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Analysis of Time Efficiency with CCPM Method and BIM in Construction Projects Construction of High-Rise Residential Building Basement

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Abstract Development in Indonesia is experiencing a rapid increase, a lot of vacant land is used by investors to construct buildings. The implementation of the construction must pay attention to the project schedule, work delays often occur. The factors that cause work delays are usually from weather disturbances, delivery and supplies of materials and tools that are not in accordance with the plan, changes in design and other external, internal factors. For this reason, this study will discuss about controlling project time using the critical chain project management (CCPM) method and 4D building information modeling in high-rise residential building projects, especially in 5-layer basement work. The critical chain project management method eliminates safe time and replaces buffer time. Adding buffer time using the cut and paste method, namely adding a project buffer half the duration of the critical chain (critical chain) at the end of the chain and placing the feeding buffer with half the activity duration to activities on the non-critical chain. Delays in the construction of a 5-layer basement usually include changes in the level of soil surface conditions, the stability of the excavated soil during the secant pile excavation period as a retaining wall as deep as -17,350 m below the ground level. The results of this study can optimize the duration of the implementation with the final completion time of the structural work faster than 432 working days to 293 work days of implementation so that the time efficiency is 32,17%.

Keywords Critical Chain Project Management, Building Information Modeling, Buffer Time, Basement, High-Rise Residential Building Project

1. Introduction

Referring to the data released by the skyscrapper Center in 2020, during the period 1960 to 2020 is an increase in the construction of buildings with a height of over 150 meters so rapidly throughout the world. The increase in high-rise residential buildings or high rise buildings according to the global competitiveness report data from 2014 - 2020 will be the largest growth country in the construction sector with an average total growth value of 6.3% so that engineers - architecture carry out and make project management engineering from the initial project phase to the project completion phase and the increasing complexity of the problems in the planning process to the management of high-rise residential buildings. Figure 1 shows the estimated growth in the construction sector:

Figure 1. Estimated Growth of the Construction Sector 3 Countries in Asia for the period 2014 - 2020[1]

During the construction period, this project must pay attention to the factors that inhibit the occurrence of delays with a high risk of special attention to keep buildings and infrastructure around the project environment from being damaged due to the cause and effect of construction implementation such as environmental damage, changes in ground level conditions and stability. The excavated soil during the excavation period is secant pile as a retaining wall as deep as - 17,350 (minus) meters below the ground level, to anticipate this delay the researchers used critical chain project management and building information modeling methods to control the project time.

This research will analyze cost efficiency, quality and time using the method of critical chain project management and BIM in the construction of high-rise building basement. This journal will reduce work delays in the field. After applying the two methods, time efficiency will be obtained which greatly saves costs and maintains quality.

1.1. Formulation of the Problem

The formulation of the research problem is

1. How to apply critical chain project management (CCPM) and building information modeling (BIM) 4D to a 5-tier basement work?
2. What is % the time optimization obtained by applying critical chain project management methods and building information modeling?
3. How many days of optimization work time is obtained by applying critical chain project management methods and building information modeling?

1.2. Research Purposes

The purpose of this research is to:

1. Implement critical chain project management (CCPM) and 4D building information modeling (BIM) methods in the 5-layer basement work.
2. Analyze the % time efficiency obtained from the application of the critical chain project management (CCPM) method and 4D building information modeling (BIM) in the 5-layer basement work.
3. Analyze the optimization of the day gained from the application of the critical chain project management (CCPM) method and 4D building information modeling (BIM) in the 5-layer basement work.

1.3. Benefits of Research

The benefits of this research are:

1. Can add knowledge about critical chain project management methods and building information modeling.
2. Can apply and apply critical chain project management methods and building information modeling to projects that experience delays from the planning time

2. Literature Review

2.1. Critical Chain Project Management

The Critical Chain Project Management (CCPM) method is introduced [2], with Theory of Constraints (TOC) being applied as a project management strategy. The Theory of Constraints (TOC) method is a competent approach to managing project risk. The approach is as follows:

1. Removing the hidden safety in the duration of the activity to protect the activity from starting too late which is called student syndrome.
2. Preventing pretense busyness by staff called Parkinson's Law.
3. Prevents late completion of activities due to murphy's law.

The result of Theory of Constraints (TOC) which cannot be done is the critical chain idea [3] and CCPM adopts a linear procedure and the calculated buffer size increases linearly with the critical chain length, which often results in too long schedules and leads to a waste of resources. [4].

2.1.1. Introduction to Critical Chains

The development of the critical chain is a method problem and cannot be ruled out [5]. There are four steps to identifying the critical chain in a project [6] that is:

1. Allocate duration.
2. Advancing the activity.
3. Break the excess allocation of resources.
4. Set the buffer in place at the end of the duration.

The difference in activity between the traditional Critical Peth Method (CPM) and Theory of Constraints (TOC) is as shown in Figure 2. below:

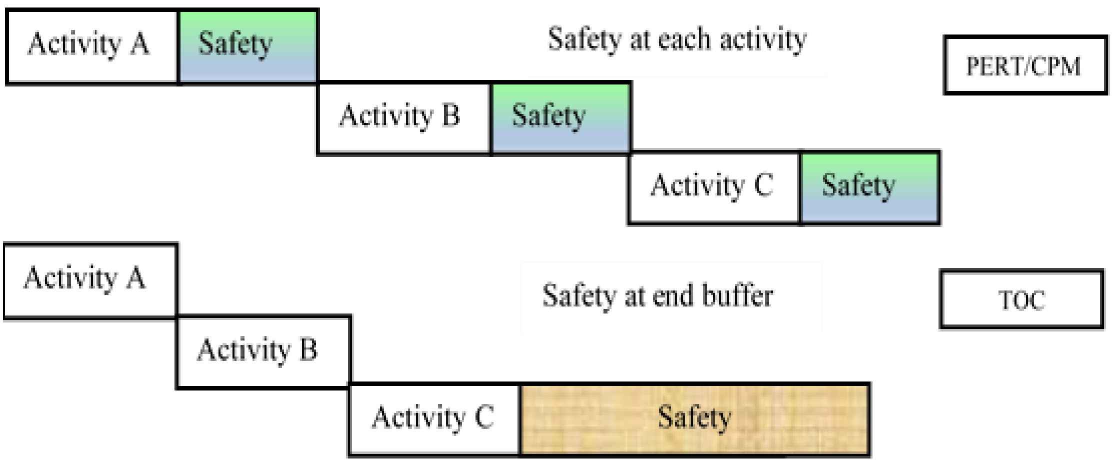

Figure 2. PERT / CPM and TOC comparison [7]

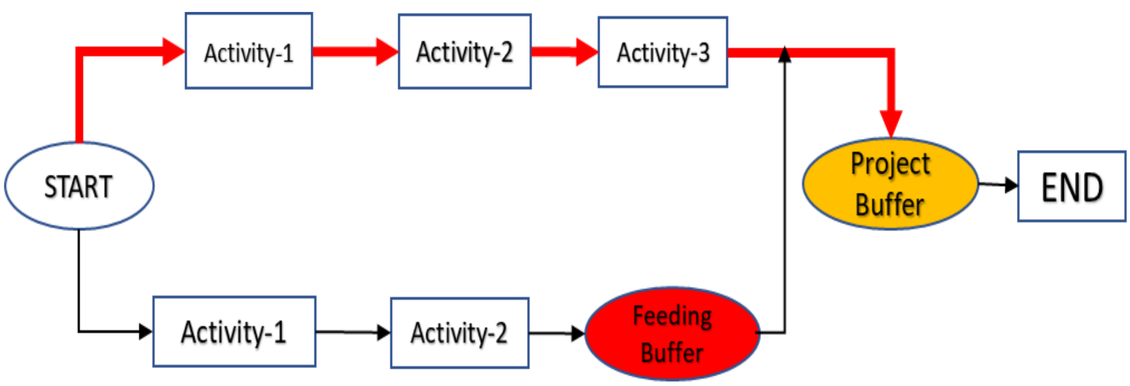

Figure 3. Project buffer and buffer feeding [11]

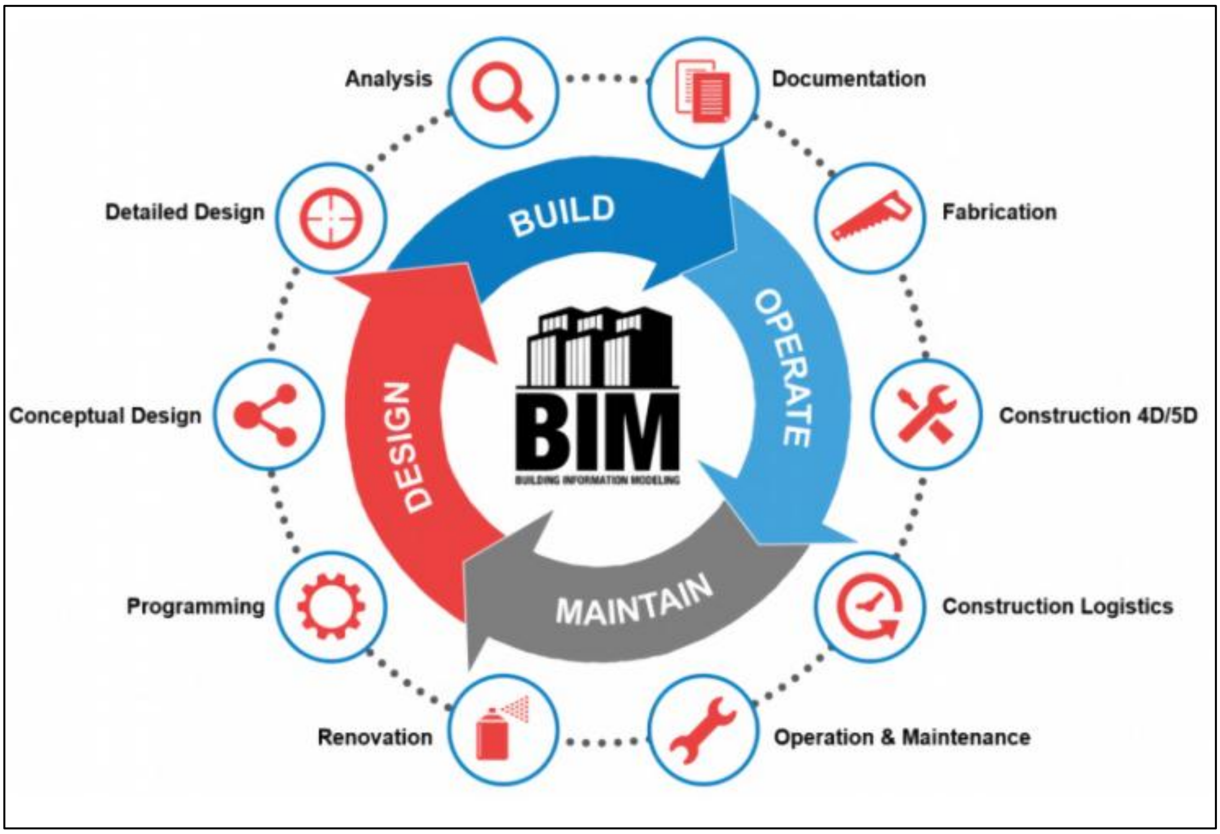

Figure 4. Rodmap Building Information Modeling (BIM) Indonesia 2017-2024

2.1.2. Project Buffer and Feeding Buffer

Manage projects by Critical Chain Project Management (CCPM) using buffer time, basically the Theory of Constraints (TOC) and provides a simple tool to monitor the project and set a realistic deadline. It is increasingly used in construction scheduling and its methods have undergone a number of refinements and existences [8]. The average task duration in the Critical Chain Project Management (CCPM) method instead of duration with safe time and between the two types of duration on each activity in the critical chain will be placed at the end of the project as a project buffer (shown in Figure 3). This buffer is used to determine the completion date. Realization Execution of the project must be in excess of one chain so the CCPM predicts a buffer to protect this chain from delays. These buffers are called feeding buffers (buffer feeding in Figure 3) and are placed where non-critical chain activity joins the critical chain. Finally, this buffer protects critical chain activity from disruption and delay of start. Buffers play a key role in CCPM [9] and finally, these buffers protect critical chain activity starting from delay interruptions [10].

Take into account any defense that may exist between the activity, because all require the same resources [12] and the square root of the sum of the squares of this difference for each activity is then used as a buffer [13] and according to [14] this advantage becomes clearer as the size of the problem increases.

2.2. Development of Building Information Modeling (BIM)

The development of Building Information Modeling (BIM) in Indonesia is marked by an initiative from the government under the Ministry of Public Works and Public Housing which has launched the Indonesian digital construction Roadmap program through the application of Building Information Modeling (BIM) technology to increase productivity in construction projects, especially projects - government projects as shown in Figure 4.

The use of Building Information Modeling (BIM) modeling in high-rise residential building engineering in conjunction with collaborative design teams is one of the most useful approaches in achieving high-quality, cost-effective design results. The purpose of Building Information Modeling (BIM) is to create virtual construction before actual physical construction and an approach to building design, management and cutting costs significantly and in terms of time. Building Information Modeling (BIM) has the implication of giving change, encouraging the exchange of virtual 3D models between different disciplines, so that the information exchange process becomes faster and affects construction implementation. Application of Building Information Modeling (BIM) will create cost and time efficiency. Project is implemented because data designers usually use a variety of design tools to complete their own design tasks with respect to the different characteristics of these disciplines. [16]. Building information modeling (BIM) is one of the most important technical and management innovations in the last two techniques in architectural, engineering, construction and operations (AECO) engineering [17] and BIM adoption rates in the US increased from 28% to 71% in five years, with general contractors representing the highest growth rates for adoption of BIM applications and [18] compares the flow of information between traditional and BIM-based projects in the building design phase, where information flows are represented using interactions among various team members.

2.2.1. Definition of Building Information Modeling (BIM)

Building Information Modeling (BIM) is a system, management, method or sequence of work on a project that is applied based on related information from all aspects of the building being managed and then projected into a 3-dimensional model. BIM is a process and information that generates a methodology for managing building design and important data from projects implemented in digital form throughout the building cycle and BIM as a sophisticated platform that will help reduce risks in construction projects, especially in eliminating common mistakes in design management. , regarding how BIM will increase productivity on construction sites, but more empirical findings are needed to know extensively how BIM can be practically used to improve quality in construction projects.

There are two common scheduling methods that can be used to create a 4D Building Information Model which are the critical path (CPM) method and the balance line. In the critical path method, each activity is listed, linked to another activity, and the duration specified.

2.3. Scheduling in Construction Planning

Scheduling is the allocation of time to carry out the completion of an activity properly and correctly will result in cost efficiency. Rework caused by design errors caused an increase of 5 - 20% of the total contract value so that if the process of scheduling activities on each relationship between activities is made in detail to assist the implementation of project evaluation.

Construction project planning includes the process of determining the project scope, formulating the structure and project hierarchy, selecting the type of construction technology and method, formulating activities, estimating the required resources and the duration for each activity and identifying the linkages between activities. [21].

2.4. Building Structural Work

High-rise building system building on the structure is the core of the robustness of the building above ground level. This structural system functions to hold and distribute horizontal and vertical force loads evenly on the core structural systems and supporting structures, so that the building can bear horizontal and vertical loads as well as lateral forces.

Several factors in the planning of a tall building structure construction system are:

1. General economic considerations
2. Soil conditions
3. The ratio of the aspect to a building
4. Fabrication and construction considerations
5. Mechanical considerations (utility system)
6. Consideration of the level of fire hazard

2.5. Methods of Carrying out Work in the Basement of High-Rise Residential Buildings

The implementation method for basement work is divided into 2 popular methods, namely:

a. The "Top-Down" method is the work of the basement structure carried out simultaneously with the basement excavation work, the sequence of finishing the beams and floor plates starts from top to bottom, and during the execution process, the structure of the plates and beams is supported by a pillar structure (king post) that is installed together. with bored pile and basement walls, first cast with a diaphragm wall system or commonly referred to as a way of building upside down.[22].

b. The BOTTOM - UP method is a structure implemented after all excavation works have finished reaching the design elevation. The bottom basement plate is cast first, then the basement is finished from bottom to top, using scaffolding and in the earth excavation system it can be open cut and the retaining wall structure can be temporary or permanent with the reinforcement of the ground anchor.

3. Research Methodology

This study is analyzed using the method of critical chain project management and BIM 4D, data processing using SPSS processed from the questionnaire experts who are skilled and never apply such methods in the implementation of the construction of high-rise buildings. Following will be described in figure 5:

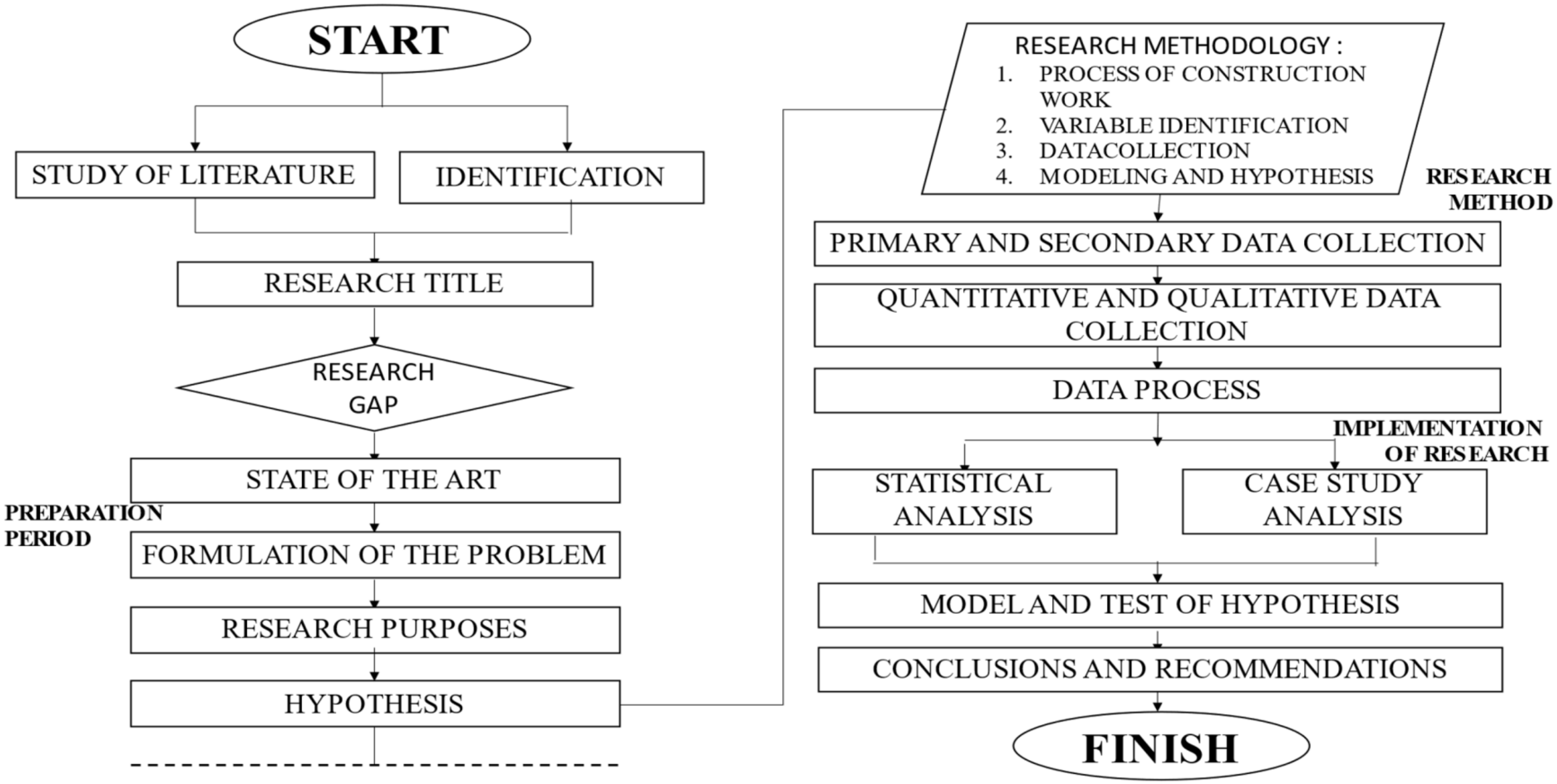

Figure 5. Research Flow

Table 1. Duration of existing 5-layer basement work

Work Item		Duration	Start	Finish
Basement Floor		432	06/03/19	28/10/20
1.1	Earth Work	160	06/03/19	28/10/20
1.1.1	Excavation & Soil Disposal	120	03/04/19	14/10/19
1.1.2	Capping Beam	90	06/03/19	08/07/19
1.1.3	Steel Strutting dan Ground Anchor	100	28/05/19	14/10/19
1.1.4	Dewatering Wall	60	03/04/19	24/06/19
1.2	Structure Work	272	15/10/19	28/10/20
1.2.1	Found-B5 Slab (Elv. 14.71)	95	15/10/19	24/02/20
	Sky Tower	40	15/10/19	09/12/19
	City Tower	30	05/11/19	16/12/19
	Podium	50	17/12/19	24/02/20
1.2.2	Basement 4 (Elv. -14.150)	95	24/10/19	04/03/20
	Sky Tower	20	24/10/19	20/11/19
	City Tower	20	14/11/19	11/12/19
	Podium	50	26/12/19	04/03/20
1.2.3	Basement 3 (Elv. -10.950)	135	21/11/19	27/05/20
	Sky Tower	20	21/11/19	18/12/19
	City Tower	20	12/12/19	08/01/20
	Podium	60	05/03/20	27/05/20
1.2.4	Basement 2 (Elv. -7.750)	165	19/12/19	05/08/20
	Sky Tower	20	19/12/19	15/01/20
	City Tower	20	09/01/20	05/02/20
	Podium	50	28/05/20	05/08/20
1.2.5	Basement 1 (Elv. -4.550)	205	16/01/20	28/10/20
	Sky Tower	20	16/01/20	12/02/20
	City Tower	20	06/02/20	04/03/20
	Podium	60	06/08/20	28/10/20

4. Results and Discussion

4.1. Duration of Work

Duration of time based on planning implementation by contractors in the basement completion stage 1 - 5 for the civil division. Earth work is 432 days for basement work 5 to basement 1 work consisting of concrete slab work and parking floor beams, ramps, brick wall beams and other buildings calculated after work started. The calculation of duration optimization will be carried out using 4D Critical Chain Project Management (CCPM) and Building Information Modeling (BIM) methods based on existing project activity data. The conditions for the actual duration of the field plan can be seen in Table 1. As well as the Bar chart schedule in Figure 6.

In Figure 6 is a project scheduling using Ms. Project.

4.2. Analysis of Critical Chain Project Management Scheduling

Determining the network diagram using the Critical method Project Chain Management (CCPM) is a dependency between related jobs, assuming that the job relationship is a constraint that will affect resources to complete the project. In the case study on this project, there were several overlapping schedules, including the basement-4 structure work was completed 100% but basement-3 work was done before basement-4 work was completed 100% so that the work for basement-2 and basement-1 had an error in the plan planning and implementation schedule so that there is an increase in resources for the overlapping work. In figure 6, there is an overlapping of the 5 layer building basement work as follows:

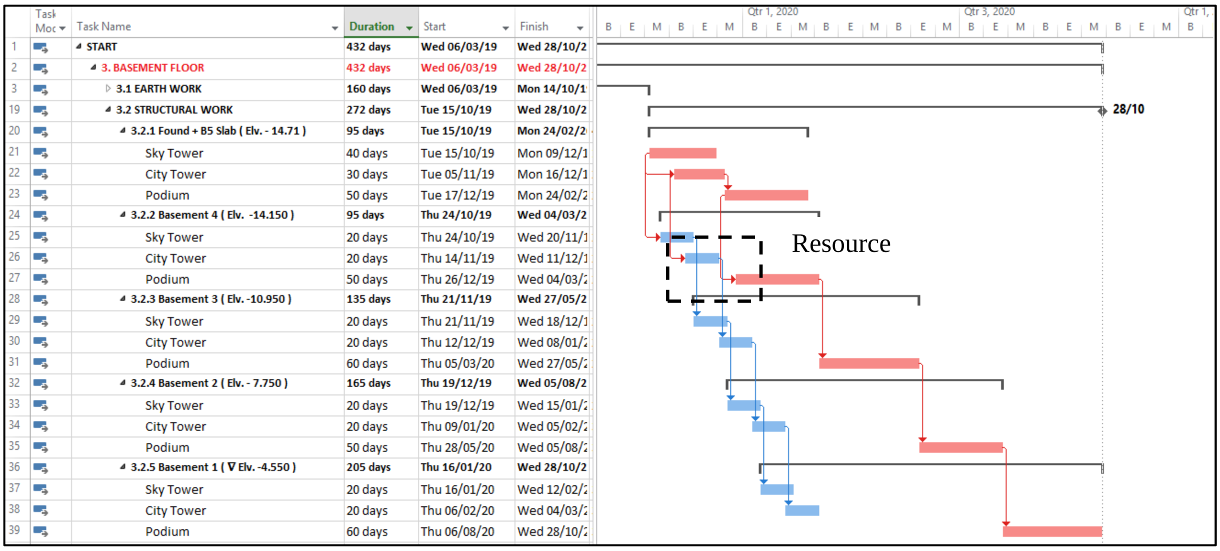

Figure 6. Overlapping work of the 5 layers of the building's basement

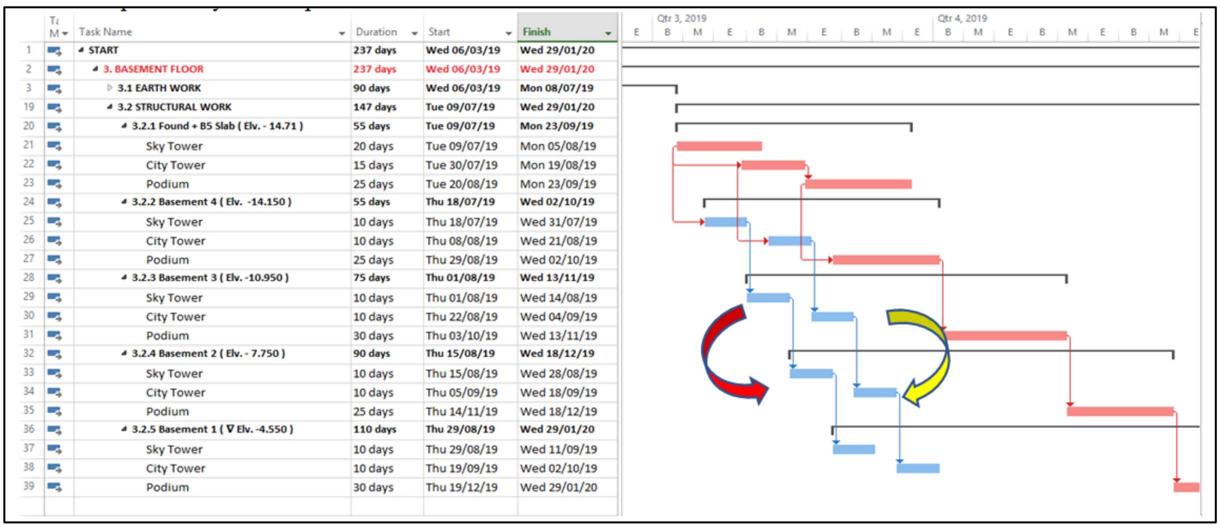

Figure 7. The work resource pool structure for basement 3 and basement 2

Dependency of the job relationship has dependency on resources on the needs of the field due to the nature of the activity itself. In the same zone, basement-3 work can be done if basement-2 work is completed 100% because the number of attachments to work items is very high and is called a critical path / activity. Implementing the schedule for the use of the Critical Chain Project Management (CCPM) method, the dependency relationship between work is carried out with the Finish to Start relationship and steps to eliminate hidden safety are crashing of 50% probability of implementation time for each completion of work for each structural work basement 5 layers of building buildings.

The explanation of the picture below is a bar diagram that explains the main work and sub-work divisions consisting of earthworks, strutting works, ground anchors, basement-5, basement-4, basement-3, basement-2 and basement-1. Basement-4 work can be completed, which initially can be completed Basement 3 in a duration of 20 days after the 50% probability of work is done, the duration of the basement-3 work becomes 10 calendar days. This can be seen in Figure 7.

Figure 7 explains the conflict that in red is the team that will work on the basement-3 and basement-2 work. In this condition, it is explained that the red arrows carry out work on the sky tower and the yellow city.

Applying the theory of Critical Chain Project Management (CCPM) by taking a 50% probability at each step of completion of the work by identifying the limited capacity of manpower, equipment and material resources during the project implementation period. A typical concept such as a 5-layer basement building can be done in groups with Finish To Start. An overview of work linkages and conflict problems in the use of resources from the resource pool is shown in Figure 8.

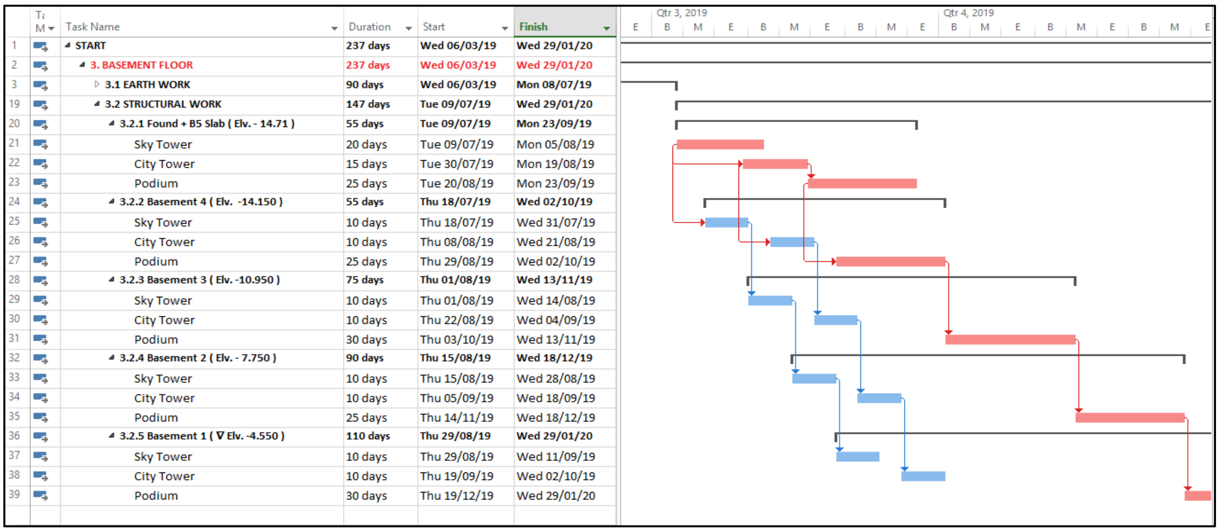

Figure 8. Conflict of basement work resources for 5 layers of building

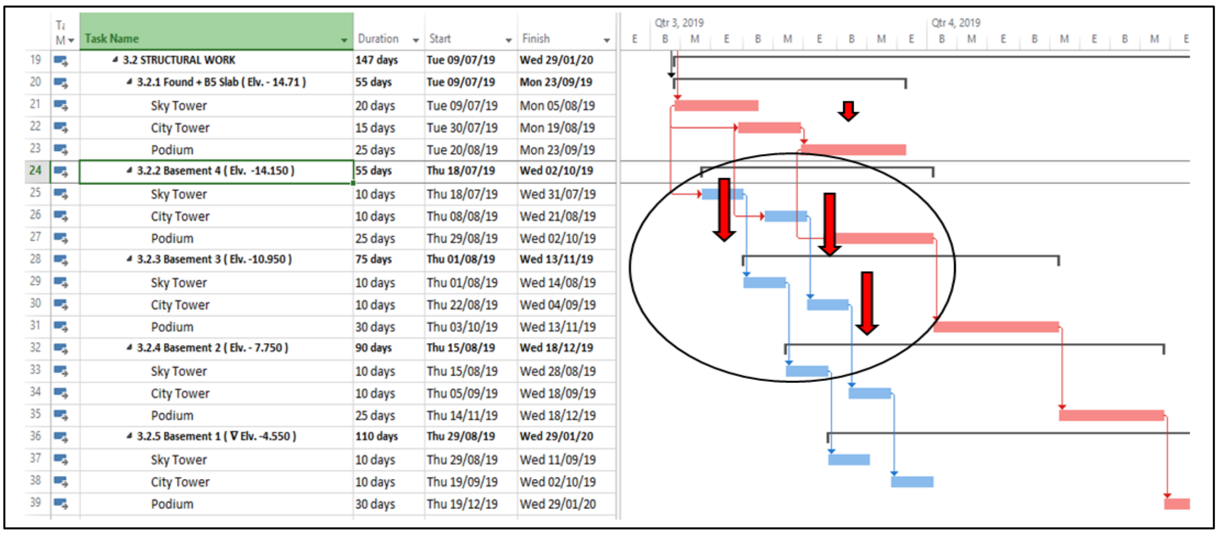

Figure 9. Conflict solving work resource basement 5 layer building

Conflict solving on resource management from a typical resource pool of a basement area of 5 layers of high-rise residential buildings for each work based on the same zoning if the previous zoning has been done with the finish to star concept will be shown in Figure 9.

Critical work is a priority in reference to the level of sensitivity compared to project delays and / or the critical chain life is the same as the project age, so to protect every job that is in the critical chain path and is assumed to be in the Project buffer at the end of the critical chain shown.

The amount of the Project buffer is calculated using the cut and fit (C&PM) method by cutting 50% of the total project implementation time or can be calculated using the formula:

Estimated cut and paste duration = duration x 50% (1)

The critical chain path time duration = 432 calendar days, hence:

Estimated cut and paste duration = duration x 432 days x 50% = 293 calendar days of the 5-layer basement structure is a critical path, which means that there will be a delay in one of the activities which will affect other activities.

Time calculation based on time estimation based on critical chain schedule method based on table 2 Critical path buffer diagram for basement work on 5 layers of buildings below figure 10:

Table 2. Basement Work Buffer 5 Layers of Buildings

Work Item	Original Schedule /Day	Estimate Duration Critical Chain			Critical Chain Schedule
		Cut Paste Method	Chain Duration	Project Buffer	
Excavation & Soil Disposal	120				
Ground Floor	20	10			
Basement 1	20	10			
Basement 2	20	10			
Basement 3	20	10			
Basement 4	20	10			
Basement 5	20	10	10	5	15
Capping Beam	90	45	45	23	50
Steel Stratting Dan Ground	100				
Basement 1	20	10			
Basement 2	20	10			
Basement 3	20	10			
Basement 4	20	10			
Basement 5	20	10	10	5	15
Dewatering Wall	60	30	30	15	35
STRUCTURAL WORK	272				
Found-B5 Slab (Elv. 14.71)	95				
Sky Tower	40	20			
City Tower	30	15			
Podium	50	25	20	10	25
Basement 4 (Elv. -14.150)	95				
Sky Tower	20	10			
City Tower	20	10			
Podium	50	25	15	8	20
Basement 3 (Elv. -10.950)	135				
Sky Tower	20	10			
City Tower	20	10			
Podium	60	30	17	9	22
Basement 2 (Elv. -7.750)	165				
Sky Tower	20	10			
City Tower	20	10			
Podium	50	25	15	8	20
Basement 1 (Elv. -4.550)	205				
Sky Tower	20	10			
City Tower	20	10			
Podium	60	30	17	9	22
Total Duration	432	237	195	98	293

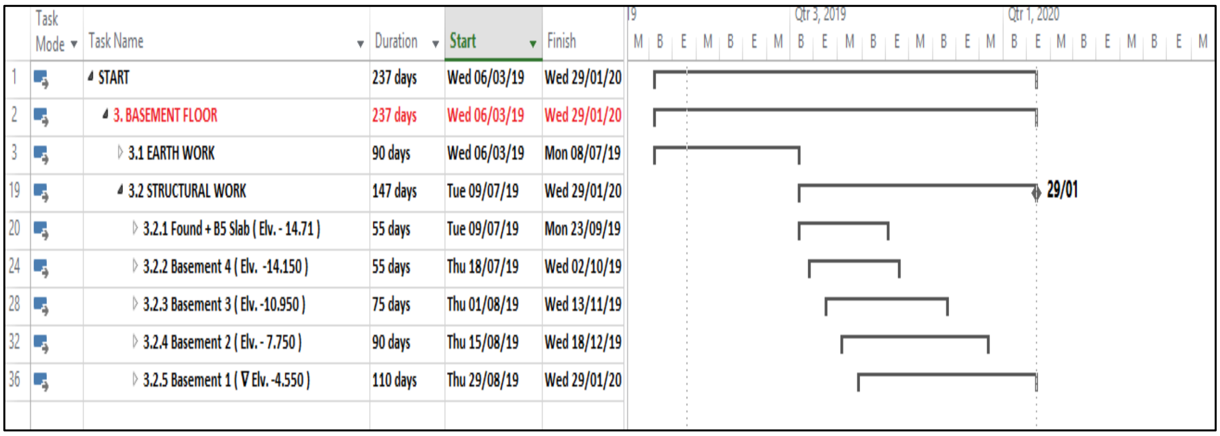

Figure 10. Project Buffer

4.3. Application Building Information Modeling (BIM) 4D

In a case study project in this study, the application of 4D Building Information Modeling (BIM) will be explained in the basement work of 5 layers of high-rise residential buildings by explaining the concepts and procedures of 4D scheduling.

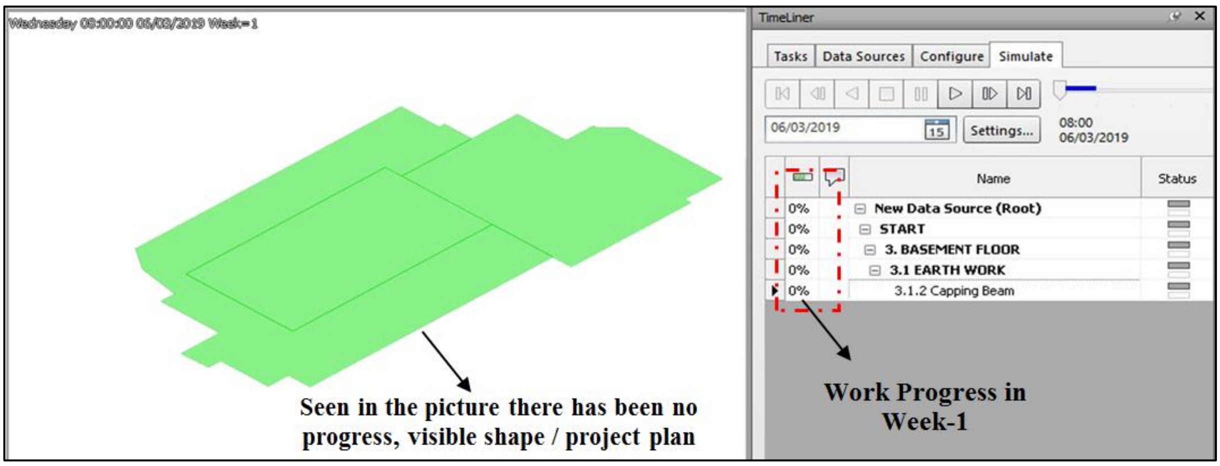

Figure 11. Work progress on Week 1

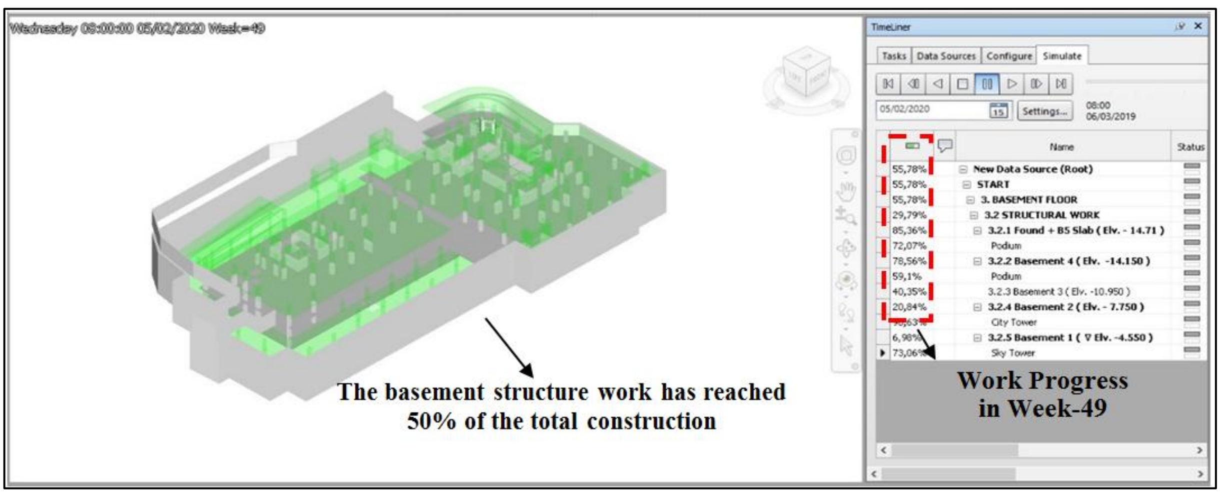

Figure 12. The progress of work on Week 49

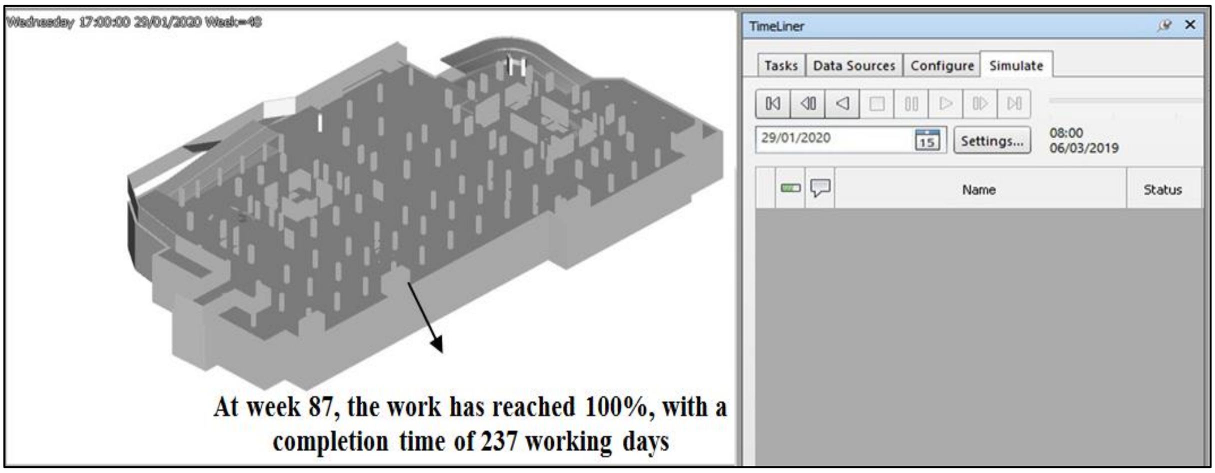

Figure 13. The progress of work on Week 87

5. Conclusions

The conclusion of this study is:

1. The results of the application of critical chain project management and building information modeling are the stages of duration optimization, namely 1. Review Master Schedule 1. Determine the critical chain, 2. Estimate the duration of the Critical Chain Project Management (CCPM), 3. Estimate the buffer time. 4. Scheduling Critical Chain Project Management (CCPM), 5. 3D modeling of implementation methods, 6. Set group models, 7. Export 3D models to Naviswork, 8 link scheduling and 3D model of activity stages, 9. 4D simulation models.
2. The resulting time optimization from this study is 32,17 %.
3. The day savings generated by applying this method were from 432 working days to 293 working days, thus saving 139 working days.

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