TIME PERFORMANCE UPGRADE BY CRITICAL CHAIN PROJECT MANAGEMENT AND BIM 4D INTEGRATION ON TOP STRUCTURAL WORK OF A HIGH RISE BUILDING CONSTRUCTION PROJECT

by Albert Eddy Husin

VOL. 14, NO. 17, SEPTEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

TIME PERFORMANCE UPGRADE BY CRITICAL CHAIN PROJECT MANAGEMENT AND BIM 4D INTEGRATION ON TOP STRUCTURAL WORK OF A HIGH RISE BUILDING CONSTRUCTION PROJECT

Albert Eddy Husin
Master Program of Civil Engineering, Mercu Buana University, Jakarta, Indonesia
E-Mail: albert_eddy@mercubuana.ac.id

ABSTRACT

Upper structure work has a contribution of 21% of the total weight of the project work of a high-rise building construction project. Nearly 70% of high-rise building projects experience delays. Therefore, to overcome this, the application of Critical Chain Project Management and Building Information Modeling (BIM) 4D is the choice of researchers in this study. Critical chain project management improves the construction project scheduling by aggregating uncertainty into buffers at the end of activity paths. BIM 4D simulations are more effective than traditional planning in terms of visualization and scheduling control. The purpose of this study is to improve time performance and effective visualization of the construction schedule. The results of the case study obtained time efficiency of 19% so that the project completion time was faster from the original schedule.

Keywords: efficiency, critical chain, BIM 4D, upper structure, high-rise building.

1. INTRODUCTION

The improvement of the construction industry in the private sector and the accelerated development program proclaimed by the Indonesian government have caused the trend of increasing the value of the construction sector from year to year so that the Indonesian construction market becomes the largest in Asia after China [1]. With this huge investment potential, the capital owners demand construction products be more efficient and effective both in terms of time, cost and quality. Construction completion time is the most dominant factor for determining key performance indicators for the success of a building construction project [2]. Therefore, the completion of the project on time is part of efforts to improve efficiency in construction projects.

Delay is a major problem that often occurs in construction projects in various parts of the world. According to the survey of The Chartered Institute of Building (2009), only 33% of projects were completed on time or faster and 67% were late from the schedule. In Indonesia, only 47% of projects are completed on schedule, 15% are completed ahead of schedule, and 38% are late from schedule [3].

To anticipate delays, project acceleration is carried out by doing a compression schedule by the contractor at the planning stage (pre-construction phase) which aims to get an optimal schedule so that the project completion time is faster. In this case, the project is a high-rise building with a classification determined by the performance schedule from the contractor's side which means that the time schedule that must be optimized by the contractor must be higher than 4% [4]. Classification of construction project scheduling performance is shown in Table-1.

Table-1. Classification of Project Schedule Performance Caption [4].

Schedule performance as measured against estimated construction duration	Classification	Class value
Early completion > 4%	Good	2
Early completion 0 - 4%	Slightly good	1
Delay ≤ 8%	Average	0
Delay 8 - 16%	Slightly bad	-1
Delay > 16%	Bad	-2

In general, high-rise building projects consist of five work packages: lower structure, upper structure, architecture (interior and façade), MEP and Preliminary [5]. Upper structure work is an element of activity that has the greatest weight with a percentage value of 21% of the total work weight in the construction of high-rise buildings as shown in Figure-1.

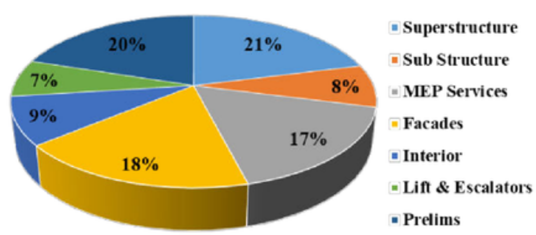

Figure-1. The weight of the high-rise building project work.

The traditional CPM technique faces a number of problems such as bad multitasking, Parkinson's Law,

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

student's syndrome and deliberate padding [6]. The problem that often occurred on the use of construction service is concerning its project management, which if described thoroughly are the construction project's resource allocations [7]. The Theory of Constraints approach focuses on completing timely work on the overall project by improving performance [8]. Critical Chain based on methods derived from the Theory of Constraints by developing the concept of Critical Path to consider resource constraints. Critical Chain based on the method derived from the Theory of Constraints and the proximity of the Theory of Constraints is to set the buffer to optimize project performance by using existing resource capacity [9]. BIM 4D simulations are more effective than traditional planning in terms of visualization and scheduling controls [10]. According to the survey of McGraw Hill Construction [11], Building Information Modeling can reduce the overall project duration by 19%. Furthermore, 4D modeling (3 dimensions plus time) provides effective visualization and communication tools and provides project teams (including owners and contractors) a better understanding of the stages of activities and construction plans [12]. Thus, this study aims to develop construction scheduling to improve time performance and effective visualization of the construction schedule so that the project completion time is faster than the original schedule.

2. METHODS

To achieve the research objectives, a detailed case study was carried out on multi-story building projects in Jakarta. Basic project data such as master schedule, building size, bill of quantity, detailed building specifications, construction techniques are collected. Figure-2 shows the flow of the overall research framework consisting of the following steps:

a) Analysis project data such as master schedule, activity duration, and the relationship between activities.

b) Calculate duration using Critical Chain Project Management to obtain the optimal duration

c) Create 3D modeling of the top structural elements of a high rise building for visualization work sequence.

d) Integrate 4D model and CCPM using BIM 4D simulation to obtain optimal scheduling.

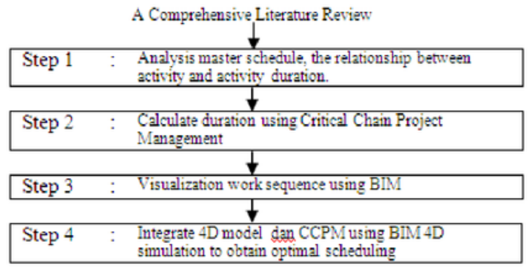

Figure-2. The flow of the overall research framework.

2.1 Critical chain project management

Critical Chain Project Management is the direct application of the Theory of Constraints developed [8]. Critical Chain Project Management is defined as the longest chain of interrelated events, where the interrelationships lie in interconnected work or resources [13]. The requirements in this Critical Chain Project Management method are the absence of multitasking, Student's Syndrome, Parkinson's law, As late as possible, removing hidden safety and moving it in the form of a buffer behind the project [14]. To determine the project buffer and feeding buffer in the Cut & Paste method basically cuts 50% of the duration for all activities, and to attach the project buffer to half the duration of the critical chain at the end of the chain.

There are nine approaches in using critical chain project management that distinguishes from other scheduling methods [15]: Estimating, Buffer, Students syndrome & Parkinson's Law, Bad multitasking, as late as possible scheduling, Relay race approach, Buffer management, dan resource allocation.

2.2 Building information modeling (BIM) 4D

BIM application in construction projects provides benefits such as improving communication between parties involved in construction projects and facilitating faster design decisions [16]. BIM is a system, management, method or sequence of work on a project that is applied based on relevant information from all aspects of the building is managed and then projected into a 3-dimensional model [17]. Furthermore, [18] concluded that the 4D model is a useful alternative for project scheduling such as CPM networks and bar charts. BIM 4D allows users to quickly understand scheduling and identify potential problems. In addition, [19] concluded that project planning with a combination of location-based scheduling and 4D BIM can improve the planning process in the analysis of workflow. Visualization of the planning process by carrying out 4D modeling that connects the 3D model with Bar Chart scheduling so as to achieve efficiency and accuracy in the planning and scheduling processes as shown in Figure-3.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

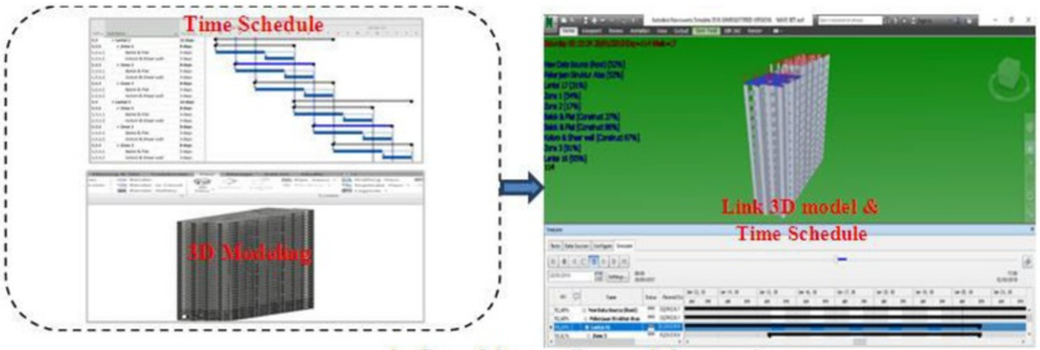

Figure-3. The flow of the overall research framework.

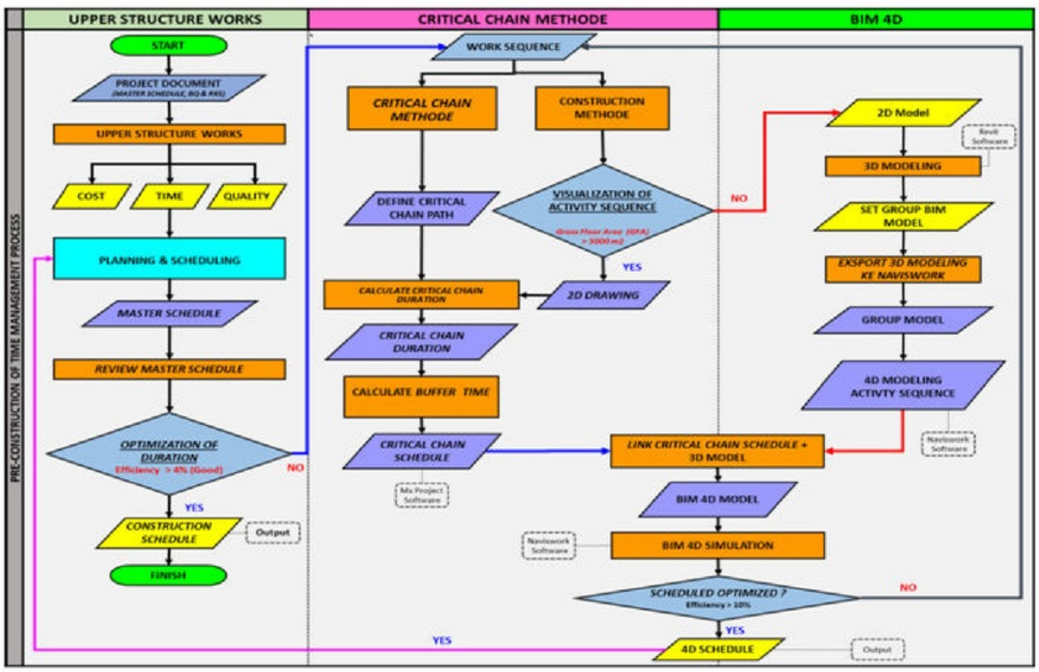

Figure-4. Implementation of CCPM and BIM 4D on Upper Structure Work.

3. RESULTS AND DISCUSSIONS

3.1 Critical chain project management and BIM 4D project validation

The integration of Critical Chain Project Management and BIM 4D to the upper structural work as the object of the research could be observed in Figure-4. If you are using Word, use either the Microsoft Equation Editor or the Math Type add-on (http://www.mathtype.com) for equations in your paper (Insert | Object | Create New | Microsoft Equation or Math Type Equation). "Float over text" should not be selected.

3.2 Critical chain project management

In this study, the duration was optimized using Critical Chain Project Management on structural work on high-rise residential building projects located in West Jakarta. Critical Chain scheduling analysis process as follows:

A. Structural work consists of formwork, rebar work, concrete work and are divided into horizontal/vertical as shown in Figure-5.

VOL. 14, NO. 17, SEPTEMBER 2019 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

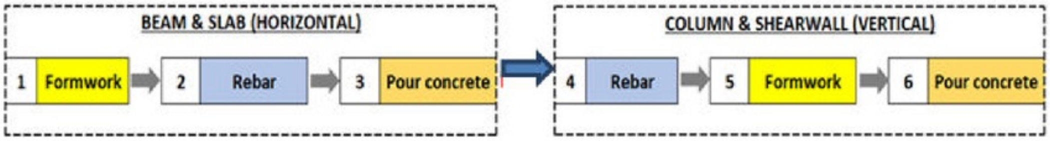

Figure-5. Work sequence of upper structure work.

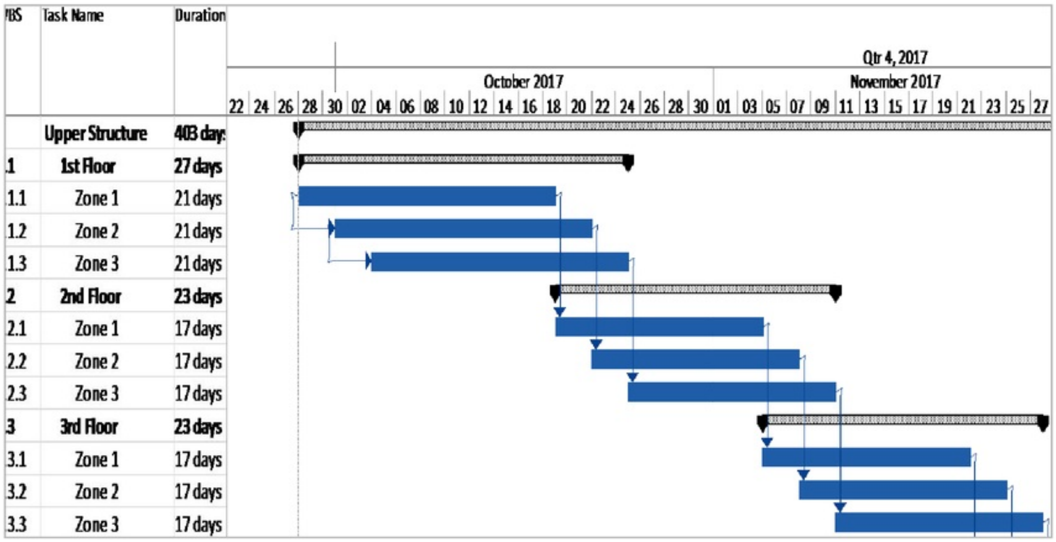

Figure-6. Gantt chart for original schedule.

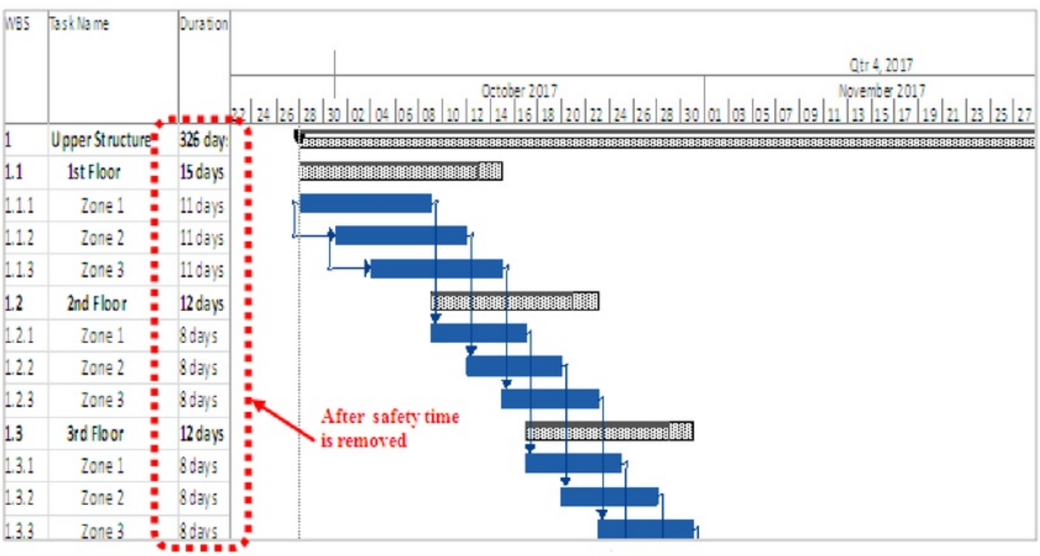

Figure-7. Gantt chart for CCPM using cut & paste method.

B. Determine the duration of the critical chain by eliminating the safety time using 50% probability of execution time are shown in Figures 6 and 7. Furthermore, identify critical network is a network that has the longest work execution time of the incident interdependence.

Calculate project buffer using cut and paste method that is 50% of the total time of project

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

implementation on the work in the critical chain. The results of the calculation of the critical chain scheduling are shown in Table-2.

Table-2. Calculation of Critical Chain

No	Activity	Original Schedule (days)	Critical Chain Estimation (days)	Project Buffer (days/ floor)	Critical Chain Schedule (days/floor)	Efficiency (%)
1.1	1ST Floor	27	15			
1.1.1	Zone 1	21	11			
1.1.2	Zone 2	21	11	6	17	-
1.1.3	Zone 3	21	11			
1.2	2nd Floor & 3rd Floor (Typical)	23	12			
1.2.1	Zone 1	17	8			
1.2.2	Zone 2	17	8	4	12	-
1.2.3	Zone 3	17	8			
1.3	4th Floor s/d 6th Floor (Typical)	21	12			
1.3.1	Zone 1	15	8			
1.3.2	Zone 2	15	8	4	12	-
1.3.3	Zone 3	15	8			
1.4	7th Floor s/d 32nd Floor (Typical)	17	10			
1.4.1	Zone 1	11	6			
1.4.2	Zone 2	11	6	3	9	-
1.4.3	Zone 3	11	6			
	TOTAL	403	217	109	326	19

C. Calculate duration of activity with a quantity based on the bill of quantity and the production capacity obtained the amount of duration shown in Table-3. Furthermore, to develop a schedule using the critical chain project management method, the dependency a relationship between activities is only done by the relationship of finish to start as shown in Figure-8. Based on the scheduling using Critical chain project management, the duration of the upper structure is 77days faster than the original duration. Furthermore, to protect activities are in the critical chain can be done by entering a project buffer at the end of the critical chain as shown in Figure-9.

Table-3. Detail activity duration and resource calculation.

No	Activity	Duration (days)	Number of Resources	Resources need	Resources available (Max.)
1	Formwork				
	Beam & Slab	2	65	**100**	**110**
	Column & Shearwall	1	35		
2	Rebar				
	Beam & Slab	2	35	**65**	**80**
	Column & Shearwall	2	30		
3	Pour concrete				
	Beam & Slab	1	20	**30**	**45**
	Column & Shearwall	1	10		

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

3.3 Scheduling based on BIM 4D

2D visualization on typical work that is placed overlapping so that the possibility of conflict and not accuracy in the activity stage planning process and Bar Chart scheduling. Therefore, 4D modeling that connects 3D models with Bar Chart schedule to overcome the constraints of visualizing the planning process so that achieved efficiency and accuracy in the planning and scheduling process.

The stages of BIM 4D modeling using the Revit 2016 and Naviswork 2016 applications are 2D Drawing, 3D modeling structure elements, 3D modeling exports, grouping models, connecting time schedules with 3D modeling, scheduling simulations using Naviswork 2016. BIM 4D modeling process as shown in Figure-10.

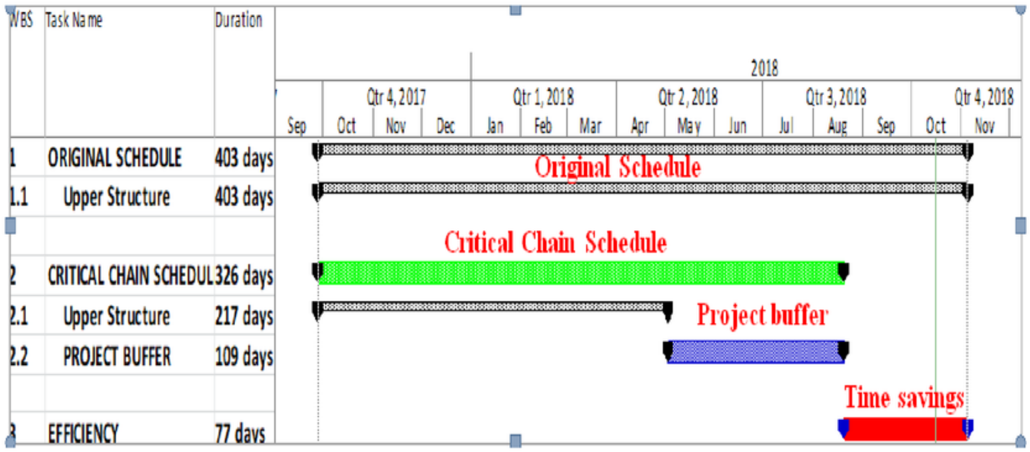

Figure-8. Gantt chart for detail activity duration.

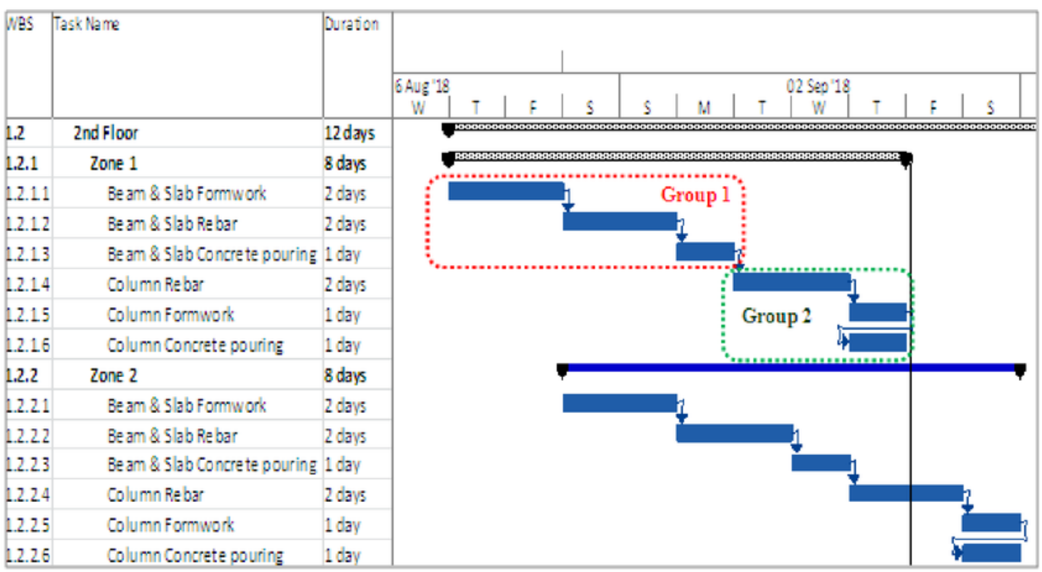

Figure-9. Gantt chart for Critical Chain Schedule vs Original schedule.

3.4 Simulation critical chain project management and BIM 4D

Simulation and Visualization of BIM 4D show the progress of implementation with progress every month (1st to 8th month). Above the left side of the simulation is listed the date, the sequence of ongoing activities, the percentage of work progress and the duration of implementation as shown in Figure-11.

3.5. Evaluation result

Based on the final results of the development of the schedule using the critical chain method of the

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

resulting schedule faster project execution time. In addition, a solution to overcome the constraints of visualization of the planning process by conducting 4D modeling that connects 3D models with Bar Chart scheduling so as to achieve efficiency and accuracy in the planning and scheduling process. Improved planning and scheduling performance can be seen in Figure-12.

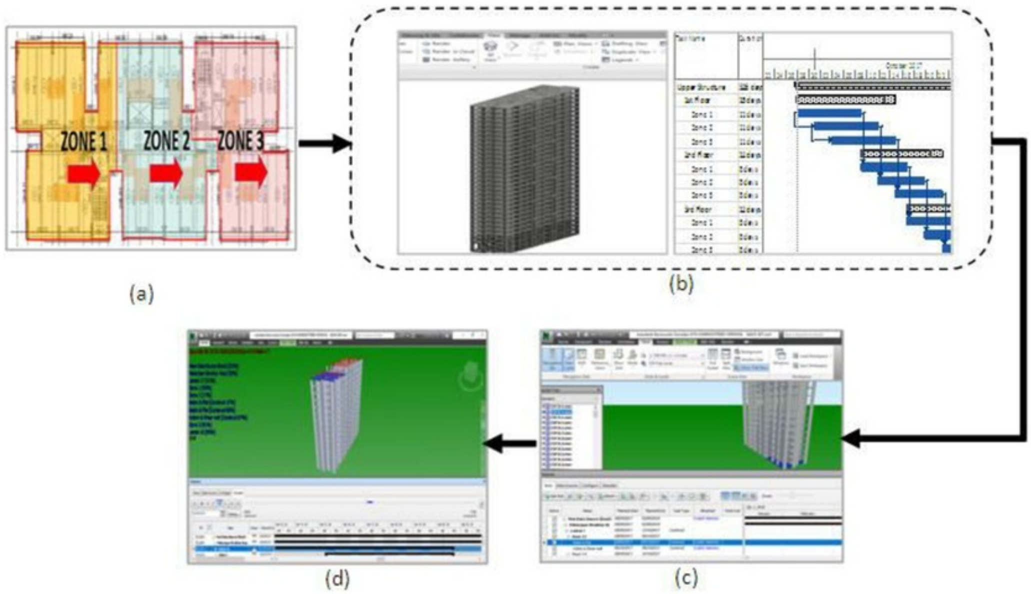

Figure-10. BIM 4D process: (a) 2D Drawing; (b) Link time schedules with 3D modeling; (c) Visualization work sequence; (d) Scheduling simulations

BIM is an emerging technology in the architecture, engineering, construction, and facility management (AEC/FM) industry. Its application covers the whole spectrum of a project's lifecycle from the conceptual stage to pre-project planning, engineering, construction, operation and maintenance, and decommissioning stage [19]. With 4D modeling provides more effective visualization that is not possible through traditional methods such as using 2D images and Bar Chart scheduling.

In the project case study in this research, 2D visualization of the typical work placed overlapped, including the typical structural work of the tower before the beam and floor structure work in zone 1 was 100% completed, beam work and floor in zone 2 had already been must begin. Thus the method is carried out on the next floor work, so the possibility of conflict and not accuracy in the planning process stages of activities and scheduling Bar Chart.

To overcome the constraints of the visualization of the planning process by performing 4D modeling that connects the 3D model with Bar Chart scheduling so that efficiency and accuracy are achieved in the planning and scheduling process.

The simulation and visualization of 4D BIM shows the rigorous implementation of progress every month (1^{st} month to 8^{th} month). Above the left side of the simulation are the dates, the order of money activities in progress, the percentage of progress of the work and the duration of the work.

The next step is to make sure the work is completed on time, so it is necessary to put a buffer of resources on the work that is a priority scale, namely work that can affect the project implementation time globally (critical chain). But in this analysis, the resources used in planning the scheduling with the CCPM method follow the availability of resources in the project.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Figure-11. Simulation Critical Chain Project Management and BIM 4D.

ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

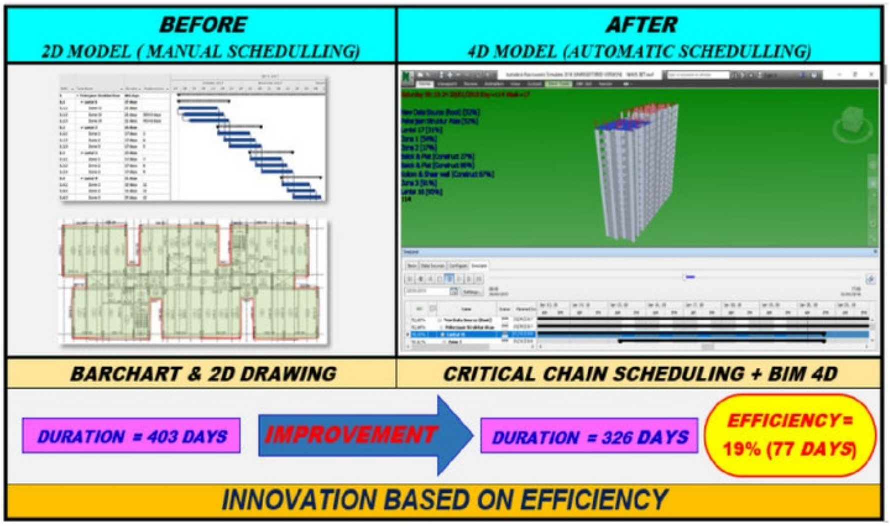

Figure-12. Improvement Planning and Schedule.

4. CONCLUSIONS

This study illustrates the implementation of Critical Chain Project Management and BIM 4D can be well applied in construction projects to achieve shorter project duration without driving up costs. Implementation of critical chain project management in project scheduling will increase effectiveness, especially in the construction plan phase. In addition, removing the safety time of individual activities can eliminate the main causes of time waste and reduce the impact of constraints. Furthermore, BIM 4D simulations are more effective than traditional planning in terms of visualization and scheduling controls. Developing 4D model classifies activities from the initial schedule, creates 3D models from 2D models, and creates links between activities with 3D model components in 4D simulation applications. Innovation in scheduling methods through Critical Chain Project Management and BIM 4D-based digital construction technology can produce a more accurate and efficient time schedule so that it can improve the time performance of structural work on high-rise buildings. According to the results of the case study obtained optimum duration with a faster completion time of 403 working days to 326 working days of implementation so that the time efficiency of 19% was obtained.

REFERENCES

[1] Trigunarsyah B. 2004. Constructability practices among construction contractors in Indonesia. Journal of Construction Engineering and Management, 130(5): 656–669. https://doi.org/10.1061/(ASCE)0733-9364(2004)130:5(656)

[2] Kog Y. C., Chua D. K. H., Loh P. K. & Jaselskis E. J. 1999. Key determinants for construction schedule performance. International Journal of Project Management. 17(6): 351-359. https://doi.org/10.1016/S0263-7863(98)00058-1

[3] Watts S. & Langdon D. 2010. The Economics of High-rise (as per 2nd Quarter 2010). CTBUH Journal 2010 Issue III - Tall Buildings in Numbers, (III), 44-45. Retrieved from http://www.ctbuh.org/LinkClick.aspx?fileticket=rJbb7oNXnZw=&tabid=1108&language=en-GB

[4] Steyn H. 2002. Project management applications of the theory of constraints beyond critical chain scheduling. International Journal of Project Management. 20(1): 75-80. https://doi.org/10.1016/S0263-7863(00)00054-5

[5] Goldratt E. M. 1990. Theory of Constraints. New York: North River Press.

[6] Chua D. K. H. & Shen L. J. 2005. Key Constraints Analysis with Integrated Production Scheduler. Journal of Construction Engineering and Management. 131(7): 753-764. https://doi.org/10.1061/(ASCE)0733-9364(2005)131:7(753)

[7] Husin A. E., Priyanto D. 2018. Lean Construction Based Tower Crane Requirement Optimization in High Rise Building Construction Project.

International Journal of Scientific Research Engineering &Technology (IJSRET). 7(10): 738-743.

[8] Candelario-Garrido A., García-Sanz-Calcedo J. & Reyes Rodríguez A. M. 2017. A quantitative analysis of the feasibility of 4D Planning Graphic Systems versus Conventional Systems in building projects. Sustainable Cities and Society. 35(February): 378-384. https://doi.org/10.1016/j.scs.2017.08.024

[9] McGraw Hill Construction. 2014. The business value of BIM for construction in major global markets. Smart Market Report. https://doi.org/b

[10] Benjaoran V. & Bhokha S. 2009. Enhancing visualization of 4D CAD model compared to conventional methods. Engineering, Construction and Architectural Management. 16(4): 392-408. https://doi.org/10.1108/09699980910970860

[11] Kerzner H. 2006. Project Management: A Systems Approach to Planning, Scheduling, and Controlling (Ninth Edit). Canada: John Wiley & Sond.

[12] Leach L. P. 2000. Critical Chain Project Management Critical Chain Project Management. Artech House, 337. https://doi.org/10.1201/9780203912508.ch15

[13] Dachyar M. & Saputra U. D. 2009. Comparison between Critical Chain and Critical Path Method in Telecommunication Tower Construction Project Management. Proceeding of the 11th International Conference on QiR (Quality in Research) Faculty of Engineering, University of Indonesia, Depok, Indonesia, 3-6 August, (August), 1-6.

[14] Cho H., Lee K. H., Lee S. H., Lee T., Cho H. J., Kim S. H. & Nam S. H. 2011. Introduction of construction management integrated system using BIM in the Honam high-speed railway lot no. 4-2. Proceedings of the 28th International Symposium on Automation and Robotics in Construction, ISARC 2011, (4): 1300-1305.http://www.scopus.com/inward/record.url?eid=2-s2.0-84863768365&partnerID=tZOtx3y1

[15] Wong A. K. D., Wong F. K. W. & Nadeem A. 2010. Attributes of building information modeling implementations in various countries. Architectural Engineering and Design Management, 6(SPECIAL ISSUE): 288-302. https://doi.org/10.3763/aedm.2010.IDDS6

[16] Davalos B. J. F., Member A., Zipfel M. G. & Qiao P. 1999. F Easibility S Tudy of P Rototype Gfrp-R Einforced W Ood, (May): 92-99.

[17] Jongeling R. & Olofsson T. 2007. A method for planning of work-flow by combined use of location-based scheduling and 4D CAD. Automation in Construction. 16(2): 189-198. https://doi.org/10.1016/j.autcon.2006.04.001

[18] Shan Y. & Goodrum P. 2014. Integration of Building Information Modeling and Critical Path Method Schedules to Simulate the Impact of Temperature and Humidity at the Project Level. Buildings. 4, 295-319; doi: 10.3390/buildings4030295.

TIME PERFORMANCE UPGRADE BY CRITICAL CHAIN PROJECT MANAGEMENT AND BIM 4D INTEGRATION ON TOP STRUCTURAL WORK OF A HIGH RISE BUILDING CONSTRUCTION PROJECT

ORIGINALITY REPORT

20%	17%	11%	%
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	www.arpnjournals.com	Internet Source	5%
2	tpea.cpss.org.cn	Internet Source	1%
3	pingpdf.com	Internet Source	1%
4	pure.ltu.se	Internet Source	1%
5	www.ppml.url.tw	Internet Source	1%
6	trepo.tuni.fi	Internet Source	1%
7	en.wikipedia.org	Internet Source	1%
8	cris.vtt.fi	Internet Source	1%

9	e-journal.uajy.ac.id Internet Source	1%
10	researchonline.ljmu.ac.uk Internet Source	<1%
11	Berk Ekici, Seckin Kutucu, I. Sevil Sariyildiz, M. Fatih Tasgetiren. "Addressing the high-rise form finding problem by evolutionary computation", 2015 IEEE Congress on Evolutionary Computation (CEC), 2015 Publication	<1%
12	Jing Yu, Zhe Xu, Chen Hu. "Buffer sizing approach in critical chain project management under multiresource constraints", 2013 6th International Conference on Information Management, Innovation Management and Industrial Engineering, 2013 Publication	<1%
13	kolegia.sgh.waw.pl Internet Source	<1%
14	nibis.ni.schule.de Internet Source	<1%
15	"Optimum Haul Road Track Selection on Open Pit Coal Mine By Fuzzy Analytical Hierarchy Process (FAHP) Implementation", International Journal of Engineering and Advanced Technology, 2019	<1%

Publication

16 map.biorf.ru
Internet Source
<1%

17 asu.pure.elsevier.com
Internet Source
<1%

18 www.lontar.ui.ac.id
Internet Source
<1%

19 users.metu.edu.tr
Internet Source
<1%

20 Bonsang Koo, Martin Fischer. "Feasibility Study of 4D CAD in Commercial Construction", Journal of Construction Engineering and Management, 2000
Publication
<1%

21 people.dyu.edu.tw
Internet Source
<1%

22 Kyonghoon Kim, Gutaek Kim, Kyunghwan Kim, Yoonsun Lee, Jaejun Kim. "Real-Time Progress Management System for Steel Structure Construction", Journal of Asian Architecture and Building Engineering, 2009
Publication
<1%

23 programme.exordo.com
Internet Source
<1%

24 Wei Wu, Glenda Mayo, Tamera L. McCuen,

	Raja R. A. Issa, Dana K. Smith. "Building Information Modeling Body of Knowledge. II: Consensus Building and Use Cases", Journal of Construction Engineering and Management, 2018 Publication	<1 %
25	www.praiseworthyprize.org Internet Source	<1 %
26	ltu.diva-portal.org Internet Source	<1 %
27	ijcsit.com Internet Source	<1 %
28	Taehoon Hong, Kyuman Cho, Changtaek Hyun, Seungwoo Han. "Simulation-Based Schedule Estimation Model for ACS-Based Core Wall Construction of High-Rise Building", Journal of Construction Engineering and Management, 2011 Publication	<1 %
29	Herman Steyn. "An investigation into the fundamentals of critical chain project scheduling", International Journal of Project Management, 2001 Publication	<1 %
30	hpcmo.hpc.mil Internet Source	<1 %

31	scholarbank.nus.edu.sg Internet Source	<1%
32	Guofeng Ma, Lingyun Gu, Nan Li. "Scenario-Based Proactive Robust Optimization for Critical-Chain Project Scheduling", Journal of Construction Engineering and Management, 2015 Publication	<1%
33	Vineet R. Kamat, Julio C. Martinez, Martin Fischer, Mani Golparvar-Fard, Feniosky Peña-Mora, Silvio Savarese. "Research in Visualization Techniques for Field Construction", Journal of Construction Engineering and Management, 2011 Publication	<1%
34	Hyun-Soo Lee, San Roh, Moon-Seo Park, Han-Guk Ryu. "Optimal option selection for finishing works of high-rise building", KSCE Journal of Civil Engineering, 2010 Publication	<1%
35	Mahmoud Sodangi, Ahmed Fouad Salman, Muhammad Saleem. "Building Information Modeling: Awareness Across the Subcontracting Sector of Saudi Arabian Construction Industry", Arabian Journal for Science and Engineering, 2017 Publication	<1%

Exclude quotes	Off	Exclude matches	Off
Exclude bibliography	Off		