economy. The Vietnamese CI contributed approximately VND 360 trillion and accounted for about 6% of the total GDP of the country in 2019 (Vietnam General

Statistics Office, 2020). Projects in the CI are usually delivered through construction contracts between clients and contractors. Depending on the type of contract signed, contractors may outsource some of the tasks and work packages through sub-contract arrangements, the quantity take-off (QTO) activities may need to be performed to determine phased payments. In Vietnam, majority of construction work quantities are often surveyed manually, thus, leaving practitioners the time-consuming and tedious manual task throughout the construction project (Ho *et al.*, 2016; Luu and Nguyen 2020).

Building Information Modelling (BIM) has been officially introduced and adopted in Vietnam through Government initiatives (Ta and Tran 2018). In general, BIM is about developing, updating and exploiting a set of information-based models for the construction project throughout its life cycle. BIM applications secure a wide range of benefits: reducing costs and risks (Bryde, Broquetas, and Volm 2013; Azhar 2011), saving time (Aibinu and Venkatesh 2014; Abanda, Tah, and Cheung 2017), improving productivity, improving work quality and safety (Zhang et al. 2015; Malekitabar et al. 2016), smoothing collaborative working (Daniotti et al. 2020), facilitating knowledge exchange (Ho, Tserng, and Jan 2013), minimalizing waste (Liu et al. 2011; Ahankoob et al. 2012), and more. Despite the advantages, BIM is used as an innovative approach only in the early stages of the project lifecycle as its adoption posed numerous obstacles and setbacks (Nguyen et al. 2018). Though the BIM use of QTO has been implemented widely in selected countries (Aibinu and Venkatesh 2014; Olsen and Taylor 2017; Plebankiewicz, Zima, and Skibniewski 2015), its application in Vietnam is still limited, especially in the public sector. As for QTO, existing and popular BIM-based solutions have exposed Vietnamese practitioners into errors and time-consuming operationalisation owing to their incompatibility with national construction regulations, codes and practices (Ngo 2018; Nguyen et al. 2020).

Cost for implementing BIM is high in Vietnam (Nguyen and Nguyen 2021) and in other countries (Ahmed 2018). To enhance efficiency and the return on investment (ROI), a developed BIM model should be exploited optimally throughout the project lifecycle, and beyond. Using BIM models for measuring quantity of work items in the design stage is common. Practitioners are now expected to use the models to facilitate the contract progress payments. To do this effectively and efficiently, few questions have been raised: (i) When to start the QTO processes in order to facilitate the contract progress payments? (ii) What is the information required for measuring quantity of works to estimate contract progress payment? (iii) What are the challenges to manage (create, store, update and exploit) the required information for this BIM use? and (iv) How to process the information to deliver BIM-based QTO to facilitate contract progress payment?

This paper developed, discussed and validated a framework to address questions above. Starting with a literature review, it discusses current practices in BIM-based QTO in general and high-rise building projects in particular. Challenges were compiled from the previous studies and used as references when realising the challenges in the context of BIM-based QTO to facilitate contract progress payment for high-rise building projects in Vietnam. The framework was developed in consideration of a standard information management process throughout the construction lifecycle - from project conception and implementation phases, when the BIM use of this study is delivered.

2 BIM Quantity Take-Off

Few studies have published BIM-based quantity take-off, including the case of high-rise building projects. However, there were no previous research specifically focusing BIM-based QTO for contract progress payment. For QTO, BIM has been widely claimed to bring various advantages, for example, Khosakitchalert, Yabuki, and Fukuda (2020) proposed an automatic compound element modification method evidenced by two case studies and demonstrated time-savings, cost-efficiencies and lowered errors. Likewise, using Skanska's resources, Vitásek and Matějka (2017) validated the usefulness of BIM in QTO and cost estimation in transport infrastructure projects in the Czech Republic. As BIM models comprise of different components (BIM objects), which have built-in properties (Monteiro and Martins 2013) that can be used for storing data. Most BIM tools have a predefined function to extract geometric data from the object properties; those data can be used for the purpose of works measurement. If works that need to be measured can be directly calculated based on the dimensions and the number of BIM objects, the challenges for BIM-based QTO are limited. However, since QTO is the beginning of succeeding processes such as cost estimation, construction planning or tendering (Monteiro and Martins 2013), not to mention the specific requirements for each project, there is a variety in the requirements set for the outputs of any QTO job. Therefore, the data extracted directly from BIM objects are normally insufficient or not detailed enough for facilitating a BIM-based QTO job. The myriad of project stakeholders have different ways using the BIM model, from model designs t0 information categorization (Aram, Eastman, and Sacks 2014).

Standard off the shelf software built-in functions for measuring quantities in the BIM authoring tools normally cannot fit needs from diverse countries and different clients (Zhou et al. 2016). Researchers and practitioners have tried to develop new add-ins or APIs, or stand-alone software packages (e.g. CubiCost, CostX) to carry out QTO. This new approach, however, faces the challenges of data loss in the process of data conversion when exchanging data between the BIM model and the external software due to the incompatibility in data structure, including the units used. Existing solutions focus on standard and compound quantities like volume, surface area, etc. (Aram, Eastman, and Sacks 2014). Complicated and/or detailed quantities such as weight (reinforcement bars) or quantities by product shapes, sizes and materials are often neglected. Different shape parameters that impact the cost and in what value ranges their cost relationships and behaviour change could not be identified.

Some authors have acknowledged these technical issues as significant drawbacks of BIM-based QTO systems (Ngo 2018; Kim, Chin, and Kwon 2019; Olsen and Taylor 2017). To avoid additional customised commands and manual work, which leads to time and cost inefficiency, BIM-based QTO solutions must ensure that the information embedded in the BIM models can be reused easily throughout the project. Ensuring interoperability in BIM-enabled projects is never more important to ensure BIM QTO in embedded with different the project stakeholders, including designers, contractors and facilities management. However, interoperability is still insufficiently explored. Akanbi *et al.* (2020) showed the robustness of QTO algorithms to design workflows with respect to IFC-based BIMs, but it lacks the justification for adjustable parameters and practicality.

For the job of QTO, provided the manual operation, dimensions of the objects need to be collected and put into the calculation formulas, or the number of each type of object are counted for the generation of quantities of work. For a BIM-based QTO, this could be completed automatically or semi-automatically with data extracted from the BIM models, using a built-in feature, a user-defined API or a software package. However, previous research studies pointed the difference between the object classifications integrated into BIM platforms and the construction component categorisation used in the methods of measurement (Luu and Nguyen 2020). This approach is possible but it failed to take into account non-graphical data for grouping the elements considering data extraction for QTO. Graphical data (showing the shapes and sizes of construction elements) is important to ensure conformity of the extracted information with the list of the quantity of works in the BOQ. This also applies to the QTO job for facilitating contract progress payment. In order to address the non-graphical data, features of the high-rise buildings and also the contract types, contract progress payment schedules adopted must be discussed.

3 Research Methodology

To address the research questions, the paper applied a deductive approach to adapt towards current innovation around BIM-based QTO, specifically for contract progress payment on high-rise building projects. The research process consists of three steps, as shown in Figure 1.

Step 1 investigates the information management in BIM-enabled projects. It reviews the general process of information management towards industry standards and explored the approaches in BIM-based QTO, then reviewed to analyse relevant challenges. Content analysis is adopted in a mixed data source of data in industry standards, previous research and technical reports.

In Step 2, literature review techniques and practical observation were conducted to identify the requirements and challenges of the BIM-based QTO. The contextual required information for BIM-based QTO can be analysed from the myriad types of construction contract adoption, progress payment schedules, periods of BIM use, high-rise building features, BOQ Template and Standard Methods of Measurement adopted for BIM-enabled projects. The contextual requirements were then aligned with the standard of information management and data from practice observation in order to identify the challenges of BIM-based QTO.

In Step 3, the framework for BIM-based QTO is developed. This framework describes a "specific function and set of relationships within the research process", which serves as a link between theories that provide explanations for the issues under investigation (Leshem and Trafford 2007). More common methods to develop a framework include: existing methods and guidelines, refining and validating, using experience and expertise, conducting literature review, and using data synthesis and amalgamation (McMeekin et al. 2020). For validation, the Delphi technique is selected as it is considered as a "reliable empirical method for collecting opinions of subject matter experts and deriving consensus among them" (Sitlington and Coetzer 2015). As its nature, BIM-based QTO requires interdisciplinary skills and knowledge, ranging from construction economics, building information modelling, project management, contract management, etc. Therefore, the Delphi technique can enhance the validity of the framework with the right experts.

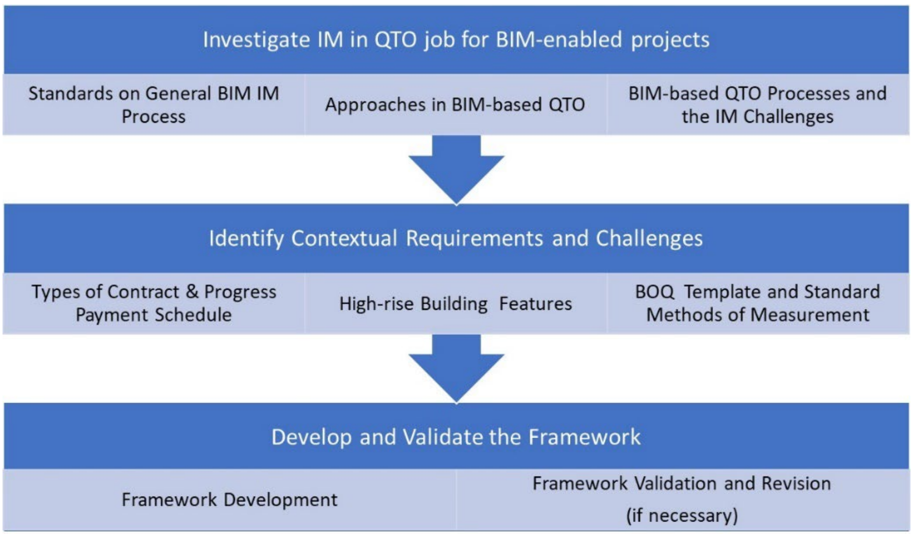

Figure 1. Research process

4 Information Management for BIM-enabled Projects

In order to make most from BIM, managing information becomes the very core of its success, where "accurate information available at the right time in the right format to the right person" (Chen et al. 2015). In BIM-enabled projects, information will be integrated into the BIM models at the authoring process and updated during the project delivery progress for later use. Therefore, BIM practitioners need to identify the information required throughout the lifecycle of the project to be embed in the BIM objects, while developing or updating the models.

According to the standards BS EN ISO 19650-1 and BS EN ISO 19650-2, the required information for a BIM model may be graphical data, non-graphical data and associated documents (BSI 2018). A typical list of information required in a BIM model can be found in Table 1, which are needed not only for the delivery phase of capital assets but for the operation and maintenance of the assets.

Table 1: Information required in a BIM model for a building.

Type of information	**Description**
Rooms/spaces	Ideally geo or spatially located
Zones/departments	Collections of rooms/spaces/volumes
Systems or assemblies	Groups of components
Components or equipment	Which system/assembly/zone/space they belong to
Products/materials	Characteristics of the products/materials
Maintenance tasks, spare parts, and tools/resources	Required to maintain and operate the building
Contact details of companies/people involved in the project	The designers, contractors, suppliers, and others
Documents related to the project, building, systems, products, and materials	Contents and types of the documents

Source: Adapted from (TheNBS 2016)

The integration of information in BIM models and the extraction of information for BIM uses are parts of an "Information delivery" process. An information delivery plan should be developed with consideration of the whole lifecycle of the project. Before any information can be officially used, an approval process is required to ensure its eligibility and accuracy. With those processes in place, information can now be managed using the approach recommended in the BS EN ISO 19650-1 (Figure 2).

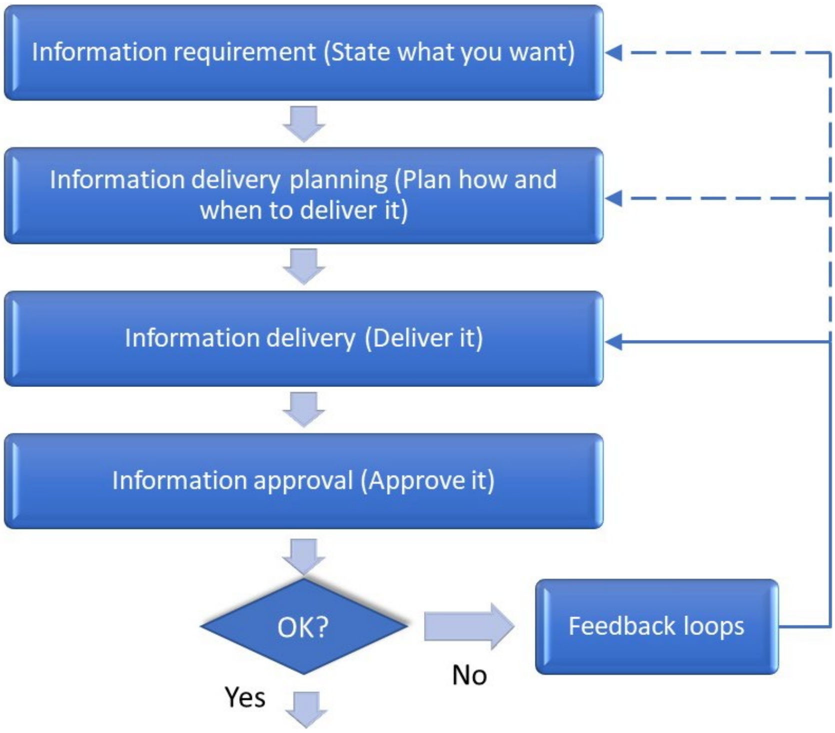

Figure 2. Approach for information management as in the BS EN ISO 19650-1 (BSI 2018)

Several task information delivery plans (TIDPs) and a master information delivery plan should be developed for any BIM-enabled projects. TIDP should be established and maintained by each task team to manage the delivery of the task-related information, while a MIDP is developed by collating all the TIDPs, therefore, there is only one MIDP for each project. MIDP plays as a primary plan for preparing the project information, specifying information deliverables and answering the "Whs" questions of when, by whom, and how regarding project information delivery for each stage of the project (BSI 2020). In BIM-enabled projects, they are considered most important plans of action for the project to be delivered with successful information management. Information contained in each TIDPs and in the MIDP, including the objects' unique IDs and titles, the level of information need, the information author responsible for its production and production and delivery information are specified clearly in the BSI 19650-2 standard.

4.1 Approaches in BIM-based QTO

According to a recent study of Nguyen *et al.* (2021), there are seven approaches for BIM-based cost estimation with different levels of automation, as shown in Figure 3. BIM() is the software for BIM model development, QTO() is the application to extract quantities of works, EST() is the automatic solution for cost estimation and MAN() is a manual job for processing information. The single arrows (→) outside the functions show the relationship between the two applications (the first application's outputs are the second application's inputs), while the arrows inside the functions show the transformation from the first parameter to the second. The biarrows (← →) show the information exchange (both ways) between the applications. The BIM-based cost estimation approaches have also been discussed in an earlier research of Zhou *et al.* (2016) but with fewer options.

Based on these approaches, BIM-based QTO, as the first step for cost estimation, can be automatic or semi-automatic. Data and geometrical information can be automatically extracted from BIM models using built-in commands of authoring software packages (Khosakitchalert, Yabuki, and Fukuda 2020; Vitásek and Matějka 2017) in the form of quantities of works, or extracted data can be further manually manipulated to get quantities of works. However, as the built-in functions for measuring quantity in the BIM authoring tools normally cannot fit the needs from diverse countries (Zhou et al. 2016), then the automatic data extraction does not provide all the necessary data to put directly in a Bill of Quantities (BOQ) (Monteiro and Martins 2013), new add-ins or APIs, or independent software architectures are developed to support the process (Khosakitchalert, Yabuki, and Fukuda 2020; Vitásek and Matějka 2017; Zhou et al. 2016).

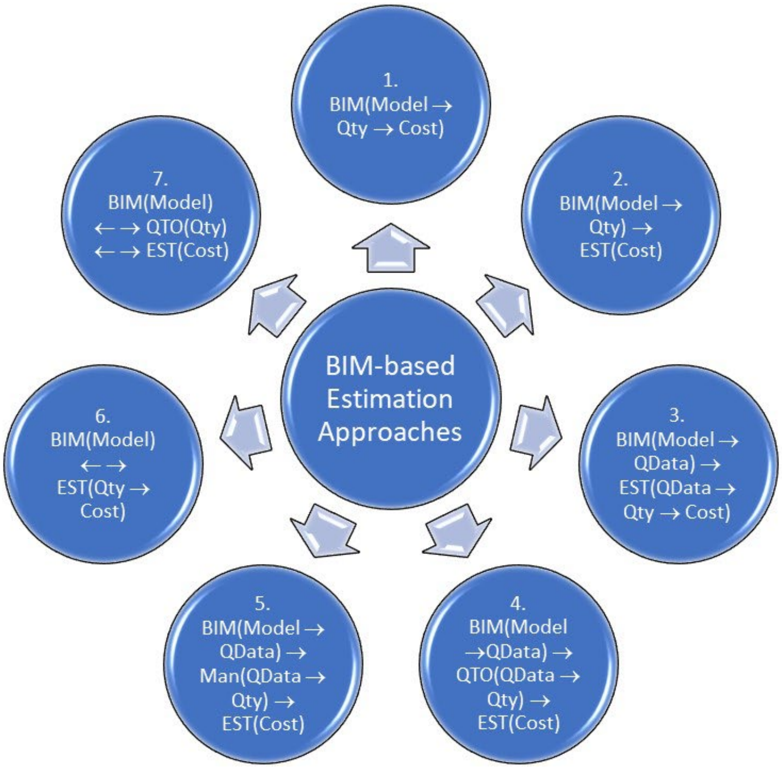

Figure 3. Approaches in BIM-based construction cost estimation with different levels of automation (Nguyen, Nguyen, and Nguyen 2021)

4.2 Challenges in the information management for BIM-based QTO

Literature demonstrated various challenges in the information management process for BIM-based QTO due to the way the BIM models were developed, integrated and updated; and the way information is extracted from the BIM model for its use. Aram, Eastman, and Sacks (2014) pointed out three conditions for ensuring the success of BIM-based QTO: (1) BIM models need to be "readily suitable" for use with all complete necessary information that are quantifiable for the tasks. According to Lee, Sacks, and Eastman (2006), a BIM model is composed of different building elements having their own set of configurations that are stored in the model as properties. Khosakitchalert, Yabuki, and Fukuda (2020) emphasized on the accuracy of the results generated from the BIM models, which can be considered a challenge due to the popular overlapping of elements composing the BIM models and also human errors while developing the models and inputting information.

The process for integrating information into a BIM model, then exploiting data from the model for BIM uses, in this case, QTO for facilitating the contract progress payment for high-rise building projects, is illustrated in Figure 4. Most building elements, composing of a BIM model can be developed in advance in the form of objects in families (as in Autodesk Revit) or libraries (as in Tekla - Trimble), the development of those objects as families/libraries can be considered as a separate stage prior to the BIM-enabled projects. Depending on the requirements of the usage of BIM in the project lifecycle, objects are required to be either compound or detailed; the latter leads to a greater number of objects to be developed. The objects in the families/libraries are initially embedded with initial information for later use. Many BIM objects have been created by practitioners globally where users can inherit these models in projects to save time and improve efficiency. Additional information can be entered into the BIM models during its development and updating processes. Therefore, the information in the objects in the BIM model can be used for extracting data for manipulating the quantity of works. However, two major challenges emerge. Firstly, information management processes must be adopted and agreed very early in the project lifecycle to ensure the development of families/libraries are followed throughout the project - continued during the model development and updates, then the extraction of information for BIM uses. This is to ensure the correct information is available, accurate, complete and ready to be used. However, this process is hardly followed as stakeholders at the later stages of the project lifecycle may not be completely identified and their requirements unknown and not considered from the beginning (Edwards *et al.*, 2019). Secondly, there is a trade-off between the BIM object quality and details, against project BIM modelling productivity – considerations in making a reasonable decision on the level of detail adopted for the BIM objects at the pre-project phase, leaving other information to be integrated into the BIM models at later stages.BIM modellers are often responsible for entering the required information to the model elements throughout the project lifecycle and the later phase of the project. However, they may not have the relevant knowledge and expertise, therefore, causing work disruption, incorrect information entered, poor efficiency and low productivity.

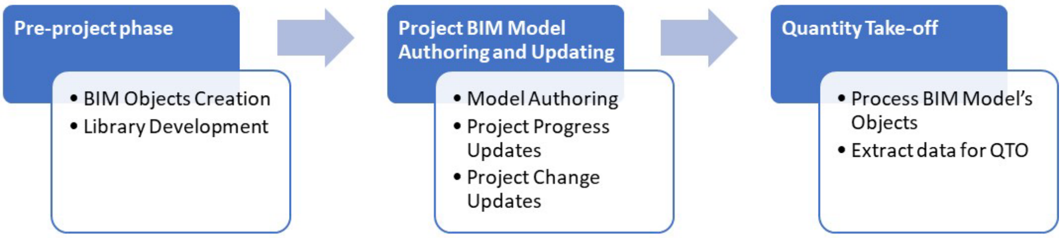

Figure 4. The process for integrating and exploiting data from the model for BIM-based QTO

Most BIM tools have a predefined feature to extract information from the BIM elements for the purpose of generating the quantity of works (Monteiro and Martins 2013). However, BIM tools cannot provide all the necessary information to create a BOQ, therefore, surveyors or the estimators will need to fill the gaps with manual inputs (Ma *et al.* 2011), or with an Application Programming Interface (API) or an external application (Zhou et al. 2016) to increase the level of automation. This leads to the importance of ensuring the interoperability between with BIM models and objects to facilitate the data exchange between the tools and applications (Monteiro and Martins 2013). This can be considered as the biggest hurdle for BIM-based QTO.

5 Identification of Contextual Requirements

5.1 Types of Contract & Progress Payment Schedule

In delivering construction projects, contractual agreements are set up in advance for the contractors, consultants, and suppliers to officially participate in the projects. Contractual agreements are often in the form of a contract between two parties, which is a "legally binding agreement" made in writing (Surahyo 2017). There are a myriad of contract types in the CI, but one of the more popular classifications is based on the pricing arrangements, which can be categorised as price based or cost based. In Vietnam, construction contracts based on pricing arrangements are commonly signed under two common types: lump sum contracts (i.e. the contract value is paid according to the signed contract price, provided that the scope of work of the contract remains unchanged), and contract based on unit price (i.e. payment according to the actual quantity which the two parties verify) (Nguyen and Dao 2018). In some cases, the unit prices may be adjusted for payment when both parties agreed in advance, or sanctioned by the Law (National Assembly 2014). As a contract is formed, the contracting parties must co-define a payment schedule to be included in the contractual terms. To be more specific, subtracting the advance payment, instalments are regularly paid during the implementation of contract and finalised when all work is completed upon acceptance. Instalment or progress payments method is normally employed, all of which are applicable to both lump-sum contracts and unit price contracts:

- Construction phase-based payment (Type 1): progress payments are made upon the completion of a construction phase, which is composed of a number of work packages;
- Cumulative percentage payment (Type 2): progress payments are based on certain percentages of completion;
- Periodic payment (Type 3): progress payments are made after a certain period of time (monthly, quarterly etc.).

Type 1 payment is regularly tied to the achievement of selected milestones in work, which should show clearly the boundaries between phases. If the payment is made according to the percentage of completed work (i.e., Type 2), the percentage will be determined based on the completed and accepted work packages' values compared to the total contract value. Type 2 requires a rounded percentage of payments (percentages are often multiples of 5% such as 30%, 55%, 70% or the like) for easy management and controlled to ensure no overpayment of completed work packages. Type 3 is more flexible than others; where contracting parties agree on accepted the time periods for the payment of completed work mutually verified. In Types 2 and 3, the project team also enter into an agreement based on completed work packages, not work in progress (incomplete). The payment schedule is phased out based on the BOQ. For Types 1 and 3, the calculation of the progress payment value is based on the corresponding sub-BOQ, whose work are expected to completed and accepted for payment.

During the contract period, all parties in the contract estimate the planned work to be completed based on the value (or percentage) for progress payment (payment schedule), embedded in the contract terms. During contract execution, all parties will calculate the actual work completed for payment under the contract. Under normal conditions, if work is on schedule, it is still necessary to determine the actual work completed during contract execution to re-check the previous stage's calculation. However, many projects including high-rise building projects do not progress as planned (Erol et al. 2018). In cases of variation, the progress payment will be adjusted or the payment schedule revised. In these cases, the changes and updates throughout the project will need to be considered as important inputs for the QTO.

Therefore, the following scenarios should be considered for BIM-based QTO:

- Scenario 1: Measuring quantity of works to establish contractual terms for progress payment.
- Scenario 2: Measuring quantity of works for checking/estimating completed works for progress payment (the contract is on track, or when there is a change in the progress, but the same payment schedule applied),

- Scenario 3: Measuring quantity of works for estimating progress payment when there is a change in the progress, with a revised payment schedule (the works to be paid for changed in one or all the instalments).

Scenarios 1 and 2 are similar in terms of the works to be measured for progress payment although performed in different stages. In Scenario 3, due to the adjustments, the QTO process is more complicated due to that the changes need to be integrated into the BIM model before extracting information. Information required for different scenarios are differennt. This will need to be considered while developing and implementing the information management plan for the BIM-enabled projects in general and for the QTO job in particular.

The progress payment schedule brings another set of. In Scenario 1, the establishment of contractual terms on the payment schedule requires an iterative calculation to ensure the value of the works linked to BIM objects will be included in each instalments – to be equal to or just greater than the maximum value allocated for each of the progress payments. For scenarios 2 and 3, information showing the completion percentage of each object must be updated to be included in the progress payment, or not. For Scenario 3, there is also a chance that a BIM object is large enough to be partially completed in different construction stages. The completed part can be considered to be included in one phase payment. The new set of challenges arise when the information embedded in the object may need to be processed, or the object may need to be split to facilitate the QTO.

5.2 Features of High-rise Buildings

A typical high-rise building is composed of structures principally made of reinforced concrete and steel, or modularised components (Szolomicki and Golasz-Szolomicka 2019); and a myriad of materials for the finishing works (~~Ho et al. 2004;~~ Avetisyan 2020). As high-rise buildings are often constructed floor by floor, the components are separated in different parts (substructures, superstructures, finishing works etc. or works on each floor), the BOQ for progress payment needs to reflect this. The need for including the features of the high-rise buildings has brought in some more challenges to the BIM-based QTO process. Components in high-rise buildings can be reused many times in different positions, floors and structures, then if a component is placed next to another similar component, the two can be combined to form a single object. A number of components spread over a large plan or develop to several floors. Those components can be modelled as single objects or be split into separate objects. The challenges also come from the trade-off of speed – level of detail - applicable breadth as discussed above. Since the decomposition of the BIM models into objects must reflect the construction techniques, methods and processes for high-rise buildings, construction expertise is needed for declaring the information in BIM objects, but the modellers often do not possess this expertise. In a more general view, again, a trade-off between quality and productivity in BIM modelling and updating must be considered. The variations from the actual and planned progress in completing high-rise buildings also lead to these challenges when updating the BIM models.

5.3 BOQ Template and Standard Methods of Measurement

Measuring quantity of works means counting items or calculating the lengths, areas, volumes, mass etc. of components to get the quantities to fill in a pre-specified BOQ template while ensuring the conformity of the units used. In addition, QTO is performed for the purposes of estimating construction costs or quantifying material usage or other resource requirements. Since the outputs of a QTO process are the inputs of cost estimation or other quantification jobs, the BOQ template must be structured to facilitate those processes. In the case of contract progress payment, the quantity of works taken from the projects' model must conform with the structure of the cost norm system to facilitate the cost estimation, or in other words, to ensure the "interoperability" between the BIM model and the cost norm system embedded in the estimation software. The BOQ template, with a list of construction works, therefore, should be developed based on the cost norm system applied, if any, or the method of measurement adopted. As a rule of thumb, the categorisation of components in popular methods of measurement and the cost norm systems have considered the distinctive features of the works, in this study are the features of the high-rise buildings. Some building components are too long or large that they may lie in different stages regarding the construction processes. Also, in the case of QTO for the purpose of contract progress payments, the BOQ needs to be adjusted to fit the agreed progress payment schedule. Some works in the list may need to be broken down into parts to be paid in different instalments.

Globally, there are several popular methods of measurement (MOM), such as the Standard Method of Measurement, whose latest edition is the 7th edition (SMM7), which has been replaced by the New Rules of Measurement volume 2 in the United Kingdom but still applied in some countries, or the International Construction Measurement Standards (ICMS) (Senaratne and Rodrigo 2019). Locally, there are standards such as the Australian and New Zealand Standard Method of Measurement (ANZSMM) developed in 2018 (Senaratne and Rodrigo 2019), the Philippine Standard Method of Measurement of Building Works, 7th Edition in 2014 and the guidelines for quantity measurement issued with the Circular 17/2019/TT-BXD in Vietnam (Ministry of Construction 2019), etc. Most of the standards divide building works in groups and elements corresponding to building components. Table 2 shows an example of the elements as in the New Rules of Measurement. The elements in the Table are broken down into sub-elements and components. The NRM2: Detailed Measurement for Building Works presents the rules for measuring quantity of works for each of the building components (RICS 2012). Building components in those methods of measurement are categorised for the purpose of cost estimating and elemental cost planning, therefore, the categories can be used for developing the list of construction works in the BOQ. These MOMs do not include the BOQ template but provide guidelines for quantifying items, specifying with what to be included and what to be excluded in the calculations (Zaki, Magdy, and Nassar 2020).

Table 2: Group elements for building works as in the New Rules of Measurement

Groups	Elements in the groups
Group element 1: Substructure	1.1 Foundations, 1.2 Basement excavation, 1.3 Basement retaining walls, 1.4 Ground floor construction
Group element 2: Superstructure	2.1 Frame, 2.2 Upper floors, 2.3 Roof, 2.4 Stairs and ramps, 2.5 External walls, 2.6 Windows and external doors, 2.7 Internal walls and partitions, 2.8 Internal doors
Group element 3: Internal finishes	3.1 Wall finishes, 3.2 Floor finishes, 3.3 Ceiling finishes
Group element 4: Fittings, furnishings, and equipment	4.1 General fittings, furnishings, and equipment, 4.2 Special fittings, furnishings, and equipment, 4.3 Internal planting, 4.4 Bird and vermin control
Group element 5: Services	5.1 Sanitary appliances, 5.2 Services equipment, 5.3 Disposal installations, 5.4 Water installations, 5.5 Heat source, 5.6 Space heating and air conditioning, 5.7 Ventilation systems, 5.8 Electrical installations, 5.9 Gas and other fuel installations, 5.10 Lift and conveyor installations, 5.11 Fire and lightning protection, 5.12 Communication, security, and control systems, 5.13 Specialist installations, 5.14 Builder's work in

Groups	Elements in the groups
	connection with services, 5.15 Testing and commissioning of services
Group element 6: Completed buildings and building units	6.1 Prefabricated buildings
Group element 7: Work to existing buildings	7.1 Minor demolition works and alteration works, 7.2 Repairs to existing services, 7.3 Damp-proof courses/fungus and beetle eradication, 7.4 Facade retention, 7.5 Cleaning existing surfaces, 7.6 Renovation works
Group element 8: External works	8.1 Site preparation works, 8.2 Roads, paths and paving 8.3 Planting, 8.4 Fencing, railings, and walls, 8.5 Site/street furniture and equipment, 8.6 External drainage, 8.7 External services, 8.8 Minor building works and ancillary buildings
Group element 9: Facilitating works	9.1 Toxic/hazardous material removal, 9.2 Major demolition works, 9.3 Specialist groundworks, 9.4 Temporary diversion works, 9.5 Extraordinary site investigation works

Source: (RICS 2009)

For countries whose guide for method of measurement is not detailed enough, like Vietnam, the list of works in the BOQ can be generated from the cost norm system and/or construction estimation norm system. For example, in Iran, FehrestBaha - the country's cost item codes - includes 925 cost items, each of them has a unique six-digit code. Each cost item is linked to other data, including the description and the unit of the activity, the materials used, the specifications of the cost item and also the unit cost (Fazeli et al. 2020). In furtherance of the cost estimation, the BOQ generated from the BIM model must contain information to link with those cost items.

In Vietnam, these norms have been developed in accordance with the method of measurement specified by the previous versions of the guidelines in Circular 17/2019/TT-BXD. For public projects, a cost norm system is developed by local government from a construction estimation norm system issued by the Ministry of Construction. Private projects can also use the norm systems for developing the list of activities in the BOQ or use their own way. If there is no cost norm system to be applied, the method for measurement adopted will be used as the basis for developing the list of activities in the BOQ/the BOQ Template.

The structure of the BOQ template and the rules, the requirements from the method of measurement adopted have also brought in similar challenges. To ensure the conformity of the structure, the levels of details of construction works used in the template and in the object decomposition, a proper strategy for creating BIM objects to develop BIM library and for the model updating needs to be in place, considering the types of specialists who are in charge of delivering the processes and the potential uses of the BIM objects in different projects. The trade-off between the quality and productivity in BIM modelling and updating, again, needs to be made.

6 Development and Validation of the Framework

6.1 Development of the Framework

A framework for BIM-based QTO to conduct progress payment for high-rise building projects can be developed, based on the information management process (as in Section 4.1) and the phases of information development in the project life cycle (Section 4.3), from the pre-project stage to the BIM use delivery (Figure 5).

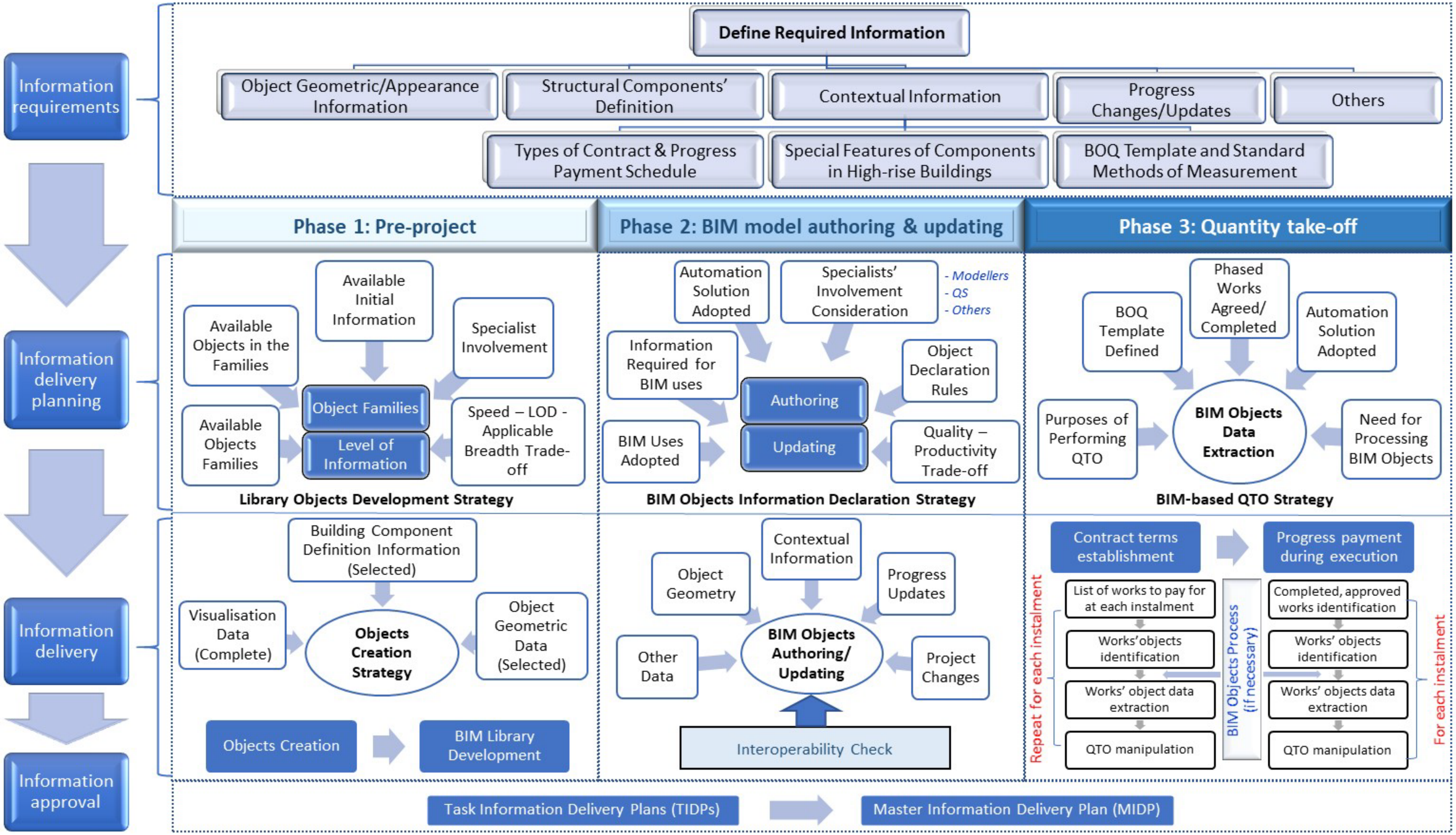

Figure 5. Framework for BIM-based QTO to facilitate progress payment for high-rise building projects

As Figure 5 shows, the framework needs considering the information management in all the three phases: before having a project with the creation of BIM objects and the development of BIM libraries, which can be utilised in multiple projects, during the processes of BIM authoring (BIM model development) and updating, and the use of information embedded in the BIM model for quantity measurement to facilitate the contract progress payments. The four stages of information management in the environment of BIM include: identifying information requirements, developing information delivery plan, delivering information, and approving information as defined in the ISO 19650 standard. The four stages are linked to all three phases through the task information delivery plans (TIDPs) and the master information delivery plan of the projects (MIDP) developed and implemented.

As the first issue to be considered in using BIM for all the BIM uses, including QTO, the information requirements for the job need to be defined. Apart from common information such as the geometric and appearance information of the objects, definition information for the typical structural components and the progress changes/updates throughout the project which must be declared, for this particular job of QTO for contract progress payment in the case of high-rise building projects, specific contextual information is required. The contextual information, in this case, includes the types of contracts and progress payment schedule adopted, the special features of components in high-rise buildings, the BOQ template and standard methods of measurement to be used. That information should be planned to be collected gradually and integrated into the BIM objects in different phases of a BIM-enabled project.

The information delivery plans for a BIM-enabled project are developed in the type of several TIDPs and a MIDP as guided in the 19650 standards (BSI 2020). In addition to the TIDPs for the project as specified in the 19650 standards, another TIDP for the pre-project phase, for creating BIM objects and developing BIM libraries should also be established. Apart from the information required by the standard, the plans should clarify the responsible person(s) to approve the information before they can be officially used.

For the pre-project phase, the TIDP needs to define a Library Objects Development Strategy, which clarifies the object classes to be created and enclosed in the BIM libraries and the level of information to be initially embedded in the objects. The strategy considers the available object classes, the available objects in each of the classes, the available information to be embedded in the objects, the specialists who can contribute to the object creation at this stage. Before creating BIM objects, an investigation should be carried out to explore the BIM objects available from existing libraries and other sources which can be reused for this project, to save effort and time. Only objects that could not be found or reused effectively should be put down to the list for creating in this phase. Objects can be decomposed or combined to correspond with the building components they represent in order to have maximum potential use in future projects.

The potential use of proposed new objects in future projects is discussed to make decision on the list of object classes, balancing the number of objects to be created at this stage and the time and effort for processing them in the future. This list also considers the fact that one building component can be linked to several construction works, e.g. data from a column can be used to do the measurements for concrete, formwork and also the finishing works for the column. The availability of specialists and initial information in this phase is used to consider the level of information to be initially embedded in the objects, then contributing to the decision on the list of objects to be created. The idea of input all of the information at the start is not advisable, because there are shortcomings of: (i) the information in its original form may not be detailed enough as requested; and the breakdown will be time consuming, (ii) BIM practitioners in a particular stage may not be fully qualified for processing information which is out of their expertise due to the job specialisation, (iii) low productivity in processing individual information or data in different disciplinary, and (iv) the changes in the required information due to that the project may not be implemented as planned. Therefore, when a BIM company creates BIM objects for their own uses, it needs to consider the amount of information to input at the start. Other will be updated later for each specific project, this leads to additional efforts required later when the objects are used. A trade-off between Speed – Level of Detail - Applicable Breadth can examine all the issues discussed in this pre-project phase. The trade-off shall result in decisions on level of information to be initially embedded to the objects, which include all the visualisation data, selected information on building component definition information and object geometric data. Objects developed are then stored in libraries for future use.

Several TIDPs also need developing when a project starts, such as the TIDP for authoring the BIM models and the TIDPs for updating the BIM models throughout the project progress. In the authoring process, objects are taken from the existing libraries and inserted into the models (which can be initially developed as separate models by disciplinaries). The objects are then updated with progress updates and changes during the project implementation. Information for identifying the project components and data for the future BIM uses need to be declared in the objects either at the authoring process or the later model updates. Several issues need addressing to develop a BIM objects information declaration strategy. Firstly, the future BIM uses adopted need to be identified, then the required information for those BIM uses must be described. In this study, the concerned BIM use is QTO for facilitating progress payment in high-rise building projects, with required information as discussed in detail above, especially the contextual information and the project updates/changes and also the data that have not been processed in the pre-project phase. Secondly, the involvement of the specialists in the authoring and updating process, in this case including BIM modellers, quantity surveyors and other types of personnel, must be considered for balancing the speed, the cost of data input and the accuracy of the information declared. It is advisable that there is a strategy on what sorts of information should be declared by what types of specialists. If there is any automation solution to be adopted, an interoperability check should be discussed in the information delivery plans as well as in the progress of BIM objects authoring and updating. The issues decide the object declaration rules for both the authoring and updating processes. If there is any automation solution to be adopted for the BIM use, this should also be considered in the information declaration rules. In short, a trade-off between quality and productivity must be conducted for developing the BIM Objects Information Declaration Strategy in this phase.

In phase 3, a BIM-based QTO strategy for the purpose of estimating contract progress payment for high-rise building projects must be incorporated in the TIDPs. As discussed earlier, a QTO process needs to be performed for establishing the contractual terminologies and other QTO processes will be conducted for progress payment throughout the project, and the strategy needs to cover all the two types of processes. For all the processes, the inputs which need significant attention include the BOQ templates, the phased works to be/have been completed. These are the information and data that might be updated or changed during the project progress, therefore, should be carefully explored. The updates or changes may lead to the need for processing BIM objects and manipulating the embedded information to facilitate the QTO processes, depending on the functions of the automation solution, if any.

This framework, together with its proposed components, will be validated in the Vietnamese context using expert judgment method which is presented in the next section.

6.2 Framework validation and revision

Expert validation was sought throughout the research process to ensure there was no impracticality that underlies the proposed framework. Using Delphi technique, data has been gathered with the involvement of nine BIM practitioners and researchers who have relevant skills and/or knowledge on BIM-based QTO (Table 5). They appear to be good representatives of the professionals who have great knowledge and experience in the topic of interest.

Table 5. Experts for validating the framework

Code	Position	Expertise	Relevant Experience
A	BIM Researcher 1	Construction Management, BIM, Autodesk Revit, CubiCost	~~Research expertise includes BIM-based QTO.~~ ~~5 years' experience in quantity surveyor and 3-year experience in working with BIM~~
B	BIM Researcher 2	Quantity surveyor, BIM, API development	~~6 years' experience in quantity surveyor and 3-year experience in working with BIM~~
C	BIM policy maker	Leading the expert team of the BIM Task Group	~~6 years' experience in developing BIM policies, BIM guides for Vietnam~~
D	Estimation software developer	Construction estimation, estimation software development	~~10 years' experience in construction estimation~~ ~~5 years' experience in developing construction software~~ ~~3 years working with BIM (research)~~
E	BIM Software vendor, BIM coordinator	Tekla, Revit, BIM, construction consultancy and BIM consultancy	~~5 years as software vendor~~ ~~3 years as BIM coordinator~~
F	BIM Coordinator	BIM, construction management, BIM uses	~~5 years working as a BIM Coordinator in a large contractor with lots of BIM-enabled projects~~
G	Quantity Surveyor	QTO, contract payment in construction	~~7 years' experience in quantity take-off and estimation in construction~~ ~~2 years' experience in quantity surveying~~ ~~Have knowledge on BIM~~

H	Senior member of a project management team	Project management in a BIM-enabled project	~~Participated in a BIM-enabled project (high-rise building).~~ ~~10 years' experience of project management (including cost management)~~
I	BIM Manager	BIM Lead in a BIM adopted organisation	~~>5 years' experience in BIM-enabled projects (owner and contractor)~~

Apart from questions on demographic information, the questionnaire to be sent to the experts cover six key groups of issues in QTO for progress payment in the case of high-rise building projects. The groups of issues include:

- the types of progress payment adopted,

- the challenges in creating BIM objects to be included in BIM libraries, in BIM authoring and updating processes regarding data input,

- the challenges in exploiting data from BIM models for this BIM use,

- solutions for overcoming the aforementioned challenges,

- approaches in extracting data from BIM models for QTO,

- the review, verification and approval of data embedded in the BIM models before using.

The experts have agreed that there are three popular types of progress payment as illustrated in the framework. Regarding the challenges during the BIM objects creation, attention should be paid to the classes of BIM objects to be created to represent building components. Apart from the specific objects in libraries that have been developed by manufacturers, the generic objects that need to be created include piles, foundations, beams, columns, floors, walls, stairs, etc. for structures and compound objects for finishing layers. For saving time and effort, the modellers often create one object for each of the component categories; the object's shape and size can be adjusted later to represent different components of the same category when they are put into the BIM model with more geometric parameters declared. However, this will increase the workload in the BIM authoring in projects. The workload of the later phases can be reduced if more information is put in the original BIM objects, but this will limit their application flexibility, leading to more objects need to be created. Therefore, the questions on the number of object classes to be created at the pre-project stage, what information is declared when creating the objects, what information is declared when developing and updating the models need to be addressed to maximise the overall efficiency and effectiveness of the BIM-enabled projects. This is a difficult task because it needs a full view of all the BIM uses of the project, which are only identified after the project is established. All of these issued have been addressed in the framework.

Regarding the challenges in exploiting data from BIM models for the specific QTO job in this study, the experts all agreed that interoperability between the BIM authoring software and estimation software is the most significant challenge, especially in projects adopting the cost norms systems published by the government agency. The incompatibility can be the difference in the level of details required by the estimation software and that of the data extracted from the BIM models. The incompatibility can also be from the object classification standards adopted, since BIM authoring software uses international standards such as Masterformat, Uniclass, Omniclass, etc. while the QTO process uses a local standard as specified in Circular 17/2019/TT-BXD. Some clients/general contractors required a justification for each of the measurements of works; for which there is no automation or semi-automation solution can do at the moment. There are also challenges due to the changes and updates during the project progress which can lead to the need of processing BIM objects and/or data embedded to reflect the changes. Productivity, accuracy of data and models (as a component of quality) are the ones that specifically emphasised by experts regarding object creation and also exploitation.

When discussing the solutions for overcoming the challenges, experts have no objections on the proposed ones in the framework, which include the establishment of object declaration rules, the proposed use compound objects and the creation of new types of information for linking an object with its related construction works. They also shared their consensus on the approaches for different levels of automations that can be adopted in the QTO jobs, including the job in this study. All experts agreed on the need of conducting review and approval for BIM models, on what to review to ensure the completeness and quality of the information.

However, there are some issues that the experts emphasised when discussed the framework. Regarding the development of BIM object libraries, experts highlighted that due to the required speed of the design process and the low influence of quantity surveying team on the entire design job, the modelling team does not consult the quantity surveying team in creating BIM objects. Therefore, the quantity surveying team often needs to do their job on what they can get from the model, not what they want from the model; they must use some onscreen take-off or manual techniques, then their effort is huge. Experts warned that if the level of information is not put into consideration, the BIM objects may contain some "rubbish information" which has no use for that particular project; it is noted that not all the information required for QTO can be extracted from the BIM models. Also, if the data is not structure well to fit the later BIM uses, not to mention the changes and updates throughout the project, among them the updates on construction methods and processes are very popular, the parties who join later may not exploit the data effectively. Resources for storing and managing data, including hardware is an input for considering the parameters to be declared in different phases of the BIM-enabled projects. For structural elements, the definition of object classes must favour the design and drawings production, therefore the over-decomposition must be avoided. Different clients require different levels of details for the BOQ, these may also not be the same in different phases of the projects. These statements strongly support the importance of recognition of contextual information for each project. One expert emphasised that since BIM is new in Vietnam, the BIM modellers are mostly recruited from fresh engineers who have no or little practical experiences, especially the lack of other expertise such as quantity surveying, therefore, they are passive and less creative in developing BIM models. As BIM becomes more popular in the AEC industry, job enlargement may be considered to fill this gap. Regarding the review and approval of BIM models and objects' parameters, it should be noted that due to having insufficient BIM capability, clients in Vietnam may hire an external body to do the review, who cannot join earlier for contributing to the object creation, bringing difficulties to the development of the TIDP for object creation due to that the information required for BIM uses cannot be defined. Though some automation solutions for BIM-based QTO have been perceived by the experts, they emphasised that semi-automation by using BIM authoring software functions and spreadsheet such as Microsoft Excel should be adopted for the time being due to the current capability of the BIM human resources. Also, BIM practitioners need to develop formula to measure the works based on the existing data and object parameters embedded in the objects.

7 Discussions

BIM-based QTO and estimation have been considered as a challenging job, not only in Vietnam (Nguyen et al. 2020), but also internationally (Zhou et al. 2016; Olsen and Taylor 2017; Khosakitchalert, Yabuki, and Fukuda 2020). As literature shows, BIM built-in functions for quantity measuring in the off-the-shelf BIM authoring tools normally cannot fit needs from diverse countries (Zhou et al. 2016). New approaches such as APIs or the use of external software also experience a drawback that the process of data conversion from the BIM model often results in data loss due to the incompatibility in data structure (Zhou et al. 2016). Other proposed solutions include to apply an object classification approach right at the pre-project phase when developing the BIM library to make decision on the types of objects to be created with a certain level of information embedded in each type (Nguyen, Luu, and Ngo 2020). However, the solutions have not discussed in detail the local conditions and also the contextual information for a particular QTO job in the case of progress payment for high-rise building projects.

The proposed framework has addressed the challenges in BIM-based QTO for contract progress payment in the case of high-rise building projects, which include ensuring the availability, accuracy and completeness of information embedded in the BIM models, the interoperability of different tools for BIM uses and estimation. When making decision on creating the BIM objects and developing BIM libraries, declaring parameters for BIM models' objects and updating information while the BIM-enabled projects are in progress, the trade-offs such as "speed – level of detail - applicable breadth" and "quality and productivity" must be considered.

For contract progress payments for high-rise building, more information for defining the completed works corresponding to each of the instalments is required. However, it is not advisable to input all of the detailed information into the models at the start and also while updating, due to the four shortcomings discussed in Section 6.1, which include: (i) the information in its original form may not be detailed enough as requested; and the breakdown will be time consuming, (ii) BIM practitioners in a particular stage may not be fully qualified for processing information which is out of their expertise due to the job specialisation, (iii) low productivity in processing individual information or data in different disciplinary, and (iv) the changes in the required information due to that the project may not be implemented as planned. The framework developed in this study has addressed the shortcomings in the strategies (Library Objects Development Strategy, BIM Objects Information Declaration Strategy and BIM-based QTO Strategy) proposed for each of the phases.

The proposed framework points out that, unlike the traditional QTO process which can start only when the drawings are ready (which means the project has been completely designed), the QTO for the case in this study starts from the pre-project phase, when there is nothing of the BIM-enabled project available. However, knowledge from previous projects and expertise of BIM practitioners will be helpful in identifying the required information to facilitate the BIM objects creation for future uses. The aim of this stage is to create sufficient number of, but not too many, BIM objects to represent typical components of the high-rise buildings. In order to increase modelling productivity, modellers often find ways to group components of the same type so that the quantity they have to model is the least. Though the BIM object creation process is managed by BIM modellers, it is advised to have other specialists, in the case of this study, the quantity surveyors, to be involved for the trade-off between the speed of object creation, the level of details of information to be initially embedded in the objects, and their potential applicability in future projects while ensuring the BIM objects are still usable for the later BIM uses of QTO. This trade-off limits the number of objects to be created and encourages the involvement of other specialists in the BIM object creation for the ease of their later jobs.

When there is a BIM-enabled project, initially, a BIM model must be developed as the basic foundation for later BIM-related activities. Objects are then selected from available libraries to be inserted into the BIM model; the remaining components can be created directly during the authoring process. Specific information requirements for the BIM use, in this case, BIM-based quantity take-off to facilitate contract progress payment for high-rise building projects, can be identified based on the BOQ structure and the payment schedule type adopted. This ensures the compatibility of the data embedded in the BIM model with estimation method adopted; therefore, increases the interoperability of the BIM model data. During the BIM authoring and updating, data can also be classified considering their relevance to project management disciplines. Therefore, data input job can be allocated to different team members to maximise the productivity and reduce errors. Apart from enhancing productivity, this can increase the quality of the model data. As a result, the project model can be better used up for the purpose of measuring quantity for contract progress payment, both for the establishment of contractual terms and actual progress payment during execution.

8 Conclusion

There has been plenty of transcendent hype in the marketplace about BIM, especially ever since some governments mandated BIM Level 2 on all public projects. Applications of BIM to quantity take-off and progress payment have been growing rapidly for years. The volume extracted from the BIM model can be exploited for the sake of cost estimation, procurement and project management. To date, the more-than-3D application of BIM has been underrepresented in Vietnam regardless of the government calling for the acceleration of digital and smart built environment. This article has proposed the general process of creating and updating the BIM model that can underpin the quantity taking-off job in high-rise building projects. It is operationalisable for a wide variety of building types to ensure the quality of the work volumes extracted from the BIM models and for the furtherance of contract payments therefrom. The present study raises the possibility that BIM-based solutions could enhance the efficiency and accuracy of quantity taking-off tasks, leading to a better cost and scope management system in the Vietnamese CI. The proposed method can be a good reference for practitioners who want to transform quantity taking-off from a conventional manner into a BIM-enabled process. This present study aims to reform the contract establishment and payment that deem to be the most problematic quantity-related phases in Vietnam. Our study provides a stimulus for a new way to do quantity surveying jobs in construction projects. One downside regarding our proposal is that this is a semi-automatic process, still with many manual operations. To further our research, we plan to develop a completely automatic process as an integrated solution for quantity take-off, cost estimation, tendering and contract payment.

Despite the positive results, this study has some limitations. Firstly, it only shows the framework as a guide for BIM-based QTO process, more research study is needed for developing practical solutions. Secondly, the framework has been validated with expert judgment, just a little number of experts have been consulted, then it may not cover all the variations in progress payment scenarios, such as the case that accepted materials on-site can be paid for in progress payment before they are installed into the buildings. Lastly, this study only discussed the quantity take-off for contract progress payment, but not the quantity take-off for other purposes or other BIM uses. Future studies on the current topic are therefore suggested in order to establish the framework for a highly BIM mature contract management.

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