Karatzas S. and Chassiakos A. (2017). “Building Information Modelling as a Cost Control Tool for Critical Chain Construction Project Management” In: *LC3 2017: Volume I – Proceedings of the Joint Conference on Computing in Construction (JC3)*, July 4-7, 2017, Heraklion, Greece, pp. 681-689. DOI: https://doi.org/10.24928/JC3-2017/0228.

BUILDING INFORMATION MODELLING AS A COST CONTROL TOOL FOR CRITICAL CHAIN CONSTRUCTION PROJECT MANAGEMENT

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Abstract: The Critical Path Method (CPM) has been used in the construction industry as a project planning and control tool for a long time, however, project delays and cost overruns still happen. Compared to CPM, Critical Chain Project Management (CCPM) represents an improved management approach that focuses mostly on human behaviour and resource conflicts, addressing concepts like Student Syndrome, Parkinson’s Law and multitasking resolution. Additionally, CCPM simplifies project control and utilises buffers to reduce the risk of delay, bringing the project ahead of schedule without increasing costs. On the other hand, Building Information Modelling (BIM), being a methodology that enables enhanced and flexible management of construction project data within a virtual environment, could be exploited as a platform for the introduction of innovative project control methodologies into the construction management practices. This research aims to take advantage of BIM to support the implementation of Critical Chain Project Management methodology along the construction phase of a project. A framework for using BIM as a cost control tool to improve project buffer management is developed and analysed to facilitate the timely project execution and profit increase goals of the contractor.

Keywords: Critical chain, cost control, Building Information Modelling, project management

1 INTRODUCTION

Construction projects are subject to a wide range of constraints such as work complexity and vagueness, resource scarcity, duration and cost uncertainty, and external factor involvement. Failing to manage any of these constraints can create scheduling distortions. Traditional and widely used project management techniques (i.e. CPM and PERT) are not always justifiable and effective due to their reliance on certain assumptions that become more questionable as projects grow in size, complexity, and resource needs (Kastor and Sirakoulis 2009). To address such challenges, the theory of constraints (Goldratt 1997) was applied to project management resulting in the development of a new scheduling method called Critical Chain Project Management (CCPM). The method proposes a solid theoretical background to deal with uncertainties within projects and avoid time overruns by addressing human behaviour issues along with the schedule development. Some of the concepts addressed with this method in

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reducing activity duration are the elimination of the Student Syndrome and Parkinson's Law, the elimination of resource conflicts and multitasking.

In construction projects, however, much of the work is outsourced to subcontractors who are hired for a certain period of time to perform specific tasks according to the contract. In this sense, it is not reasonable to expect subcontractors to voluntarily reduce the duration of their assignment in order to align with the CCPM provisions. In addition, while construction projects are highly sensitive to variations on schedule and cost (Feng et al. 2013), CCPM basically ignores cost management and focuses mostly on time management by using a buffer management control system, as part of a flexible strategy to address human variability. However, time and cost are interrelated with a trade-off and, in this sense, cost control can be delivered through effective time management of project components.

The emerging BIM methodology could be the platform to provide the flexibility for the implementation of the critical chain concepts with a more realistic, cost management focused approach. Building Information Modelling is a methodology that comprises policies, processes and technologies to manage the essential project design and data in a digital format throughout the project life-cycle (Succar 2009). Through the adoption of BIM, construction companies gain the ability to develop and manage virtual models of a project that will support the design, procurement, construction, operation and maintenance processes in an effective and collaborative manner. The mainstream use of BIM has focused on 3D BIM application to support architectural design. Further, 4D BIM application links each element of the 3D to activities in a schedule and allows the simulation and visualization of the construction process, with the aim to identify potential problems during project execution in advance. Recently, the 5D BIM management tool has come up considering, in addition, cost related data. Popov et al. (2010) describe several advantages which 5D BIM environment provides to project managers, it fosters improved collaboration, enhances clash detection and visualization capabilities, and provides more accurate take-offs. The most profound benefit of 5D BIM is its potential to analyze alternative project implementation scenarios, allowing for the selection of the most effective one in reducing execution cost.

2 PROBLEM STATEMENT

CCPM theory is easy to understand but challenging to implement because it requires a new way of thinking about planning and managing projects as well as alters the mindset and culture of the entire project organization. Meanwhile, many organizations have implemented a CCPM methodology for managing and monitoring their projects but not all efforts have been successful, while some had to give up (Leach 2005). The statistics of 150 CCPM implementation attempts indicate that only one third of them were successful. Further, despite the initial success, about 15% of them failed to be maintained (Gupta 2005).

Construction projects are mostly performed by subcontractors, who are outsiders to the general contractor, and this might be a barrier for the implementation of the fundamental concept of CCPM, namely that activity duration should be reduced to eliminate unprofessional human behaviour that has been cultivated and unconsciously encouraged for a long time. There are certain barriers in the successful implementation of CCPM and the general contractor may face difficulties to do so for a number of reasons, such as lack of knowledge by subcontractors regarding the critical chain positive outcomes, strong inertia in human behaviour, and lack of commitment on behalf of subcontractors. Subcontractors are not expected to simply improve their performance, reduce the duration of work, and adopt the methodology by just telling them so. Therefore, the use of control tools may be necessary for propelling them to take the appropriate measures to achieve the target reductions.

Although buffer management (as a main concept of CCPM) provides a clear methodology to establish a warning mechanism to stimulate appropriate management actions, the cost element is not taken sufficiently into account (Xuejun 2014). While the current buffer management framework offers a handy management solution to identify when corrective actions are necessary, it fails to provide more explicit guidelines concerning to which activities (or combination of activities) to focus and to what extent in order to effectively shorten the project completion time at a minimum cost. The current buffer management model is over-simplified and based on experience without cost considerations.

This research seeks to supplement the conceptual guidance with project time and cost control tools in a framework of BIM based CCPM. It proposes a framework to enhance the implementation of CCPM in the construction phase, applying buffer management models together with 5D BIM moving thus towards a more practical and dynamic BIM cost management methodology.

3 PROPOSED FRAMEWORK

3.1 Framework Structure and Key Assumptions

The proposed framework is developed from the point of view of a general contractor who is willing to apply the critical chain methodology in a construction project with the employment of BIM tools in order to enhance certain CCPM functions with regard to project monitoring and control. The idea follows the work of Siles (2013) in which BIM tools have been used for CCPM implementation in the planning phase of a project. The main concept is to apply 5D BIM cost management practices providing the ability to develop a 'recovery' (cost) component (cost savings) which can be then allocated, based on buffer management methodology, to actions necessary to assist sub-contractor decisions in aligning the execution of critical activities with the global CCPM schedule. To develop the framework, a number of assumptions are made (Feng 2013):

- Contractual project terms (delivery date, total project price, and scope) have already been defined and signed in the pre-contractual phase between the general contractor and the owner.
- Certain parts of the project (called 'activities') are subcontracted.
- Each activity is performed by just one subcontractor (to avoid multitasking, rework, or conflicts) but one subcontractor can perform more than one activity.
- There are no resource conflicts during the construction phase.
- The general contractor is already using BIM for project representation while subcontractors may or may not use it.

The framework structure is presented in Figure 1 and described in the sections below.

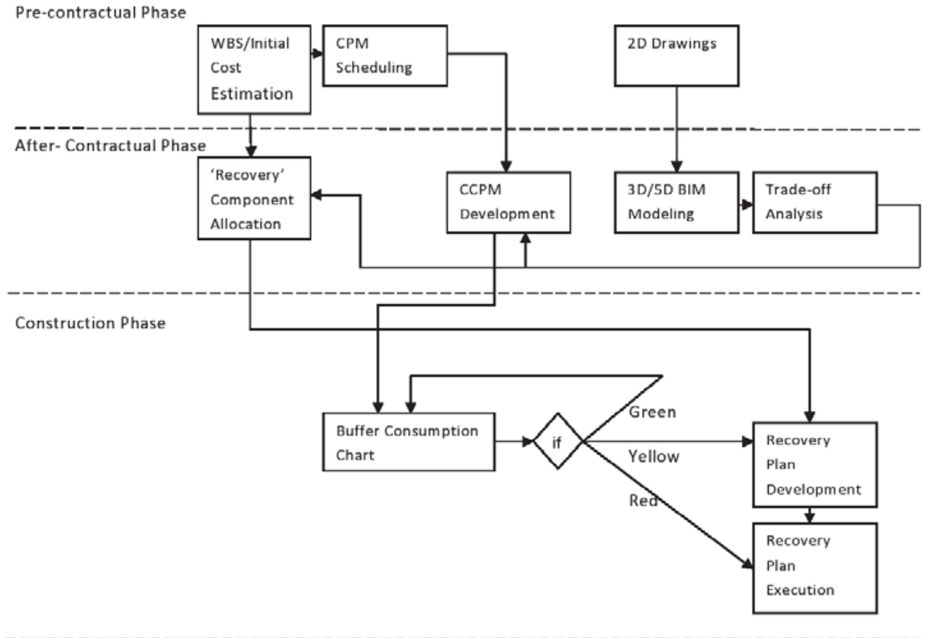

Figure 1: Proposed framework for BIM-CCPM implementation

3.2 WBS and CPM Schedule Development

In the pre-contractual phase, the Work Breakdown Structure is developed for the project and used as a scheduling and budgeting instrument for the bidding process. All elements needed for the execution of the project are clearly defined and estimated costs per activity are set. The initial CPM schedule is considered as starting point for the CCPM baseline schedule and contains the logical sequence of project activities, the initial activity duration estimates, the milestones (if any), and the project completion date, all being essential information for the development of the CCPM baseline schedule.

3.3 BIM Model Employment

A 3D BIM model of the project is developed taking as a point of departure the 2D drawings provided by the owner during the pre-contractual stage and developed in CAD form. These drawings are used to perform a manual quantity take-off that served as basis for the development of the initial budget and schedule for the bidding process. The 3D BIM model should count with enough level of development to provide accurate quantity take-off.

The previous model is upgraded to a 5D BIM environment and used to create the take-off items based on the assembly code and family type previously defined in the 3D BIM. Each construction activity is assigned with a unique task ID which is linked with components in BIM. Since a single task may involve a number of components, the one-to-many relationship is generated and the cost can be calculated based on the attributes and parameters of each component in BIM (Figure 2). One of the advantages of using this model-based approach is that these costs will be automatically updated every time the model is modified.

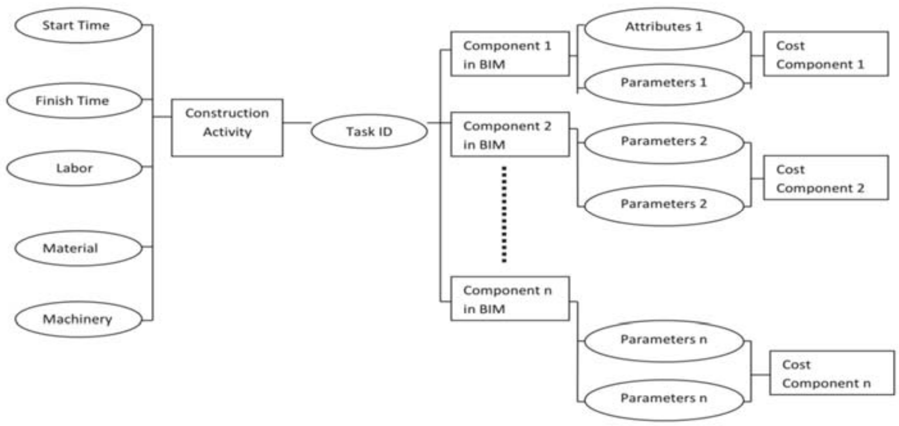

Figure 2: BIM-based activity cost components

3.4 'Cost Recovery' Component

Cost reduction is one of the most important benefits of BIM, validated by a number of case studies. For example, data of 10 construction projects indicate that BIM has secured direct savings reaching 10% of the project cost (Azhar et al. 2008) while BSI (2010) reports project cost reduction of 9.8%. Based on such outcomes, a general contractor can expect that, by using BIM, several alternatives for the execution of an activity can be modelled in order to select the one that provides a balanced and efficient resource use and, thus, reduced cost of execution. Once the costs are allocated to each of the activities from the 5D BIM model (Figure 2), based on the selected alternative, the difference between this cost and the initially assigned cost is calculated and the amount available is considered as the 'Cost Recovery' component. Considering an activity i for analysis, the 'Cost Recovery' component RC_i is the maximum monetary amount that will be available for expediting work in activity i if deviations from the buffer management scheme appear during the construction phase. This is calculated by the difference between the initial cost estimate for the activity (IE_i) and the cost allocated by the BIM analysis (CA_i) as follows (Figure 3):

$$RC_i = IE_i - CA_i \#(1)$$

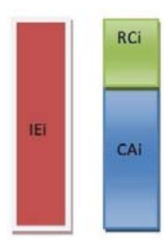

Figure 3: Cost Recovery component

Based on the concept of CCPM and focusing on critical activities, the 'cost recovery' component should be directed to activities identified as critical for the timely execution of the project, including activities that precede and might hold back the execution of critical activities (i.e. activities included in feeding chains).

3.5 CCPM schedule development

A CCPM schedule is developed (based on the CPM) according to the following steps (Goldratt 1997):

1. Reduce activity durations in the schedule

Activity duration is reduced based on the time-cost trade-off analysis.

2. Resolve resource contentions

This part does not apply here following the assumption that subcontracting will be done to different companies (each one levelling its own resources) and the execution of work packages within each subcontractor will lead to one activity at a time schedule.

3. Schedule activities to start as late as possible

Activities should be scheduled with a finish-to-start relationship and start as late as possible to eliminate lags. Subcontractors should be committed under contractual terms to start earlier, as long as they are warned in advance, when the predecessors are about to finish, so the effort for duration reduction is not wasted.

4. Identify the critical chain

As defined by the critical chain methodology, the critical chain is the longest chain of dependent activities after the usability of resources has been considered and the activity durations have been reduced. The duration of this set of activities will define the expected reduced duration of the project.

5. Insert project and feeding buffers

The time gain resulting from activity duration reduction is set as project buffer (at the end of the critical chain to safeguard the project completion date) and as feeding buffers (used to non-critical activities to protect the critical chain from delays that might occur from activities of the feeding chains).

The output of the CCPM methodology is an aggressive (reduced duration) schedule which enables the general contractor to make better use of resources and contingencies and, at the same time, provide the chance for higher profit taking. This information must be known only by the general contractor, since knowledge of the safe estimates from the subcontractors might induce them to lower their productivity.

3.6 Buffer Management

3.6.1 Project Monitoring

Monitoring is a key element of the critical chain method. Although estimates may not be perfect and activity durations in this aggregated CCPM schedule may vary as construction progresses, instead of trying to finish every task 'on time', the buffers created during the planning phase are monitored. CCPM software (e.g., Asta Powerproject or Prochain) allows plotting of the buffer consumption. A buffer chart displays the buffer status in time (Figure 4). It is divided in three zones, green, yellow and red representing the various levels of buffer consumption. The actual placement and slope of the threshold lines, which distinguish between buffer zones, depend on how the buffer is considered according to the specific project characteristics.

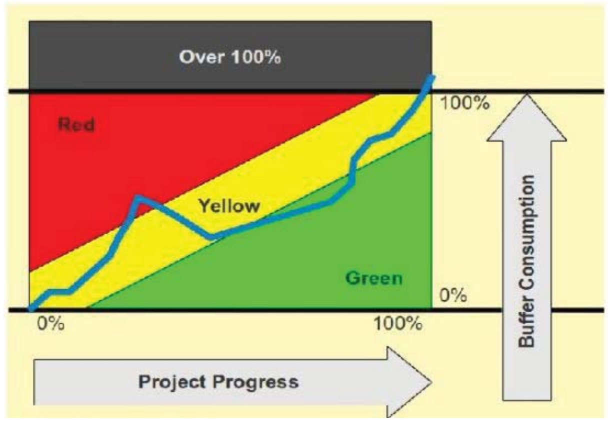

Figure 4: Buffer chart showing buffer status in time (http://chronologist.com)

- If the buffer consumption rate is low (within the green area), the project is progressing well.
- If the rate of consumption is such that most likely little or no buffer will be available at the end of the project (yellow area), buffer recovery plans need to be examined.
- If the buffer consumption rate exceeds some critical value (consumption is within the red area), alternative plans need to implemented.

Managers can identify which tasks result in high buffer burn rates and focus on these tasks at any particular instant.

3.6.2 Project Recovery

The main contractor, based on buffer consumption monitoring, can accelerate activities presenting high buffer burn rate by providing incentives to sub-contractors to increase the number of work hours or shifts, hire additional resources (crews/machinery), assign additional supervisory personnel, etc. The 'cost recovery' component for each activity derived from the 5D cost allocation model can be used to cover the additional cost for taking these corrective actions to accelerate the delayed activity. The proportion of the 'cost recovery' component RC_i to be used results from the 5D BIM model as a trade-off which compares loses and gains between cost and duration for specific corrective actions towards the timely execution of the project (Figure 5).

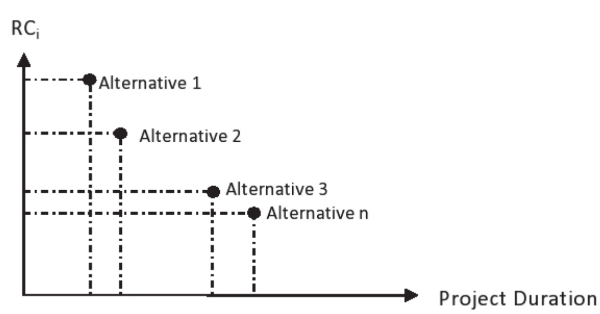

Figure 5: Trade-off between 'Cost Recovery' consumption and project duration

If the buffer consumption is within the yellow area, the general contractor can develop and choose among a number of alternatives as a correction plan to protect the project from delays. If the buffer consumption moves to the red area, the chosen alternatives should be immediately implemented. In general, the trade-off between the project completion time and the cost of recovery actions results in an efficient project control method on the basis of buffer management for dynamically evaluating and recovering project activities in a cost-effective manner. Figure 6 provides a view of how the contractor acts according to the buffer consumption rate and based on the BIM-based cost/duration trade-off.

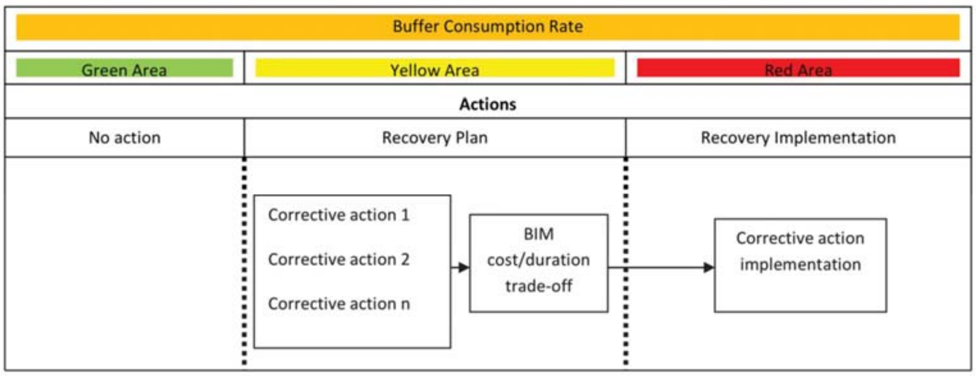

Figure 6: Corrective actions flowchart

4 Conclusions

This research gives valuable early evidence on the applicability and usefulness of BIM as a support tool for the implementation of Critical Chain Project Management into construction projects. By introducing the use of BIM models, not just as visualization tools but primarily as project control and buffer management instruments within the context of CCPM principles, this framework is expected to improve the way general contractors manage uncertainty during the planning phase and control work deviations during the construction phase, increasing thus the chances for successful project completion, improving profits, and receiving more contracts. The result verification of the proposed framework through actual case studies is the step forward of this research. In another direction, lean construction principles, which emphasize on waste elimination by reducing non-value adding activities and managing hidden flows to improve the reliability of planning and production control, may be considered as part of the implementation process. In particular, with BIM-based CCPM implementation at relatively higher level to set up aggressive goals on task durations and deliveries of prerequisites, lean construction principles can be applied at low level to minimize the impact of flow uncertainties, providing thus a balance between aggressiveness (critical chain) and reliability (lean).

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