Application of Building Information Modeling (BIM) for automatic integration of construction costs management information into 3D models in consideration of Vietnamese regulations

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Abstract. Some countries concentrate to study on BIM as an effective tool in quantities taking-off and costs estimating. In contrast, due to special features of Vietnamese law regulations, issues on BIM application for these works are still not considered properly in Vietnam. Therefore, in this research, the authors would like to review studies performed on BIM uses on these works in Vietnam, and to analyze the necessities and difficulties when using BIM for automatically taking off quantities and estimating construction costs, then to propose technology methods for addressing this issue. Two methods are proposed to automatically calculate construction works quantities and costs based on models designed in Revit, more specifically, the first one is using Keynote to develop a database on components codes and to establish the components schedule in Revit; the second is using Dynamo to develop connection nodes between Revit models and Excel Sheets, facilitating the data export from Revit to Excel, then using Excel to adjust data in consistency with models.

1. Introduction
BIM becomes a trend on technology development and drives the Vietnam government to change the strategy for its construction industry. Due to its outstanding advantages for construction management and operation management, BIM application is spreading out, especially in the explosion of large-scale buildings with complicated technical features. More specifically, BIM was first applied by designers in Vietnam with Revit as the main modeling tool [1], [2]. The authors’ literature review found that BIM collaboration between various disciplines has been developed for Vietnam construction projects. Whilst BIM is boosted to apply for projects’ design phases, manual quantities taking off and manual costs estimating based on 2D drawings create a gap in BIM collaboration and development progress. Therefore, developing a solution to automatically take-off quantities based on BIM models becomes a concern for the construction industry in Vietnam.

However, the government’s rules issued on construction management is a huge obstacle for the use of BIM on bill of quantities taking-off in Vietnam. More specifically, legal forms and procedures on quantities taking off and cost estimation specified by the Government are compulsory for all construction projects, including projects funded by the private sector. Besides, the nature of quantity taking off from BIM models is the statistic on BIM objects based on models’ input data. Therefore,
standards guiding on the information needed for each BIM object’s quantities taking-off pursuant to the Government’s rules are vital for the reference of modelers, then the connection of BIM modeling tools to costs estimation software is performed to export valid cost estimate tables.

2. Literature review

Various researches on BIM and BIM application for quantities taking-off and costs estimation have been implemented in the world, concentrating on methods of BIM application for quantities taking-off [3], [4] and benefits and obstacles of using BIM for automatically taking-off quantities [5], [6], [4], [7]. Besides, general principles and BIM standards of the UK and US are mentioned. However, these researches do not consider specific conditions [8], [9] of Vietnam.

In Vietnam, various materials and scientific reports on BIM application for the construction industry have been published by state agencies, research agencies, universities and businesses with the concentration on BIM’s theoretical basis systemization, BIM’s benefits and roles and aggregation of experiences on BIM application in the world for the purpose of establishing a roadmap of BIM application in Vietnam, shifting the mindset of and developing a BIM process for relevant parties in the construction industry [1], [2], [10], [11], [12], [13]. In terms of BIM uses on quantities taking-off and construction cost estimation, all aforementioned materials and reports mainly study the experiences of other countries and express similar opinions on the necessity, obstacles, and potential of BIM application in Vietnam [1], [2], [10], [14]. Some papers present the methods on applying BIM for quantities taking off and its application for FPT City Da Nang project [15] and Safe House Building of JW-Marriott Phu Quoc project [16]; Other research [17] systematizes theoretical bases on quantities take-off based on Vietnam regulations, on BIM and quantities take-off in BIM, analyzes and evaluates the status-quo of quantities taking-off and represents advantages, disadvantages, difficulties on applying BIM for quantities taking-off in Vietnam; establishes alternatives on BIM application for quantities taking-off consistent with Vietnamese context, especially ones on the classification of objects and information establishment of objects corresponding with Vietnam regulations on quantities take-off and proposes the orientation for developing a classification system in consideration of international practices.

In conclusion, the Vietnam Government and Ministry of Construction’s strategies concentrate on BIM as a future direction of the construction industry [18], [19], [20]. Therefore, contents on BIM and BIM application for quantities taking-off have been widely studied in national research projects [1], master thesis reports [2], [10], [17] and scientific reports and articles published in prestigious journals. Almost these materials represent theoretical bases, benefits, obstacles and national experiences on BIM application for quantities taking-off. Proposals of these materials concentrate at macroscopic levels as roadmaps for changing the mindset on BIM application for quantities taking-off. Besides, preliminary methods on classification and model objects setup for automatically taking-off quantities by the use of BIM in consideration of Vietnam regulations are proposed [17]. However, detailed processes for taking-off quantities by the use of BIM are not mentioned in any researches in Vietnam. Therefore, this article would like to focus on the solution for automatic costs estimation for BIM-applied projects based on Vietnam regulations on construction costs management.

3. Automatic construction costs estimation

3.1. Components code for classification

The classification’s nature is providing a structure for a classified system. Therefore, in case of works’ volume arising, positions of components recently integrated into the available classified system must be specified. The technology advance opens up a new era for data collection, access, share, and archive, therefore, data must be considered as an indispensable asset of a specific project. In the near future, a data classification system will be a vital part of any Building Information Models [21]. Details on coding components for classification are represented as follows:
3.1.1. Implementation scope
- Establishment of a code system for basic components as Columns, Beams and Slabs
- Columns, Beams and Slabs studied in the research possess following features

| CROSS SECTION AREA | FORMWORK | REINFORCEMENT DIAMETER | CONCRETE GRADE /AGGREGATE |
|---------------------|----------|------------------------|---------------------------|
| 1-Cross section area <=0.1m² | 1-wooden formwork | 1. <=010mm | 11 – 1x2-150 |
| 2-Cross section area >0.1m² | 2-steel formwork | 2. <=11mm | 12 – 1x2-200 |
|                      | 3. >11mm | 3. >18mm | 13 – 1x2-250 |

0 – no depending on cross section area

- Implementation objectives
  - Establishment of a classification system for the aforementioned components
  - Assignment of code to each component in the 3D model created by Revit software for the establishment of data system connecting to the cost estimation work.

3.1.3. Results
Pursuant to Norm No. 1776/VXD-VP on norms for construction of civil works, the authors propose the method of coding for components of 3D models as follows:
- A component’s code consists of 02 sections: The script section expressing this component name as abbreviation and the numerical section expressing features of this component.
- A code must represent parameters on a component’s cross-section area, forms, reinforcement diameter, and concrete grade/aggregation.
- Data on a component’s height is integrated into each parameter on forms, reinforcement diameter, and concrete grade/aggregation as the basis of assigning a corresponding code on unit price/norm specified in the Government’s guidance.
- Therefore, each component code includes but not limited to [Component name abbreviation].[numerical information]

For e.g. the code for a column, with <0.1m cross-section area, 5m height, using steel forms, reinforcement diameter of 10mm, crushed aggregate of 1*2, concrete grade of 250, is C C.1 2 1 13 with details showed in Figure 2.

3.1.1. Implementation scope

Figure 1. Features of columns, beams and slabs studied

Figure 2. Example of a code for a component

Besides, for components using materials which are not specified in the Government’s norm, their codes are established as follows:
+ Each numeric character represents for each component’s material feature
+ The number after the dash (-) is additional information for the material mentioned before the dash (-)
+ The number after the dash (-) is pursuant to the regulation on coding.

For e.g. A column uses concrete of 350 grade, however, the information on concrete grade of 350 is not indicated in the Government’s norm, so code for this column is: C 1 2 2 24-5. The character “5” after the dash (-) represents for concrete of 350 grade.
+ The character after the dash (-) is additional information for one after the dash (-)
+ The code expresses whether or not a component uses materials specified in the Government’s norm.
+ There is no boundary to the classification for various users’ requirements.

Establishment of the components’ library and classification of these components as specific codes shorten the time for developing task lists when estimating costs. A list of codes made by an engineer can be re-used and shared over and over, bridging the gap on BIM application for the construction industry.

3.2. Integration of components codes into 3D models and development of the summary table by the use of Revit software

3.2.1. Development of the database on components codes
a. Formatting of archive files for the database on components codes
- The structure of file *.txt exported by Keynote indicates specifically the syntax of each line. Data adjustment and supplementation in Keynote are implemented by Notepad and Excel with the requirement on users’ understanding of syntax and carefulness.
- File *.txt format for Keynote includes:
  + Discipline Declarations as Partition - parent directory;
  + Keynote Number as norm code
  + Keynote Text as norm code description
  + Keynote Discipline as Keynote partition.

![Figure 3. Format of archive files for the database on components codes](image-url)

b. Implementation process
- File Keynote *.txt based on the specific structure is established and represented in Notepad or Excel, then saved as *.txt format for import Keynote file into Revit software.
- The example of establishing a Keynote file for Component Code C 1:
  + Keynote format:
Table 1. Keynote format

| Code | Space | Description                                                                                     | Space | Parent directory | Space |
|------|-------|-----------------------------------------------------------------------------------------------|-------|------------------|-------|
| C 1  | Tab   | Column with cross section area <= 0,1m²                                                         |       |                  |       |
| C 1 1 1 1 | Tab   | Column with cross section area <= 0,1m², using wooden formwork, reinforcement of <= 10mm diameter, concrete of 1x2 aggregate and 150 grade | Tab   | C 1             | Tab   |
| C 1 1 2 2 | Tab   | Column with cross section area <= 0,1m², using wooden formwork, reinforcement of <= 18mm diameter, concrete of 2x4 aggregate and 200 grade | Tab   | C 1             | Tab   |

3.2.2. Implementation process using Keynote

a. Import of Keynote file into Revit

Using Keynoting Settings: Annotate - Tag - Keynoting Settings

![Figure 4. Using Keynoting Settings](image)

1. The file location for file *.txt consisting of Keynote
2. Path for saving
3. File re-up in case of changing file content.
4. Absolute file path
5. The relative file path means file contained in the default folder in Option» File Locations» Place.
6. At library locations
7. Numbering method by keynote
8. Numbering method by sheet

Each time of opening Revit software, the Keynote file is automatically loaded. In case of Keynote file adjustment and the working process in Revit occurring simultaneously, data must be re-loaded by using Keynote settings presented above.

b. Assignment of Keynote code into objects

A Keynote parameter of Identify Data is integrated into each object’s properties type; the right button should be clicked to open the Keynote dialog:

![Figure 5. Assignment of Keynote code into objects](image)
c. Establishment of the components schedule

A parameter schedule for each component, including Family, Type, Keynote, Volume, Count, etc., is established by Revit; the Keynote code of each component is different from each other for classification and integration this code into costs estimation.

In Schedules/Quantities of Project Browse, the new schedule is created by selecting New Schedules/Quantities. A new schedule consists of all components (such as beams, columns, Slabs and Foundations); for example, Structural Columns represent for columns of a civil work.

The schedule Properties dialog contains 02 parts as Available fields and Schedule fields which are parameters appearing in components’ schedules in case of these components selected.

For example, the schedule exported is described as follows:

Table 2. Column schedule

| Keynote | Family                | Top Level | Structural Material | Type   | Volume  | Count |
|---------|-----------------------|-----------|---------------------|--------|---------|-------|
| C 2 1 2 14 | M_Concrete-Rectangular-Column | Ground    | Concrete, Cast-in-Place gray | 300 x 450mm | 0.53 m³ | 6     |
| C 1 1 2 13 | M_Concrete-Rectangular-Column    | Level 1   | Concrete, Cast-in-Place gray | 220 x 300mm | 0.18 m³ | 10    |
| C 1 1 2 13 | M_Concrete-Rectangular-Column    | Level 2   | Concrete, Cast-in-Place gray | 220 x 220mm | 0.36 m³ | 4     |

Table 3. Beam schedule

| Keynote | Family                | Reference Level | Structural Material | Type   | Volume  | Count |
|---------|-----------------------|-----------------|---------------------|--------|---------|-------|
| D 0 1 2 13 | M_Concrete-Rectangular Beam | Ground        | Concrete, Cast-in-Place gray | 250 x 500mm | 5.29 m³ | 6     |
| D 0 1 2 13 | M_Concrete-Rectangular Beam | Level 1       | Concrete, Cast-in-Place gray | 100 x 220mm | 0.98 m³ | 6     |
| D 0 1 2 13 | M_Concrete-Rectangular Beam | Level 2       | Concrete, Cast-in-Place gray | 220 x 300mm | 3.32 m³ | 17    |

Table 4. Slab schedule

| Keynote | Family | Level | Structural Material | Type   | Volume  | Area   | Count |
|---------|--------|-------|---------------------|--------|---------|--------|-------|
| S 0 2 4 14-6 | Floor | Level 2 | Slab’s Concrete B30 (M400) | F-100mm | 8.50m³  | 85m²  | 1     |
| S 0 2 4 14-6 | Floor | Level 3 | Slab’s Concrete B30 (M400) | F-100mm | 3.91m³  | 39m²  | 1     |
| S 0 2 4 14-6 | Floor | Level 3 | Slab’s Concrete B30 (M400) | F-100mm | 6.85m³  | 69m²  | 1     |

3.3. Application of Dynamo for components’ quantities taking-off based on 3D drawings

3.3.1. Dynamo’s Introduction

Dynamo is a graphical programming tool integrated into Revit. Dynamo facilitates the use of Revit by enabling users to access Revit API (Application Programming Interface). Besides, Dynamo enables users to initialize programs by using graphical elements called “nodes”, opening a convenient method on programming for visual tasks relevant to architecture and technical design.

Each node in Dynamo possess a separate mission. Nodes consist of input and output; a node’s output connects to another by a “wire”. Programs or graphics are transferred through nodes by a wire system. A graphical presentation on essential design steps is the final product of this process.
Accessing nodes’ libraries is an advantage of graphical programming tools as Dynamo. More specifically, each command for an individual request can be easily found in nodes’ libraries.

Besides, the Dynamo user community facilitates the success of this application. In addition to supporting each other via Dynamo forums, Dynamo users develop nodes packages which are often used and upload them into a common data environment or an online library. This online library enables users to search and download materials directly in Dynamo without accessing the website or performing the complicated installation processes. Each node package serves for a specific objective, for e.g. a nodes package for dividing and numbering rooms, a nodes package for automatically creating coating layers or another for automatically assigning names and features to components.

Various efficient nodes packages frequently used are Archi-Lab, Clockwork, Data-shapes, Lunchbox, and Rhythm. Besides, there are nodes packages supporting for special functions.

3.3.2. Integration of Dynamo into Excel for automatic quantities-taking off

a. Objectives:
- Exporting an information schedule for components (including components’ code, name, volume, and length) into Excel software without spending much time and effort. Results are used as inputs of various costs estimation software
- Finding non-coded components
- Avoiding failures on works’ quantity calculation thanks to all steps implemented with a high IT support level.

b. Utilization of Dynamo for exporting information schedules into Excel
For exporting a schedule into Excel, users must develop a chain of “node” for extracting information from Revit and writing this information into Excel. Detailed implementation steps are as follows:
* Step 1: Open dynamo in Revit software
* Step 2: Create an Excel file for archiving data on the schedule
* Step 3: Write a program using Dynamo. Creating a nodes chain for developing a schedule
* Step 4: Select a Sheet of Excel to archive data and select components to export their information
* Step 5: Select “Run” to start the program after information fine adjustment.

Detailed information on components is exported quickly and exactly into Excel using a simple protocol as mentioned above. Results can be verified based on drawings.
Table 5. Components schedule

| Component code | Component name                                      | Volume  | Height |
|----------------|-----------------------------------------------------|---------|--------|
| C 2 1 2 14     | Family Type: 370 x 450mm, Family: M_Concrete-Rectangular-Column | 0.108225 | 650    |
| C 1 1 2 13     | Family Type: 220 x 300mm, Family: M_Concrete-Rectangular-Column | 0.0099  | 770    |
| C 2 1 2 14     | Family Type: 300 x 450mm, Family: M_Concrete-Rectangular-Column | 0.08775 | 650    |
| C 1 1 2 13     | Family Type: 220 x 300mm, Family: M_Concrete-Rectangular-Column | 0.2244  | 3600   |

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c. Disadvantages of using Dynamo
Despite efforts on programming nodes for automatically exporting components’ schedules into Excel,
- Import of components quantities and codes into the cost estimation software must be implemented manually
- These components possessing the same features (such as on code, dimension, and length) are displayed into multiple lines, not into a line. Therefore, the schedules’ data must be adjusted before importing into the cost estimation software.

3.4. Use of component codes for estimating costs in consideration of Vietnamese regulations:
Costs estimation for construction projects in Vietnam must be implemented in conformity with the national norms issued by the Ministry of Construction and lists of unit prices for cities or provinces. Each unit price list for a city/province is established by the Department of Construction of this city/province and corresponds to each code of task described in the national norms. There are 02 fundamental steps to estimating construction cost for a component as follows:
- 1st step: Define all tasks needed to create this component and in the national norms, find a corresponding code for each task;
- 2nd step: apply an appropriate unit price list for these tasks based on the construction location.

Therefore, a component code containing all constitutive tasks’ codes must be established. For example, in order to estimate the constructional cost for a concrete column with the code of C 2 2 1 14, 03 tasks are taken into consideration, features and codes of these tasks are shown in Figure 7.

![Figure 7. Search of corresponding norms and unit prices for tasks](image-url)
By the use of cost estimation tools developed by Vietnamese companies, tasks’ codes specified in the norms can be easily found based on these tasks’ features. A database consisting of all task codes for all components of a building is developed and can be re-used and shared for future works. A corresponding unit price, then, is applied for each task. This step can be supported by cost estimation tools, more specifically, these tools enable users to automatically match tasks’ codes specified in the Government’s norm to their detailed unit prices and quantities as presented in Table 6.

Table 6. Detailed unit prices of construction works

| NO. | UNIT PRICE CODE | TASKS DESCRIPTION                                                                 | UNIT | QUANTITY | UNIT PRICE |
|-----|-----------------|-----------------------------------------------------------------------------------|------|----------|------------|
|     |                 |                                                                                  |      |          | MATERIAL   |
|     |                 |                                                                                  |      |          | LABOR      |
|     |                 |                                                                                  |      |          | MACHINE    |
| 1   | AF.12245        | Concrete produced by concrete mixer, placed manually. Placing concrete for column with Cross section area > 0,1m², Height <=16, Concrete Aggregate 1x2 and Grade 300. | m²   | 1.231.839 | 937.545    | 109.584    |
| 2   | AF.82111        | Manufacturing, installing and removing steel formworks when using cast in place concrete method and wooden props for walls, square (rectangular) column, beams, bracing beams using cast in place concrete method in the height of <=16m | 100m² | 2.848.782 | 8.954.572  | 589.973    |
| 3   | AF.61412        | Manufacturing and installing columns’, posts’ and concrete walls’ reinforcement with diameter of <=10mm in the height of <=16m | ton  | 16.497.030 | 3.304.141  | 110.618    |

Thanks to components codes, data used for cost estimation possesses the linkage to 3D models, facilitating the timely updates of costs estimation in case of occurring any changes in components’ information.

4. Conclusion
BIM application in construction cost management is becoming the development trend of the construction industry in Vietnam. The research proposed methods to use BIM tools for addressing some issues relevant to quantities taking off and works schedules supporting for cost estimation. Besides, supplementation of components information into 3D models facilitates the construction cost management. However, the lack of guidance on the establishment and management of these projects’ cost using BIM becomes an obstacle for applying these proposals, especially for projects funded by the public sector. Based on the long-term objective of establishing a common data environment for the construction cost management, proposals of the research would like to create a basic step in developing a framework for the BIM application process under Vietnamese conditions.

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