Establishing Construction Scheduling Progress Curve based on Buidling Information Modeling Quantity Takeoffs

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Abstract: A cost cumulative progress curve (called S-curve) is often used as a basis for effective schedule control which is a key to the success of construction projects. In establishing a planned S-curve of a construction project, the cost of each scheduling activity must be determined. Furthermore, the contractual costs associated with the cost items should be fully distributed to all scheduling activities. However, the relationships between scheduling activities and cost items are complex because these relationships may be 1-to-1, many-to-1 or many-to-many relations. This research proposes a searching algorithm to conduct quantity takeoffs in Revit and QTO to facilitate the establishment of the planned S-curve. The proposed search algorithm defines different search steps (using various searching parameters, such as "floor", "physical object", "cost item", and "area") to identify corresponding cost items associated with different types of activities. The benefits of the proposed algorithm is demonstrated by applying it to a high-tech facility building in northern Taiwan.

1 INTRODUCTION

Project scheduling is a fundamental task in the management and execution of construction projects (Hendrickson and Au 2003). A cost cumulative curve (called S-curve), a graphical representation of the cumulative progress of a construction project, from start to finish, is often used as a basis for effective schedule control of a project. In constructing a planned S-curve of a construction project, the cost of each scheduling activity must be determined. Notably, the contractual costs associated with the cost items should be fully allocated to all scheduling activities.

To calculating the costs of an activity, first, one needs to determine the quantities of the planned construction materials (such as reinforced steel, form, and concrete) associated with the activity. Then, based on the unit prices associated with the construction materials, the costs of the activity are obtained by multiplying the quantities and unit prices. However, finding the construction materials associated with each activity is complicated because the relationships between activities and construction materials (or cost items) may be 1-to-1, many-to-1 or many-to-many relations.

Consider a many-to-many relationship for example. Both activities, setting 1st-floor columns/walls steel and setting 1st-floor beams/slabs steel, are related to the costs of two cost items (construction materials), SD420W steel and SD420 steel. Furthermore, for instance, the activities of 280kgf/cm2 concrete grouting for the 1st floor slab, the 2nd floor slab and the 3rd floor slab represent a many-to-one relationship, where “many” activities corresponds to “one” cost item (280kgf/cm2 concrete). Although this above calculation process is possible, it is highly time-consuming and error-prone.

Recently, BIM quantity takeoffs capacity has progressively shown its effectiveness (Shen and Issa 2010; Chen 2011; Chai 2012; Wijayakumar and Jayasena 2013). This study thus intends to utilize BIM quantity takeoffs capacity to support the quantity takeoffs of each scheduling activity for obtaining the costs, leading to the establishment of a planned S-curve for effective schedule control.

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2 LITERATURE REVIEW

2.1 BIM Quantity Takeoffs

While traditional estimation methods conduct quantity takeoffs from 2D CAD drawings, a BIM tool can obtain the required data and measurements for quantity takeoff from a 3D model (Rundell 2006; Shen and Issa 2010). Recently, many researchers in Taiwan have developed BIM-based tools to support quantity takeoffs. For example, Chen (2011) used Autodesk Revit to perform quantity takeoffs for a twelve-story reinforced concrete office building. His study showed that the quantities of concrete and steel extracted from BIM were 0.5% and 3.7% less than the conventional estimation, respectively. Chai (2012) developed a Revit API program to automatically calculate the quantities of forms. Regarding the quantities of forms, for instance, the BIM generates the results were close to the ones calculated manually, with only 1% difference.

2.2 BIM and Cost Estimates

Eastman et al. (2011) pointed out that although there are BIM-based quantity takeoffs tools available to assist the cost estimates, there is no BIM software with full estimation functions. Therefore, a cost estimator must either export the BIM quantities into the cost estimation software, Link the BIM tool (software) to the cost estimation software through an API, or export BIM model data into a BIM-based cost estimation software (Rundell 2006; Eastman et al. 2011).

3 MODEL FOR ESTABLISHING A S-CURVE

This study proposes a model to establish S-curves of construction projects. The proposed model consists of four steps, as shown in Fig. 1: (1) developing a BIM model associated with cost items, (2) conducting searching algorithms to perform quantity takeoffs in Autodesk QTO, (3) mapping contractual unit prices from cost estimation software, and (4) converting to Excel to build a S-curve. These four steps are described in the following subsections.

Step 1: Developing a BIM Model Associated With Cost Items.

In the proposed model, first, a BIM model with the level of detail (LOD) 300 must be built. This BIM model is composed of physical components and information parameters. Physical components are such as columns, beams, walls, slabs, doors, windows and rooms.

The information parameters in each physical component are divided into two parts: additional geometric parameters and cost-item parameters. Besides to the geometric data (such as length, width, height, area, and volume) of a physical component, additional geometric parameters are required to conduct quantity takeoffs. For instance, the information required to conduct the quantity takeoffs for the steels of a wall include: the data of length and height of the wall from the common geometric parameters; and, the data of spacing of horizontal bar, spacing of vertical bar, steel unit weight, and the number of bar layer for this wall from the additional geometric parameters.

To add the cost items associated with each physical component, this study uploads the contractual cost items to the Revit using the "keynotes", "assembly codes", and "family type catalogs" functions in Revit. This step sets a base to enable each physical component to map the cost items that specify the construction materials used in erecting the component.

Step 2: Conducting Searching Algorithms to Perform Quantity Takeoffs in Autodesk QTO.

The model proposes to apply the search takeoff tool in Autodesk QTO to create takeoff objects (that is, cost items associated with each activity) and then quantify the objects. To specify the takeoff objects needs to set search criteria first. The proposed search algorithm defines various search criteria (floor, physical object, cost item, and area) with respect to different types of scheduling activities (structure, site work, and finishes activities).

For example, the structure activities are such as setting steel of 1st floor columns/walls, setting steel of 1st floor beams/slabs, setting form of 1st floor columns/walls, setting forms of 1st floor beams/slabs, etc. Thus, in the structure activities, the search criteria are floor (1st, 2nd, 3rd, etc.), physical object (column, wall, beam, and slab), and cost item (involved construction materials).

Specifically, for instance, activity “setting steel of 1st floor columns/walls” includes two physical components: columns and walls. Each component is associated with two cost items, namely, “steel, SD420, labor and material included” and “steel, SD420W, labor and material included”. The takeoffs of steel in this activity are performed in four steps:

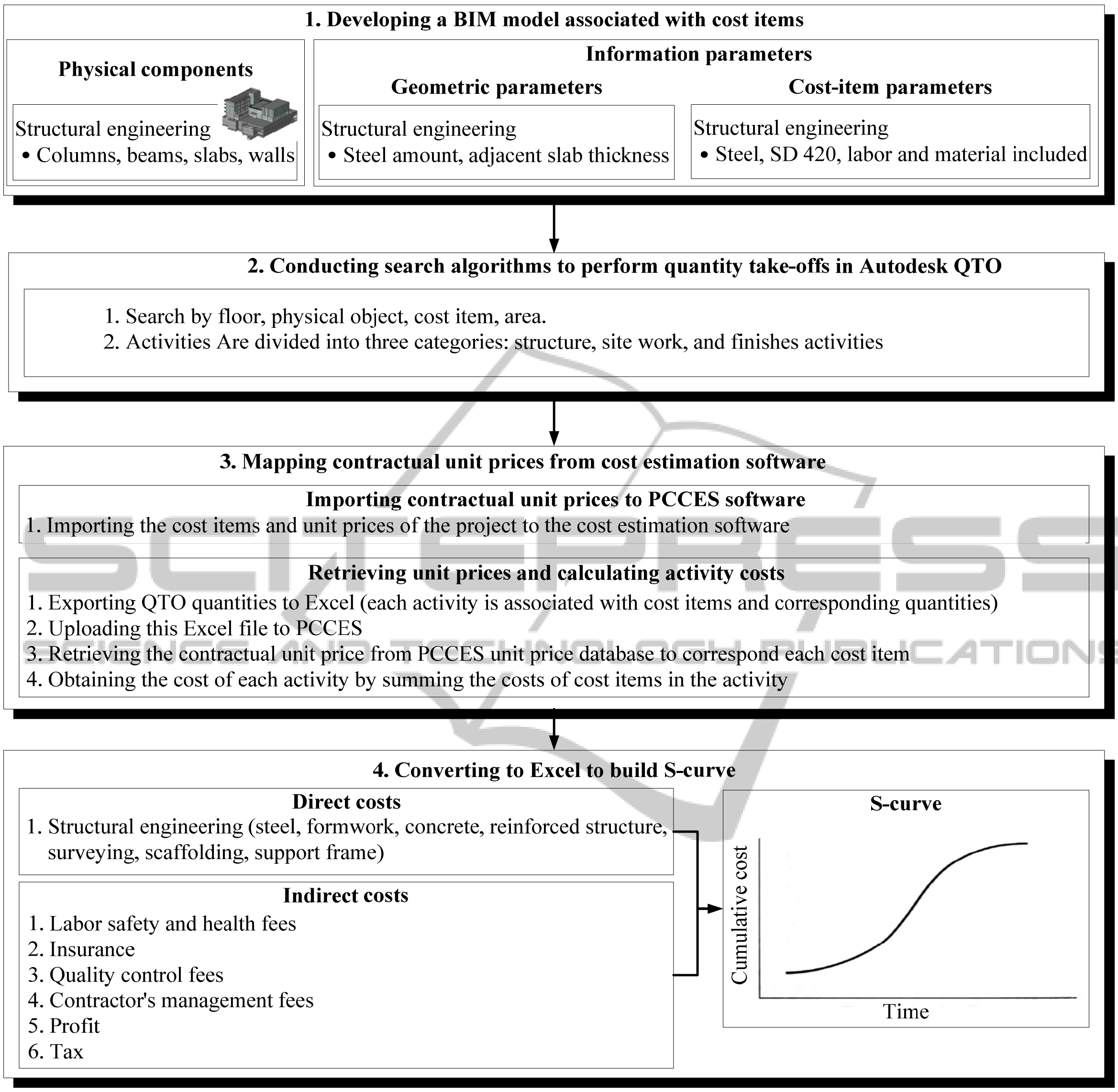

Figure 1: Proposed model.

- Step 2.1: In the search takeoff tool, use "1st floor" (floor), "column" (physical component) and "steel, SD420, labor and material included" (cost item) as search criteria to retrieve all the columns that use "steel, SD420, labor and material included" and are located on the first floor. The geometric parameters of columns are used to quantity the column steel via takeoff formulas.
- Step 2.2: Step 2.1 is repeated for the other cost item (steel, SD420W, labor and material included) of "column".
- Step 2.3: Step 2.1 is repeated for "wall" and cost item (steel, SD420, labor and material included).
- Step 2.4: the quantities of steel of "wall", cost item (Steel, SD420W, labor and material included) are also obtain through the same process.

Notably, several structure activities are associated with the same cost items "steel, SD420, labor and material included" and "steel, SD420W, labor and material included". Therefore, the example here relates to a many-to-many relationship (i.e., many activities-to-two cost items).

Step 3: Mapping Contractual Unit Prices from Cost Estimation Software.

After conducting step 2, the cost items associated with quantity takeoffs in each activity are transferred to a cost estimation software (called Public Construction Cost Estimation System or PCCES) that is widely used in Taiwan. Via PCCES, the contractual unit price of each cost item is retrieved automatically. As a result, the costs of the cost items in each activity can be computed.

Step 4: Converting to Excel to Build a S-curve.

The costs of each activity calculated in PCCES are exported to a MS Excel file. Next, in an activity, the costs are uniformly allocated in the activity duration to obtain the daily costs. Notably, the activity costs are related to direct costs. Indirect costs of a project, such as safety and health fees, and quality control fees, are assumed to be uniformly spread out the entire project duration. Finally, the daily costs of various activities in each day can be obtained, resulting into the establishment of a progress curve (or S curve) of the project.

4 CASE STUDY

4.1 Project Description

The case study concerns a project that involves a high-tech related building in northern Taiwan. This building built with RC has three upper-structure floors and two underground-structure floors. The total building floor area is 14,966 m2, and the construction budget is approximately US$7.4 million. And the project contractual duration is 598 days. This project has an intermediate schedule associated with 93 activities, in which the numbers of structure, site work, and finishes activities, are 59, 9, and 25, respectively.

4.2 Evaluations and Results

First, a 3D BIM-based model was built using Autodesk Revit Architecture, as shown in Fig. 2. This BIM model is composed of physical components and information parameters (including additional geometric parameters and cost-item parameters). This BIM model is then transferred to Autodesk QTO to conduct quantity takeoffs.

In performing step 2, Fig. 3 presents a snap shot of applying the search takeoff tool to quantify the cost item, “steel, SD420, labor and material included" of activity “setting steel of 1st floor columns/walls”.

After going through the modeling steps 1~4, Fig. 4 displays the established S curve in the project.

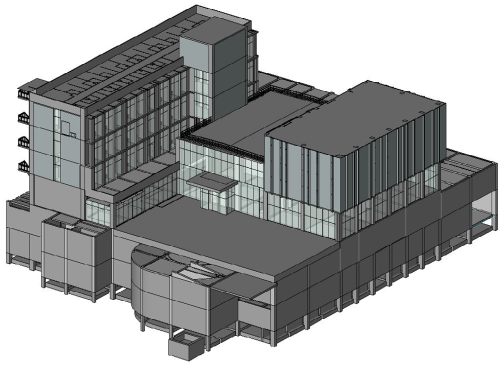

Figure 2: Autodesk Revit model of case project.

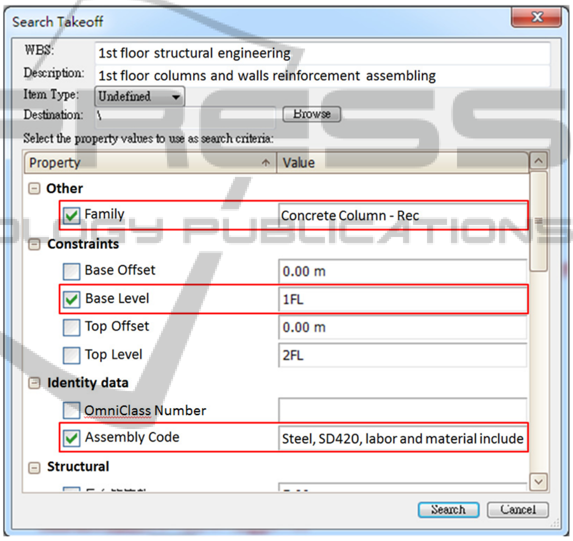

Figure 3: Searching criteria in QTO.

4.3 Discussions

During the course of this case study, lessons learned are summarized as follows.

- In establishing an S curve, if the duration of an activity is too short (for example, one or two weeks; the case of a detailed schedule), then numerous activities will be involved, increasing the computation effort in QTO. If the duration is too large (for example, two or three month; the case of a milestone schedule), the QTO effort is much less, but the accuracy of an S-curve decreases. Hence, this study recommends to use an intermediate schedule.
- The search algorithm can reduce errors in mapping the activities and cost items. However, the current algorithm is still performed manually.
- An S curve is often done after the project contract has been awarded, in which the

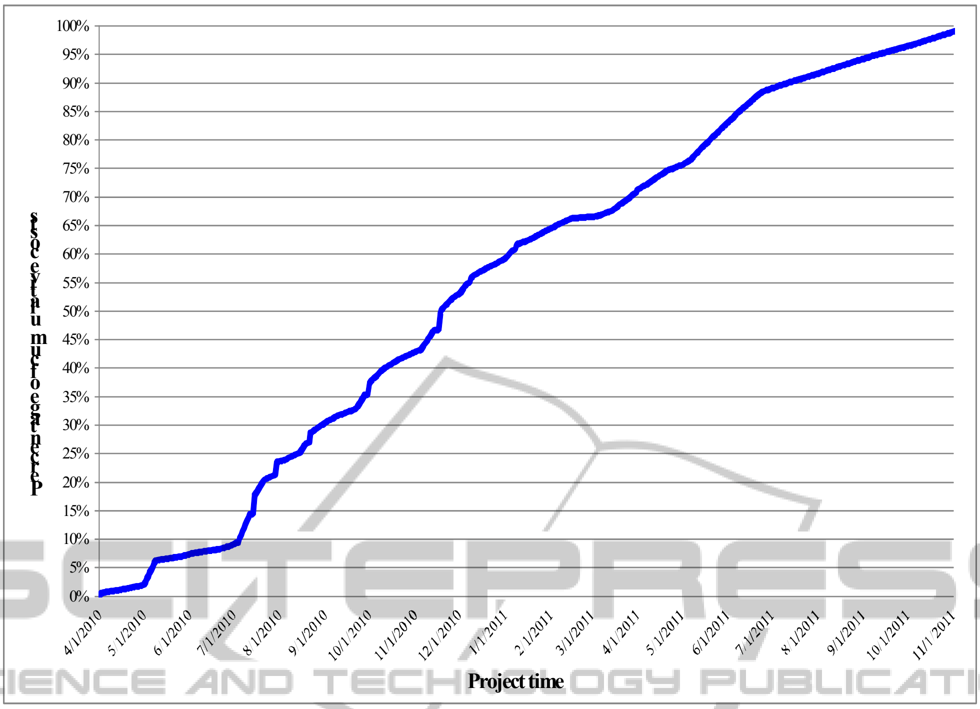

Figure 4: Established S curve of case project.

contractual quantities already exit. In a cost item, if the overall quantity extracted by QTO differs from the contractual quantity, one may need to adjust the extracted quantity.

5 CONCLUSIONS

The relationships between scheduling activities and cost items may be 1-to-1, many-to-1 or many-to-many relations, which are very complicated to specify the costs of each activity. This study proposes a searching algorithm to conduct quantity takeoffs in Revit QTO to facilitate calculate the costs of each activity. To do so, the search algorithm uses the "keynotes", "assembly codes", and "family type catalogs" functions in Revit to connect the activities and their corresponding cost items. Next, the search algorithm defines different search steps (using various searching criteria, such as "floor", "physical object", "cost item", and "area") to identify various cost items associated with different types of activities (including structure, temporary, and finishes activities). Then, the extracted quantities of cost items associated with each activity is transferred to a cost estimation software, which can provide the unit prices of corresponding cost items for obtaining the total cost of the activity. At last, integrating the costs of activities and the schedule, a planned S curve of a construction project can be established to support schedule control.

A case study has shown the benefits of the proposed search algorithm and model. Future research directions are as follows. For instance, some of the steps in conducting search algorithms and modeling are not automated. Using API to performing these steps automatically should improve the user friendliness.

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