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Key Success Factors for Critical Chain Project Management (CCPM) and 4D Building Information Modeling (BIM) for Improving Time Performance in Basement Work on 5 Layers of High-rise Residential Buildings in Indonesia

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ABSTRACT

Referring to data released by The Skyscrapper Center in 2020, during the period 1960 - 2020 there was a rapid increase in the construction of buildings with a height of more than 150 meters around 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 problems in the planning process to the management of high-rise residential buildings. The need for housing in Indonesia, especially in big cities, is high and the limited availability of land causes prices to increase, so that investment in residential high rise buildings is growing rapidly. The high demand for the community is directly proportional to the increase in the number of residential building construction for high-rise buildings. Building construction is expected by service providers to be completed on time without delay according to their planning. However, in the implementation of development there are problems that cause delays in its implementation. The delay that occurs can be from internal, external and weather factors. For this reason, this research will discuss the key success factors of critical chain project management (CCPM) and 4D building information modeling (BIM) for improving time performance on the basement work of 5 layers of high-rise residential buildings. To obtain the key success factors, the researchers used the SPSS (Statistical product and service solutions) tool. From the results of this SPSS, the researchers found 10 key success factors, namely 1. Project identification against time, 2. Basement design complexity, 3. Effect of project buffers, fedding buffer , buffer resources, 4. Accuracy of document design, 5. Scheduling and Simulation, 6. Logical relations of activities, 7. Policy and government support, 8. Top down methods, 9. Land conditions, and 10. Eliminating safety time. The 10 key success factors are expected to reduce delays in the implementation of development.

Key Words: Critical Chain Project Management, BIM, Basement work, SPSS

1. INTRODUCTION

The increase in high-rise residential buildings or high rise buildings according to the data from the global competitiveness report 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 problems in the planning process to the management of high-rise residential buildings, in Figure 1.1 is a graph of the estimated growth of the construction sector in 3 countries in Asia for the period 2014-2020 below:

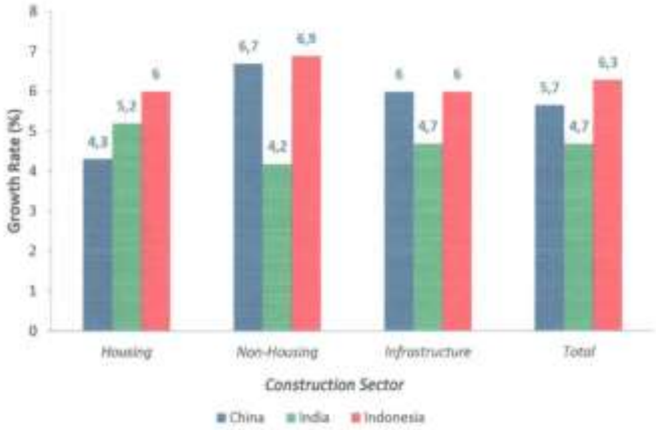

Figure 1.1 Estimated Growth of the Construction Sector in 3 Countries in Asia for the 2014-2020 Period [1]

With this large investment potential, investors will demand fast and cost effective time performance. For large-scale projects with a very large number of activities and complex dependencies / linkages between activities. Scheduling becomes complexity and very important so that activities can be carried out efficiently. Delays are common in construction projects. The delay in construction projects is caused by many factors. One of them is time inefficiency caused by errors in estimating the time needed to complete the project at the planning stage [2]. According to [3] One of the factors causing the delay is ineffective planning and scheduling by the contractor. One of the efforts to anticipate the delay in the duration of construction activities is to optimize the duration of the activities. In the field of construction project management, currently developing a new project scheduling method that is used in dealing with uncertainty in project completion. This method is known as Critical Chain Project Management (CCPM). Critical Chain Project Management (CCPM) optimizes buffer feeding and project buffers (additional time) in each activity to avoid untimely project scheduling by linking work relationships, resource constraints, safety time and eliminating waiting times and controlling safety time at each work so that you get the optimization of the schedule. According to [4] Simulation and visualization of 4D BIM can increase efficiency in the construction project planning process and 4D Simulation in terms of visual control is 40% higher than conventional planning. The 4D BIM can identify overlapping activity and analyze the level of risk for schedule overlap problems [5]. With the above background, research was carried out on the key factors of success in critical chain project management (CCPM) and BIM 4D in the basement work of 5 layers of high-rise residential buildings.

2. THEORETICAL BASIS

2.1 Critical Chain Project Management (CCPM)

The Critical Chain Project Management (CCPM) method was introduced by Dr. Eliyahu Goldratt in 1997, with Theory of Constraints (TOC) has been 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.

Critical Chain Project Management is defined as the longest chain of interrelated events, where the interrelationships with each other lie in interconnected work or resources. [6]. The requirements in this Critical Chain Project Management method are the absence of multitasking, Student's Syndrome, Parkinson's law, As late as possible, eliminating hidden safety and moving it in the form of a buffer behind the project, and focusing on the final project completion. The buffer management methodology is used to prioritize jobs with constraints on the availability of resources which cause delays in implementation in construction projects.

2.2 Introduction to Critical Chains

The development of the critical chain is a method problem and cannot be ruled out [7]. There are four steps to identifying the critical chain in a project [8] namely: 1. Allocating the duration, 2. Advancing the activity, 3. Eliminating excess resource allocation, 4. Setting 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 1.2 below:

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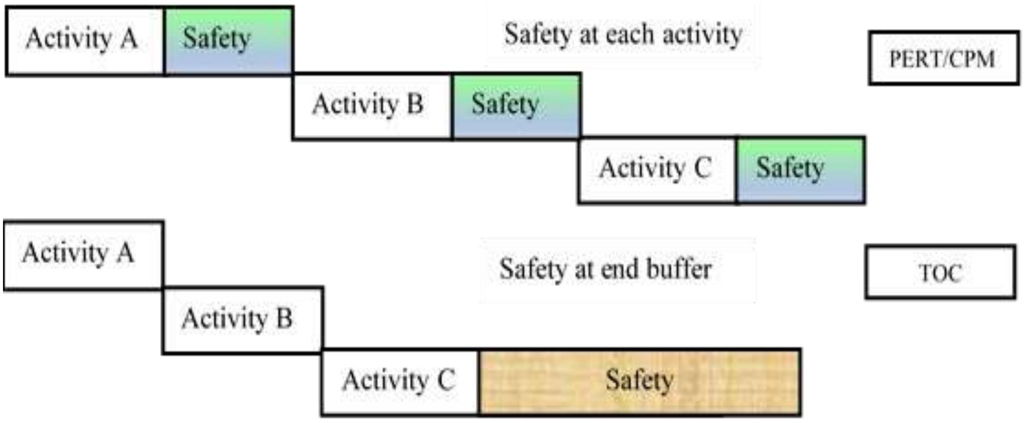

Figure 1.2 PERT / CPM and TOC comparison [9]

2.3 Project Buffer dan Feeding Buffer

Manage projects with Critical Chain Project Management (CCPM) using a time buffer, essentially Theory of Constraints (TOC) and provides simple tools to monitor projects and set realistic deadlines [10]. and is increasingly used in construction scheduling and its methods have undergone a number of refinements and existences [11]. The average task duration in the Critical Chain Project Management (CCPM) method instead of the duration with the safe time and between the two types of duration on each activity in the critical chain will be assigned to the end of the project as a project buffer (shown in Figure 1.3). This buffer is for trying 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 1.3) and are placed where non-critical chain activity joins the critical chain. Finally, these buffers protect critical chain activity from disruption and delay start [12]. Buffers play a key role in CCPM [13] and Finally, these buffers protect critical chain activity starting from delay interruptions [14].

Figure 1.3 Project buffer and feeding buffer [15]

Take into account any defenses that may exist between activities, because all require the same resources [16] and the square root of the sum of the squares of this difference for each activity is then used as a buffer [17] and according to [18] this advantage becomes clearer as the size of the problem increases.

2.4 Building Information Modeling (BIM) 4D

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 1.4 below :

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Figure 1.4 Roadmap for Building Information Modeling (BIM) Indonesia 2017-2024[19]

The use of Building Information Modeling (BIM) modeling in high-rise residential building systems in conjunction with collaborative design teams is one of the most useful approaches in achieving cost-effective and high-quality design results. 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 3D virtual models between different disciplines, so that the information exchange process becomes faster and affects construction implementation.[20] and the application of BIM will make cost and time efficient Implementation of the project 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 [21].

2.5 Basement

Basement is a vertical downward development that creates an underground space (Basement) which is part of the building.

2.6 Types of Work in the 5 Layer Basement

Planning and Implementation Methods in high-rise residential buildings for basement work have specific characteristics, in particular on work methods and application of implementation technology. Some specific things are the order of work, type of work, vertical transportation activities, work safety, location limitations, and ground water [22]. The types of work in the basement generally consist of: 1) Bored Pile work, 2) Capping beam work on bored pile concrete, 3) Earth excavation work, 4) Mechanical earth removal, 5) Ground Angkur work, 6) Waller work Beam (if any), 7) Concrete wall work / retaining wall, 8) Work and Tie Beams, 9) Basic concrete floor work, 10) Beam and column concrete work, 11) Slab deck work or concrete floors 1-4 and ram vehicles, 12) Emergency staircase work, pit lift work, 13) multipurpose building work, 14) steel reinforcing work or ironwork, 15) mechanical electrical work, 16) plumbing work, 17) dewatering work, 18) fire safety work and 19) KM / WC work.

2.7 Scheduling in Construction Planning

Scheduling is called 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 resulted in an increase of 5 - 20% of the total contract value [23] so that if the process of scheduling activities in each relationship between activities is made in detail and 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.

3. RESEARCH METHODOLOGY

This research process contains a research flow from the beginning to finding a hypothesis to answer the problem formulation by conducting scientific research, where in the process there are stages / sequences that are adjusted to the research framework that has been compiled in the form of a flow chart. The flow chart is prepared based on the formulation and research objectives to be achieved by referring to the project feasibility study [24]:

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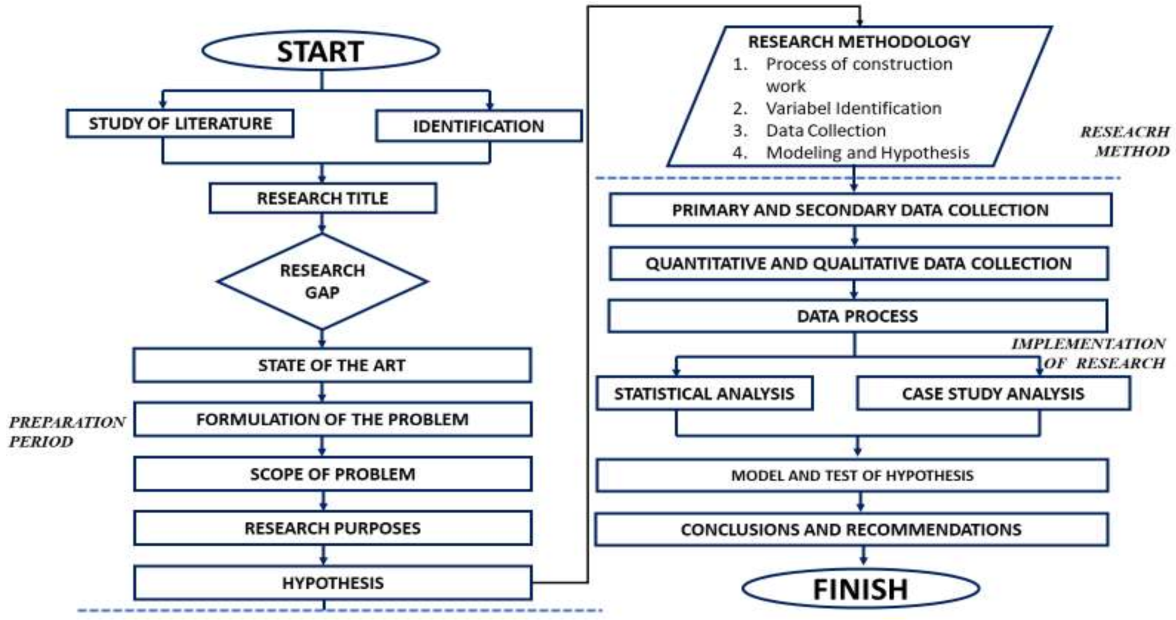

Figure 1.5 Research Flow

From this research flow data can be used to process and analyze data, in order to get the results that are expected. From this research can streamline the performance of the implementation of the construction of high-rise residential buildings on a 5-layer basement work.

3.1 Variable Identification

In this case the researcher took 1 (one) main variable to get the efficiency and accuracy of time as the independent variable, and 3 (three) variables as the dependent. The variables are:

Independent Variable : X1 = Critical Chain Project Management

X2 = Building Information Modeling (BIM) 4D

X3 = Basement 5 layers

Dependent Variabke : Y1 = Time

Identification of sub-variables related to project time performance consists of 4 variables, namely Critical Chain Project Management, 4D Building Information Modeling (BIM), Basement and Time. The number of respondents used in this study is 70 respondents.The following are the key success factors in increasing time:

Table 1.1 Key Success Factors

VARIABLE	MAIN FACTOR	SUB FACTOR		REFERENCE
CRITICAL CHAIN PROJECT MANAGEMENT	CRITICAL CHAIN METHOD	1	Faster turnaround time	Ryan Ramanda, 2019
		2	Minimizes project duration	Mohamad Aulady,2016
		3	Determine the critical project path	Ryan Ramanda, 2019
		4	Steps for design of the CCPM schedule	Mona P. Prajapati, 2017
		5	Utilization of CCPM software	Leonarda Valikoniene, 2014

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Table 1.1 Key Success Factors

VARIABLE	MAIN FACTOR	SUB FACTOR		REFERENCE
CRITICAL CHAIN PROJECT MANAGEMENT	CRITICAL CHAIN METHOD	6	Determination of human resources	Lisa M Repp
		7	Schedule planning & monitoring	Lisa M Repp.
		8	Schedule planning, monitoring, and controlling solution	Lisa M Repp.
		9	Eliminating Student Syndrome & Parkinson Law	Ghaffari & M. W. Elmsley, 2015
		10	Commitments on time schedule	Leonarda Valikoniene, 2014
		11	Real time project monitoring	Leonarda Valikoniene, 2014
	BUFFER TIME	12	Defines and defines buffers	Mohamad Aulady,2016
		13	Identify the project against timing	Mastura Labombang, 2011
		14	Effect of Project buffer, fedding buffer, buffer resource	Mona P. Prajapati, 2017
		15	Eliminates safety time	Mohamad Aulady,2016
		16	Risk Management	Ghaffari & M. W. Elmsley, 2015
		17	Understanding the stages of work	Lisa M Repp.
		18	Eliminates safety time	Repp, 2012
		19	Limited resources	Repp, 2012
BUILDING INFORMATION MODELING (4D)	CONSTRUCTION STAGE	1	Effective communication and coordination among the project team	Paul Chinowsky (ASCE), 2010
		2	Scheduling and simulation	Julie Jupp, 2017
		3	Document design accuracy	Syal, 1992
		4	Activity logical relationships	Paul Chinowsky (ASCE), 2010
		5	Government policy and support	Thomas C. H, 2020
		6	Use of BIM software tools	Thomas C. H, 2020
		7	Work flow / work stages	Julie Jupp, 2017
		8	Determine project completion constraints	Syal, 1992
		9	Identify the project success cycle	H. Randolph Thomas (ASCE) 2007
		10	Develop a project strategy	H. Randolph Thomas (ASCE) 2007
		11	Develop the project layout	H. Randolph Thomas (ASCE) 2007
	PEMODELAN 4D	12	Duration of project activities	Gledson, 2017
		13	Simulation of the construction process	P. Ballesteros-Pérez (ASCE) 2020
		14	Equipment modeling in the work environment / site	Leni Sagita Riantini, S.T., M.T., Ph.D.
		15	Modeling & lay out during the construction process	Julie Jupp, 2017
		16	Modeling and visualization of the significance of environmental impacts	Julie Jupp, 2017
		17	Study the previous project plan	Julie Jupp, 2017
		18	Templates and formats	PMBOK 6th Ed, 2017

DOI : 10.31695/IJERAT.2021.3701

Table 1.1 Key Success Factors

VARIABEL	MAIN FAKTOR	SUB FAKTOR		REFERENSI
BUILDING INFORMATION MODELING (4D)	BUILDING INFORMATION MODELING (4D)	19	Logistics modeling	PMBOK 6th Ed, 2017
		20	4D project modeling	Cristina T. Pérez, 2016
BASEMENT WORK 5 LAYER	BASEMENT WORK 5 LAYER PLANNING	1	Basic Engineering Design	Jin Ouk Choi, Ph.D et al , 2020
		2	Early identification of standardization	Jin Ouk Choi, Ph.D et al, 2020
		3	Standardization feasibility analysis	Jin Ouk Choi, Ph.D et al, 2020
		4	Building design & building system management	Ahmad Abdelrazaq, 2012
		5	Decisions on design & construction	Hadi Khabbaz et al . 2019
		6	Design	G.M. Rotisciani et al, 2016
		7	Construction	G.M. Rotisciani et al, 2016
	IMPLEMENTATION	8	Project environmental conditions	Rara Dwi Noviarti, 2018
		9	Soil conditions	Rara Dwi Noviarti, 2018
		PEMODELAN 4D	Bottom up method	Ho Steven, et al, 2014
		11	Top down method	Ho Steven, et al, 2014
		12	Basement design complexity	Han, 2012
		13	Monitoring	G.M. Rotisciani et al, 2016
TIME	IMPLEMENTATION	1	The weather is not fixed	Smarghandi 2016
		2	Subcontractors	Smarghandi 2016
		3	Lack of material	Smarghandi 2016
		4	Lack of equipment	Smarghandi 2016
		5	Lack of skilled workforce	Smarghandi 2016
		6	Project location restrictions	Smarghandi 2016
		7	Poor labor productivity	Smarghandi 2016
		8	Design changes	Smarghandi 2016
		9	The process of utility / construction land	Smarghandi 2016
		10	Flood location	Smarghandi 2016

3.2 Determining the Number of Respondents

The minimum number of respondents to answer the questionnaire is needed as a limitation in collecting the required results. According to [25] Respondents' needs can be obtained using the following equation:

m=(Z^2×P×(1-P))/ε^2 ………………………………………….(1.1)

n=m/(1+((m-1))/N) ……………………………………………...(1.2)

Where : N = 84, ε = 0,0, P = 0,5

p-value=(1-ε)/2=(1-0,05)/2=0,475

Based on the p-value, the Z value is obtained based on the Z table of normal distribution, Z = 1,96

DOI : 10.31695/IJERAT.2021.3701

Then the minimum respondent needs are as follows:

m=(Z^2×P×(1-P))/ε^2 , m=(〖1,96〗^2×0,5×0,5)/ 〖0,05〗^2 =0,96/0,0025=384,16

n=m/(1+((m-1))/N), n=384,16/(1+((384,16-1))/57)=384,16/7,72=69,07

The minimum number of respondents is 69.07, so the minimum number of respondents is 70 respondents

3.3 Data Processing Stage

In the validity test itself, a measure that can show the validity or validity of the instrument. So in testing the validity it refers to an instrument in carrying out its function. The variables obtained from the journal can be published. The process of testing the validity and reliability is carried out using the following tools in the SPSS program, which is a data processing flowchart:

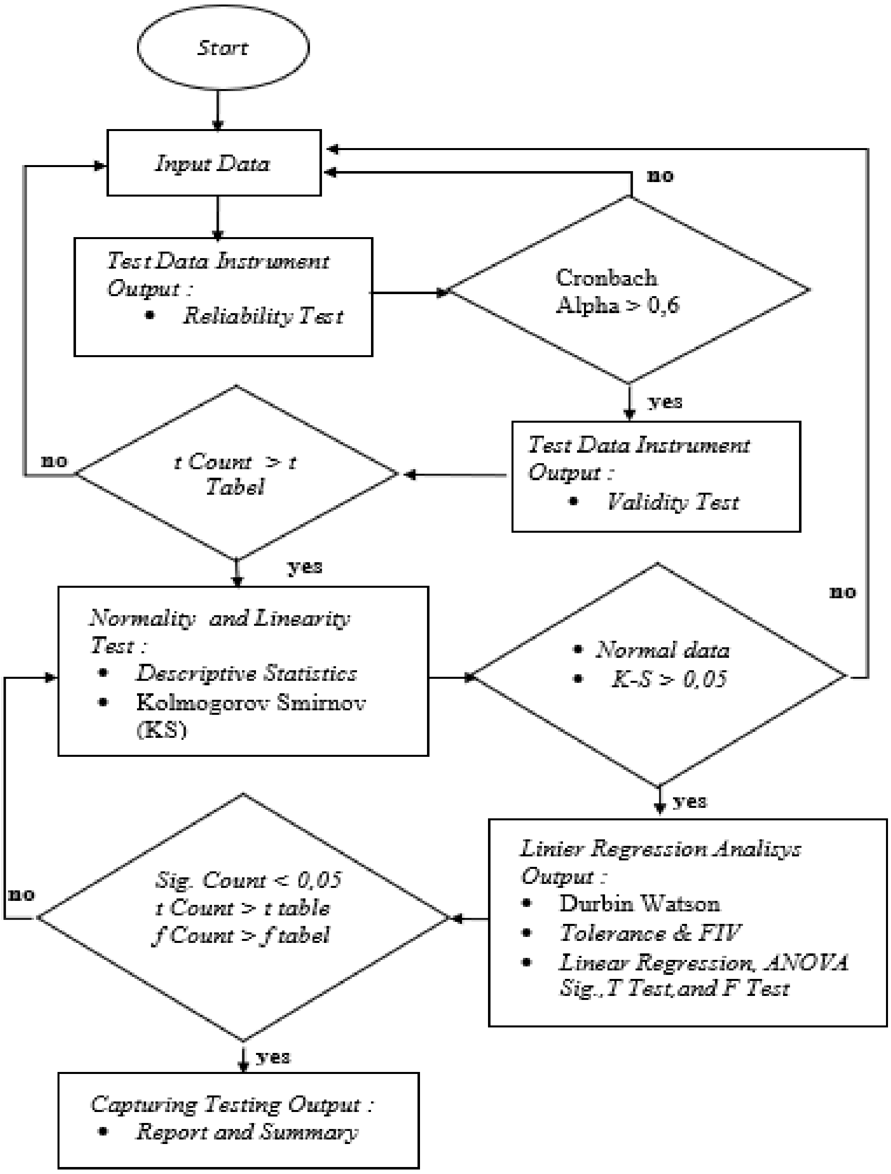

Figure 1.6 Flowchart of SPSS

3.4 Validity Test and Reliability Test

From each variable will be tested using SPSS tools, namely the value of the corrected item total correlation (calculated validity) if the value is more than 0.2146 then it can be stated as valid and the value of Cronbach's Alpha (Calculation Reliability). can be stated as realistic, here are the results of data grouping that are both realistic and valid.

Table 1.2 Validity Test Results

VARIABLE	ALPHA	VALUE	REMARK
Critical Chain Project Management	0,538	0,2146	Valid

DOI : 10.31695/IJERAT.2021.3701

Building Information Modeling 4D	0,430	0,2146	Valid
Pekerjaan Basement	0,490	0,2146	Valid
Waktu	0,624	0,2146	Valid

Table 1.3 Reliability Test Results

VARIABLE	ALPHA	VALUE	REMARK
Critical Chain Project Management	0,861	0,700	reliabel
Building Information Modeling 4D	0,706	0,700	reliabel
Pekerjaan Basement	0,705	0,700	reliabel
Waktu	0,823	0,700	reliabel

The results of the average analysis are then compiled into a recapitulation which is presented in the form of sub-factor rankings. The results of the recapitulation of statistical analysis using the average method, more details can be seen in the discussion below

Table 1.4 Recapitulation of Statistical Analysis

RANK	SUB FACTOR		MAIN FACTOR
1	X1_13	Identify the project against timing	Buffer Time
2	X3_12	Basement design complexity	Implementation
3	X1_14	Effect of Project buffer, fedding buffer, buffer resource	Buffer Time
4	X2_3	Document design accuracy	Construction Stages
5	X2_2	Scheduling and simulation	Construction Stages
6	X2_4	Activity logical relationships	Construction Stages
7	X2_5	Government policy and support	Construction Stages
8	X3_11	Top Down Method	Implementation
9	X3_9	Soil conditions	Implementation
10	X1_15	Eliminates safety time	Buffer Time
11	X1_9	Eliminate Student Syndrome & Parkinson Law	CCPM
12	X1_8	Schedule planning, monitoring, and controlling solution:	CCPM
13	X1_2	Minimizing Project Duration	CCPM
14	X1_1	Faster turnaround time	CCPM
15	X2_12	Equipment modeling in the work environment / site	4D modeling
16	X1_6	Determination of human resources	CCPM
17	X2_13	Modeling & Lay out during the construction process	4D modeling
18	X3_6	Design	Planning
19	X2_9	Identify the Project success cycle	Construction Stages
20	X2_14	Modeling and visualization of the significance of environmental impacts	4D modeling
21	X1_7	Schedule planning & monitoring	CCPM
22	X1_16	Risk Management	Buffer Time

DOI : 10.31695/IJERAT.2021.3701

23	X1_17	Understanding the stages of work	Buffer Time
24	X3_7	Construction	Planning
25	X3_5	Decisions on design & construction	Planning
26	X2_10	Project activity duration	4D modeling
27	X3_1	Basic Engineering Design	Planning
28	X2_8	Determine Project completion constraints	Construction Stages
29	X2_16	4D Project Modeling	4D modeling
30	X3_8	Project environmental conditions	Implementation
31	X3_10	Bottom up method	Implementation
32	X1_11	Real time Project monitoring	CCPM
33	X1_10	Commitment On Time schedule	CCPM
34	X2_1	Effective communication and coordination among the Project team	Construction Stages
35	X2_7	Work flow / work stages	Construction Stages
RANK	**SUB FACTOR**		**MAIN FACTOR**
36	X3_2	Early identification of standardization	Planning
37	X2_6	Use of BIM software tools	Construction Stages
38	X3_3	Standardization feasibility analysis	Planning
39	X1_3	Determine the Project critical path	CCPM
40	X1_5	Utilization of CCPM software	CCPM
41	X1_4	Steps for design of the CCPM schedule	CCPM
42	X1_18	The relationship of each stage of work	Buffer Time
43	X1_19	Count & define buffers	Buffer Time
44	X2_11	Simulation of the construction process	4D modeling
45	X1_12	Defines and defines buffers	Buffer Time
46	X2_15	Logistics modeling	4D modeling
47	Y_2	Subcontractors	Time
48	Y_1	The Weather Is Not Fixed	Time
49	Y_4	Lack of Equipment	Time
50	X3_4	Building Design & Building System Management	Planning
51	Y_7	Poor Labor Productivity	Time
52	Y_5	Lack of Skilled Workforce	Time
53	Y_6	Project Location Restrictions	Time
54	Y_3	Lack of material	Time
55	Y_10	Location Flood	Time
56	Y_9	Utilities Process / Construction Land	Time
57	Y_8	Design Change	Time

4. CONCLUSION

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From data analysis using SPSS and after ranking, 10 key success factors for critical chain project management and 4D Building Information Modeling (BIM) were obtained as follows:

1. Identify the project against timing
2. The complexity of the basement design
3. Effect of project buffer, fedding buffer, buffer resource
4. Accuracy of document design
5. Scheduling and simulation
6. Logical relationship activities
7. Government policy and support
8. Top Down Method
9. Soil conditions
10. Eliminates safety time

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