A DECISION MAKING FRAMEWORK FOR REDUCING PROJECT DURATION BY APPLYING CONCURRENT ENGINEERING IN CONSTRUCTION

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ABSTRACT: Steel frame factories were surveyed in this study in order to explore the possibility of shortening the construction time and save on construction cost through overlapping at the stages of design or construction. In the survey, construction professionals were interviewed in order to collect quantitative data. Hypotheses were then formulated, and the data was thereby analyzed using the simulation technique in order to analyze the effects of the concurrent engineering method on shorter construction time and cost saving. In addition, actual cases were analyzed to determine the overlapping rates of major processes in terms of shorter construction time and cost saving and to analyze the relationship between time and cost due to overlapping.

Keywords : Concurrent Engineering, Simulation, Overlap, Sensitivity, Production

1. INTRODUCTION

1.1 Background & Purpose

The recent construction industry's business environment is changing rapidly from the use of a simple contract to more professional, advanced, larger, and diverse contracts, which demand more complicated technology, as well as a greater financial and management ability. Due to the intensified competition, the progress in technology, the reduction of Product Life Cycle, and the increasing size of organizations, the construction industry is still expanding. Therefore, the manufacturing industry is using Concurrent Engineering to reduce the construction period and to increase efficiency. Concurrent Engineering has replaced the progressive process with concurrent processing run as a parallel process, and an overlap strategy is utilized to reduce the manufacturers' developing times from 20% to 50%. By applying concurrent engineering in construction, design and construction can occur simultaneously, thus reducing the project duration.

The purpose of this study is to present suitable relationships between activities and additional expenses to each process of a construction project, so the staff in charge is able to relate processes efficiently, and to propose a decision making framework for reducing the project duration. The aim of this study is to proposes a decision making process for the prediction of project duration, and for a more systematic analysis than that of the design-construction system. This would allow staff in charge to predict and effectively analyze the reduction of project duration, cost, and risk before and during the project.

1.2 Methods

In this study, the process of construction was analyzed in conjunction with a case study, an interview process and survey, and an analysis of references, while simulation was used to demonstrate the validity of the concurrent engineering method.

To study the influence of concurrent engineering on construction duration and cost, the authors analyzed and applied concurrent engineering in the actual case of building a factory. From the analysis, simulation was used with quantitative data such as construction duration and cost.

In this study, manufacturing industry construction project examples are considered to determine who is required to pay due regard to such factors as cost and risk by reducing project duration. The following process is used in the study.

First, the authors utilized a current actual construction project in Korea as the case study; personnel involved in the project were interviewed, and analysis was performed of the problem and influence of applying concurrent engineering for reducing project duration.

Second, an analysis was performed of studies and reports carried out overseas on concurrent engineering published in Engineering News Record (ENR). A study was then carried out on the environments of overseas projects.

The problems encountered when construction projects apply concurrent engineering were therefore determined.

Third, the established studies, sundry records and an interview with a specialist are referred to in order to determine the total influence of applying concurrent engineering. The overlap strategy is then presented with the concept that evolution, sensitivity, and production are considered in the improvement methods and in the characteristics of the relationships between operations.

Forth, case studies of projects in Korea are utilized, and each overlap case is simulated. An analysis is then performed of the relationship between cost according to reducing the project duration and the relationship between project duration and cost according to rework.

2. THEORY & PILOT STUDY

2.1 The Theory of Concurrent Engineering

The concurrent engineering method is a company's business strategy. It reduces the development time, improves the quality, and reduces the prime cost by simultaneously carrying out all the stages in the life cycle of the project, including planning, conception, design, purchasing, construction, testing, management, and destruction.

The concept of concurrent engineering is based on the produce method; when planning is in the design stage, then it needs to be finished by the process of basic design, detail design, and process design as shown in fig.1.

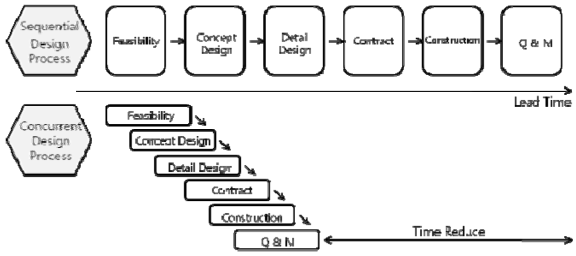

Fig 1. Concept of Concurrent Engineering

For this reason, if a problem occurs during the last process of production, the first step must be returned to and the process must be reworked from design. The project duration and costs would then be increased. However, with the concurrent engineering approach, planning, basic design, detailed design, process design, and the implementation process occur at the same time, and the duration and cost of the overlay is therefore more economic and efficient than with the traditional methods.

2.2 Characteristics of concurrent engineering

To apply the concurrent engineering strategy to the construction industry, two concepts need to be understood. Figure 2 in each operation, such as Rate of Information Development and leading to subsequent changes in operations that affect sensitivity between the predecessor and successor tasks in terms of represents the exchange of information (Bogus et al. 2005).

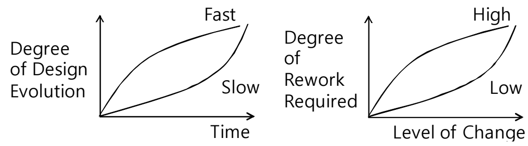

Fig 2. Concept of deployment & sensitivity (Bogus 2005)

The concept of deployment on the design can be applied to construction work. However, the construction work is affected more by physical constraints than by information constraints. Therefore, the dependent relationship of the construction work in progress is used to define the physical operation concept of deployment in Production Rate, which is a concept that can be used. Depending on the nature of the work, this production can be divided into slow production and fast production, as shown in Figure 2. The slow production rate in the second half of the task increases, and the fast production rate at the beginning of the operation also increases.

The additional work produced by overlap work is a result of the sensitivity of subsequent operations. Sensitivity is the amount of rework required by subsequent operations due to the change of leading work. Defining the work based on the characteristics of sensitivity allows options in the choice of works to overlap. Likewise, the sensitivity of the subsequent tasks and production is an important activity of successful overlap work.

2.3 Leading research and insights

According to Bogus (2005), concurrent engineering is the Rate of Information Development and information change in leading work that affects the subsequent work of sensitivity. Based on this opinion, the definition of concurrent engineering is information exchange between leading work and subsequent work.

According to Blackburn (1991) and Eldin (1997), concurrent engineering has reduced manufacturing and product development time by 20-50 percent.

According to Jae-Seob Lee, Susan Bogus and Keith R. Molenaar (2006), the design has so far been focused on the phase of concurrent engineering. Concurrent engineering can be applied to the construction phase, but it is more concerned with physical constraints. The example shows that concurrent engineering shortened the construction time by 7.9% and the cost had an 11% increase.

According to Jergeas (2000), when design and construction are combined, about 10 ~ 20% of the increases in cost can be reduced 10 ~ 29% of the time. According to Krishnan (1995), in terms of the characteristics of work and work relationships, the concept of evolution and sensitivity, rapid deployment in precedence work, and low sensitivity in subsequent work could be a good alternative for overlap.

According to Susan Bogus and Keith R. Molenaar (2005), the best condition for overlap in concurrent engineering is Fast Evolution and Low Sensitivity.

In this present study, concurrent engineering successfully reduced the duration of the design and construction of the project. However, if concurrent engineering is applied in construction projects, time can be reduced, yet the cost increases, implying the risk of rework due to overlap. To successfully apply concurrent engineering in a construction project, a great deal of effort is required in construction management business.

3. CASE STUDIES

3.1 Case Summary

The case used for this research is company 00, factory-built 00. The site is located in Ul-san, while the building area is approximately 13,554 ㎡ and is a two storey steel-frame building

(1) Design Process

11 events were critical path(C.P) and the design process was divided into the basic design and the implementation of design**.** Only the construction process was considered, and the total time taken for design was 60 days. In table 1, the analysis of design cost is divided into the basic design and the real design in the design of the factory. The design cost was divided into the cost per 3.31 ㎡ and the ratio (%) of the duration of the process.

Table 1. Cost of steel frame factory's basic design

Content	Cost		Time	
	fee (1000 won)	rate (%)	days	rate (%)
1)Land and deployment analysis	35,000	10.9	3	5
2)The form of building plan	40,000	12.4	4	6.7
3)Flat, elevation, sectional plan	53,000	16.4	5	8.3
4)Structure calculations	30,000	9.3	7	11.7
5)Complete basic design	18,000	5.6	1	1.7
6)Base Plate design	22,000	6.8	6	10
7)Steel pillar design	25,600	7.9	7	11.7
8)Plate design	18,300	5.7	5	8.3
9)Truss Design	44,000	13.6	12	20
10)Details of the structure	25,600	7.9	7	11.7
11)check the drawings review	11,000	3.4	3	5

(2) Construction Process

11 events were included in the construction process and only the steel factory process was considered. The total time taken for construction was 86 days. The greatest construction cost as shown in Table 2 is the cost of 100 pillars for the steel frame in the construction project. The analysis of steel frame construction is divided into a percentage of the construction cost from the full cost and a percentage of the steel frame construction cost from the construction cost, and was finally divided by the cost per 3.31 ㎡ in the actual construction cost.

Table 2. Construction cost of steel factory

Content	Normal cost	
	Days (day)	Cost (won)
1) Die Installation	10 / 100Unit	43,046 / 1Unit
2) Reinforcement placing	7 / 100Unit	100,317 / 1Unit
3) Installing anchor bolts	7 / 100Unit	114,400 / 1Unit
4) Pour concrete and cure	4 / 100Unit	69,016 / 1Unit
5) The dissolution of the die	4 / 100Unit	16,895 / 1Unit
6) Anchor bolts calibration	3 / 100Unit	34,320 / 1Unit
7) Install the base plate	4 / 100Unit	3,916 / 1Unit
8) Geurawooting	3 / 100Unit	3,520 / 1Unit
9) Install steel frame pillars production	14 / 100Unit	693,385 / 1Unit
10) Plate production & setup	10 / 100Unit	315,475 / 1Unit
11) Production Truss Installation	20 / 50Unit	2,773,542 / 1Unit

3.2 Case Analysis

The research survey is concerned with the actual construction of the project, and the participants were design & construction technicians. The area was divided into Seoul and Gyeong-gi.

(1) Design Stage

103 questionnaires (85.8%) were collected from a total of 120 questionnaires, and 45.6% of the participants held a bachelors degree, 37.86% held a masters degree, and 36.89% were construction experts who had an architect's license. In addition, 63.1% of the participants had more than 10 years experience and 91.26% of the design workers were involved directly with business planning, planning, design, and management planning.

The results of the survey are as follows:

ⅰ) less than 78% overlap can occur on 20 ~ 30% of the design stage. ⅱ) 72.81% answered that the real design stage is the stage of the project with the most overlap. ⅲ) 14.56% of the participants believed there was less than 20% chance of success. ⅳ) 72.8% believed that a cost saving of 0 ~ 10% is achieved with overlap ⅴ) 44.66% estimated the number of inputs to be less than 20~30% ⅵ) 28.15% answered that the engineer's ability is the most important factor for success.

(2) Construction Stage

80 questionnaires (80%) were collected from a total of 100 questionnaires, and 48.75% of the participants held a bachelors degree, 22.5% held a masters degree, and 66.25% were construction experts with construction licenses. In addition, 48.75% had more than 10 years experience and 57.5% of construction workers were involved directly with process, cost, and construction.

The results of the construction stage of the survey are as follows:

ⅰ) less than 75% overlap can occur in 20 ~ 30% of the construction stage. ⅱ) 41.25% answered that the factory is the best place for overlap to occur. ⅲ) 51.25% believed that there was less than 20% chance of success ⅳ) 75% believed there was a 0 ~ 10% cost saving when overlap is used ⅴ) 46.25% believed that the estimated number of input was less than 20% 48.75% answered that the key factor to success is the engineer's ability.

(3) Probability & Amount of Rework

Tables 3 and 4 show the probability of rework with each characteristic and the amount of rework required. The data is taken from interviews and written questionnaires, and will be used from analysis through to simulation.

Table 3. Probability & Amount of Rework - Design

Content		Probability of rework					
		0%	20%	40%	60%	80%	100%
Fast Evolution, High Sensitivity	Probability of Rework(%)	0	45	65	70	75	80
	Amount of Rework(%)	0	35	50	65	70	80
Fast Evolution, Low Sensitivity	Probability of Rework(%)	0	5	10	20	35	55
	Amount of Rework(%)	0	5	15	25	40	60
Slow Evolution, High Sensitivity	Probability of Rework(%)	0	5	15	35	55	85
	Amount of Rework(%)	0	10	20	35	55	80
Slow Evolution, Low Sensitivity	Probability of Rework(%)	0	35	55	60	65	70
	Amount of Rework(%)	0	25	40	55	60	70

Table 4. Probability & Amount of Rework - Construction

Content		Probability of rework					
		0%	20%	40%	60%	80%	100%
Fast Evolution, High Sensitivity	Probability of Rework(%)	0	55	75	80	85	90
	Amount of Rework(%)	0	45	60	70	75	85
Fast Evolution, Low Sensitivity	Probability of Rework(%)	0	15	20	30	45	65

	Amount of Rework(%)	0	10	15	25	40	60
Slow Evolution, High Sensitivity	Probability of Rework(%)	0	15	25	45	65	95
	Amount of Rework(%)	0	15	25	40	60	85
Slow Evolution, Low Sensitivity	Probability of Rework(%)	0	45	65	70	75	80
	Amount of Rework(%)	0	35	45	60	65	75

As overlap increases, the probability of rework and the amount of rework also increase.

(4) Definition of Each Activity's Characteristics

Tables 5 and 6 show the definition of each activity's characteristics in terms of design and construction. Fast Evolution does not mean the increase of overlap, but rather means the increase of overlap probability. The data is taken from interviews and written questionnaires, and will be used from analysis through to simulation.

Table 5. Definition of each Activity's Characteristics - Design

Activity	Evolution	Sensitivity
Land and deployment analysis The form of building plan	Slow	High
The form of building plan Flat, elevation, sectional plan	Fast	High
Flat, elevation, sectional plan Structure calculations	Fast	High
Structure calculations Complete basic design	Fast	High
Complete basic design Base Plate design	Fast	Low
Base Plate design Steel pillar design	Fast	High
Steel pillar design Plate design	Slow	Low
Plate design Truss Design	Slow	Low
Truss Design Details of the structure	Slow	Low
Details of the structure Check the drawings review	Slow	Low

Table 6. Definition of each Activity's Characteristics - Construction

Activity	Evolution	Sensitivity
Die Installation Reinforcement placing	Fast	High
Reinforcement placing Installing anchor bolts	Slow	Low
Installing anchor bolts Pour concrete and cure	Slow	Low
Pour concrete and cure The dissolution of the dice	Fast	High
The dissolution of the dice Anchor bolts calibration	Slow	Low
Anchor bolts calibration Install the base plat	Fast	High
Install the base plat Geurawooting	Fast	High
Geurawooting Install steel frame pillars production	Slow	Low
Install steel frame pillars production Plate production & setup	Fast	High
Plate production & setup Production Truss Installation	Fast	High

4. SIMULATIONS FOR DECISION MAKING

4.1 Case Results

(1) Flow-Chart of ARENA Simulation

To determine the change of time and cost with the overlap process, the authors performed an analysis of the simulation using ARENA.

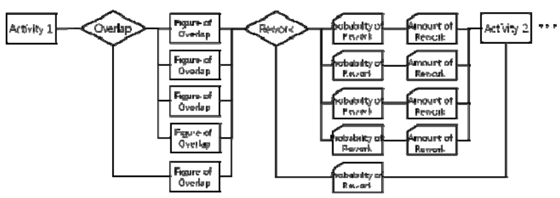

Fig 3. ARENA Flow-Chart of ARENA Simulation

The first box refers to the Activity. ② The first diamond represents the choice of whether to overlap an activity. ③ The contents of Tables 3 and 4 are in the five boxes in the third column. According to the level of each activity, 4 types of overlap levels have been used; Fast/Slow Evolution, and High/Low Sensitivity. ④ The forth diamond represents when rework occurs after overlap, while the second and third columns of boxes refer to the probability of rework and the amount of rework, respectively, according to process characteristics. After considering the amount of rework, the next process begins and each process is performed following the same pattern of flow, up until the final process.

The final result is obtained from the above process.

4.2 Simulation results analysis

(1) Design Analysis Result

Table 7 shows the 5 types of design for simulation of the design stage. From the interview and the questionnaires, type A is found to be the process that has been most overlapped and B ~ E is the value in lane. The project had a total of five types of design for which the time and cost was analyzed and then compared to a normal process.

Table 7. Type of overlap - Design

	1	2	3	4	5	6	7	8	9	10	11
A	0	20	20	40	20	60	60	40	40	60	60
B	0	20	20	20	0	20	40	40	20	40	40
C	0	20	40	60	40	80	80	60	60	80	80
D	0	20	0	40	20	40	20	40	20	20	40
E	0	40	40	60	60	60	60	60	80	60	60

Fig 4 shows the time and cost of overlap obtained from a total of 100,000 simulations. As overlap increases, time reduces but cost increases.

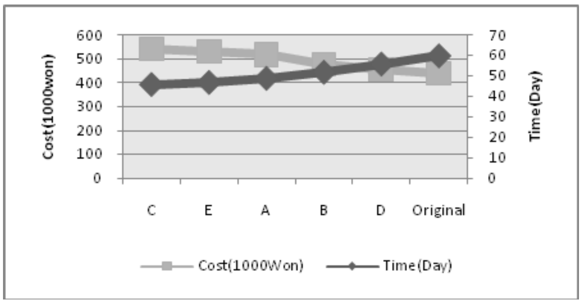

Fig 4. Result of Simulation 1 - Design

The time for types A, B, D and E was 60 days, while time reduced to 46 days for type C. However, an increase in overlap is not always beneficial because cost also increases as overlap increases.

Fig 5 shows time plotted against cost, as obtained from the simulation, in order to determine the optimum point for time and cost.

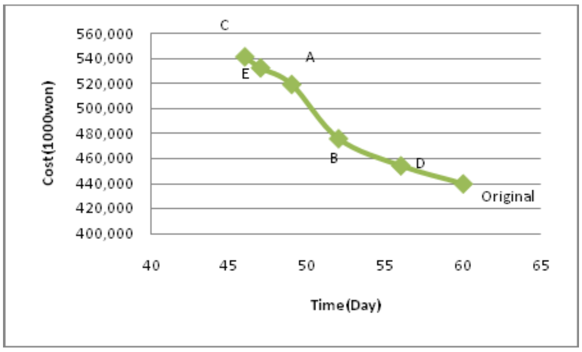

Fig 5. Result of Simulation 2 - Design

By comparing the time and cost with the original design time and cost simulation, the optimal point can be found for type B. In type C, time reduces less than cost.

Fig. 6 shows one day of cost of time reduction. Type D is most efficient because cost is reduced by 1 day. But the analysis of the relationship between total time and cost shows that type B is expected to be more effective.

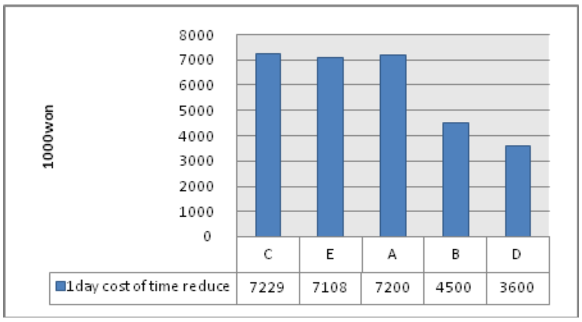

Fig 6. 1day cost of time reduce - Design

The results show that type A has the most efficient overlap, but it cannot be used in every construction project. Due to the variety of situations in each project, this result is only able to facilitate decision-making. Type

C should be applied to a projects when reducing time is the most important criterion, while types D and B should be applied to projects in which reducing the cost is the most important criterion of the project.

(2) Construction analysis results

Table 8 shows results of the simulation on the 5 types for the construction stage. From the interview and the questionnaires, type A is the process that has been most overlapped and B ~ E is the value in lane. The project had a total of five types for which the time and cost were analyzed and were then compared to a normal process.

Table 8. Type of overlap - Construction

	1	2	3	4	5	6	7	8	9	10	11
A	0	20	20	20	40	20	20	20	20	40	20
B	0	20	0	0	20	0	20	0	20	20	0
C	0	40	60	60	40	40	40	60	60	40	40
D	0	20	20	0	20	40	20	0	0	20	0
E	0	40	20	40	20	20	40	40	40	20	40

Fig.7 shows time and cost of overlap obtained from a total of 100,000 simulations. As overlap increases, time reduces but cost increases.

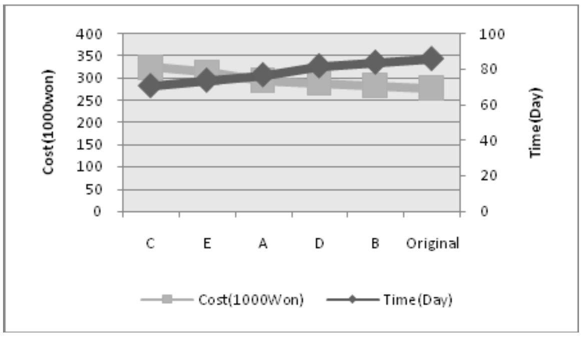

Fig 7. Result of Simulation 1 - Construction

The time was 86 days, but this was reduced to 71 days for type C. However, an increase of overlap is not always beneficial because cost also increases as overlap increases.

Fig 8 shows the best point for time and cost, as obtained from the simulation.

Comparing the results of time and cost with the original design time and cost simulation, the optimal point can be found for type A. In type C, time reduces less than cost. Types D and B do not particularly differ than the original.

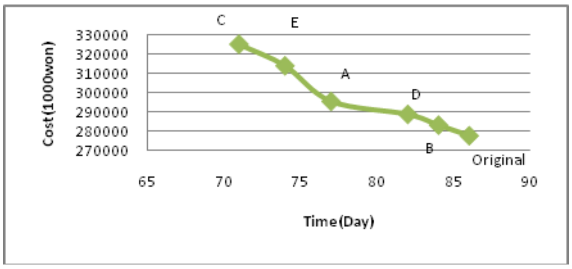

Fig 8. Result of Simulation 2 - Construction

Fig. 9 shows cost of time reduction for 1 day. Type A is most efficient, because of the cost required to reduce time by 1 day.

In contrast to the design stage, as cost increases, time can be significantly reduced. This is because during the construction stage, when input increases, duration can be significantly reduced.

Using the results of simulations, the usefulness of applying concurrent engineering for owners is demonstrated from quantitative results.

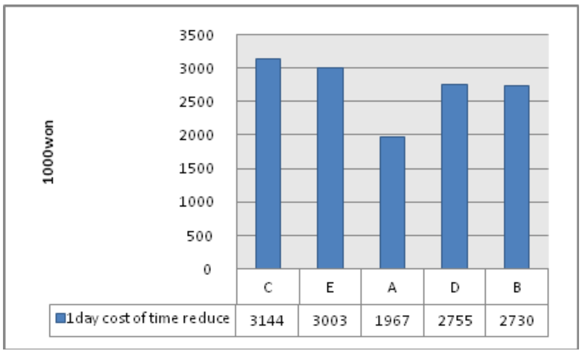

Fig 9. 1day cost of time reduce - Construction

Using the results, the owner can decide the optimal point for time and cost for the project.

5. CONCLUSIONS

The trade-off between time and cost in concurrent engineering was analyzed in this study through simulation. The results of the study are as follows.

First, for each activity, relationships between production and sensitivity were defined through a study of literature and materials, and through a survey of experts on concurrent engineering. And an actual case has been applied.

Second, quantitative data was obtained for the probability of rework and the amount of rework on overlap from research and surveys, and from interviews with engineers. 5 types of possible processes were defined and overlapped by simulation and analysis with time and cost.

Third, the actual case was selected and the data was used in simulation. The results of the survey were then compared with the simulation results. Concurrent engineering was then analyzed and applied in the construction project. In the design stage, type B is the most efficient type (overlap rate of 20%), while in the construction stage, type A is the most efficient type (overlap rate of 20%), although it cannot be used in every construction project. Due to the variety of situations in each project, this result is only able to facilitate decision-making.

Forth, the study shows that the specific measures to reduce time by overlapping are 'Fast Production, Evolution and Low Sensitivity'. However, Fast Production and Evolution do not necessarily imply unconditional overlapping and a reduction of duration. It is therefore necessary to review these measures by simulation.

A significant number of unexpected situations can occur in actual construction projects. Frequent design changes, natural disasters, civil actions, and other factors can have a significant influence in many construction projects. In this study these elements are excluded and only the changes of time and cost on overlap are analyzed. In the future, these elements should be included in the concurrent engineering strategy in order to implement plans on cost & time savings for the construction industry. In subsequent research, the fundamental problem about the construction project should be quantified, and more variables could be added. It would then be reasonable to apply the concurrent engineering strategy in construction projects.

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