The Effect of the Number of Floors on the Construction of the Houses Built by Conventional System and Precast Technology

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Abstract

This research studied the construction performance (durations, costs, and quality) of one-storey and two-storey houses built by traditional and precast load-bearing wall systems and analyzed the effects of the number of floors on the house construction performance. The study was done by (1) a detailed observation of the construction processes of eight houses, i.e. two one-storey houses & two two-storey houses built by the traditional system and two one-storey houses & two two-storey houses built by precast technology, and (2) an interview of three senior construction staffs in a housing project. The results were analyzed by Descriptive Statistics and Content Analysis. The results showed that: (1) As to the quality perspective, it was found that the number of defects per area is constant for precast load bearing wall houses while it is increased for conventional ones, when the number of floor is increased; (2) The construction durations of the traditional system houses are increased (130.26%) depending on the number of floors because the upper storey have more processes than the first storey. On the other hand, construction duration in precast houses will be less increased (55.00%) when the storey is increased because the second-floor component installation will be faster than the first floor ones and the amount of components in the upper storey is also less than the first storey; and (3) The unit cost of precast houses is decreased when the number of floor is increased while that of conventional houses is increased. The findings can help real estate developers select the building systems appropriate to the houses in their projects.

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1. Problem Statement

Nowadays, residences have various types, functions, and styles. Thailand's Real Estate Information Center (2014) revealed that single-detached house (SDH) is the most popular type of residences for Thai housing development, which was supported by the statistical data that the number of housing residences (total residential units excluding condominiums) built in Thailand in 2013 was 60,600 units, consisting of 31,100 units of single-detached houses (51.32%), 17,100 units of townhouses (28.22%), 9,700 units of shop houses (16.00%), and 2,700 units of twin houses (4.46%), respectively.

Other than the type of residences, the number of floors is one of the important parameters for developers in selecting products suitable to their projects. For example, there are one, two, and three storey products of townhouses and SDHs being sold in Thailand, responding various demands of their customers. In addition, the number of floors also affects the construction durations, costs, and quality of the residences. Moreover, the construction system is also one of the important parameters that developers have to concern. The cast-in-place concrete beam-column structure or the "conventional construction technique" was adopted for the single-detached house construction in Thailand for a long time. Taherkhani (2014) explained that conventional system is a quite handy method of construction which most activities in preparation of construction materials or components are carried out manually in the workshop. However, because of some of its disadvantages, e.g. labor intensive nature and high exposing to the physical conditions, the precast technology was alternatively adopted in housing industry. Precast concrete has various advantages such as high quality in production and construction, rapid construction on site, and lower disposal and maintenance cost (National Precast Concrete Association, 2006). Among several forms of precast technology, as classified by Abbood et al. (2015) into frame system, panel system, and box system, the load-bearing wall system or "panel system" is the most popular in Thai housing industry (Suriyawong, 2007).

Even the mentioned importance of the number of floors and the construction systems, there is no research work that direct mentions the relationship between the number of floors, the construction system, and the construction performances, in term of durations, costs, and quality of residences (Kerzner, 2006; Schwalbe 2010; Tochaiwat, 2012). From the reasons, the researchers were interested in studying the effects of the number of floors on the construction durations of the single-detached houses, which constructed by conventional system and precast technology. Developers can use the research results as guidelines in selection of the appropriate structural system for their projects in order to enchance the required performances.

2. Background

In Thailand, the houses are built by two main construction techniques: (1) conventional system, which the houses are built by cast-in-situ column and beam system, bricklaying and plastering walls (Jarutach, 1992), and (2) precast panel system (precast load bearing wall and precast slab). Xudong and Riffat (2007) explained the prefabrication housing as the processes of housing construction by producing the house elements in a plant, transporting, and installation at the site. These processes apply mass production concept, require less skilled-labors, and reduce construction wastes.

Because the different building laws, customers' preferences, construction techniques and materials, and costs of construction, the houses in Thailand seems to be different from the houses in other countries. From this reason, the literatures the authors reviewed in the field of the construction performances were mainly based on the research works in Thailand. According to Kerzner (2006), Schwalbe (2010) and Tochaiwat (2012), three main constraints of construction project management are construction time (duration), cost, and quality. There are some interesting research works that performed comparative studies between the houses constructed with the different construction systems. Anantachaiyong (2002) compared the construction performance of two-storey houses built by precast frame system (column and beam system) and conventional system and concluded that the column-beam precast system can reduce cost approximately 376 Baht per square meter (5.54%) to 965 Baht per square meter (14.22%) with 16 days (11.59%) less construction durations. Limthongthang (2005) compared the construction durations and costs between an one-storey conventional beam and column house and an one-storey precast load bearing wall house and concluded that the precast house has 155.52 Baht per square meter higher while the duration are 60 days faster than the conventional house. In addition, the precast house used nine labors less than the conventional one. Suriyawong (2007) compared between two sites with "station factory" and "site factory" and concluded that and concluded that the station factory can provide mass production with the better quality but it needs higher investment and more experienced workers. Similarly, Pongam (2005) compared the construction performance of the houses built by two real estate developers: one casts precast elements in a factory and the other casts them in a temporary factory. The results showed that the cost of structural works were 1,252 and 1,208 Baht per square meter of precast wall and floor areas for the houses built in factory and temporary factory, respectively. As to the construction duration, the duration of structural work construction of the houses were 7 days per unit for the developer with precast factory and 4 days for the developer with temporary factory.

However, there is still no research work mentioning about the effect of the number of floor on the construction performance of houses, both in conventional and precast systems. The authors believed that the findings will be the very useful information for developers in selecting the construction system for their housing projects, leading to the benefits to their business as well as their customers.

3. Research Objectives

This research has three main objectives:

1) To survey the construction durations, costs, and quality of the one-storey and two-storey houses constructed by conventional system and precast technology;

2) To compare the construction durations, costs, and quality of the one-storey and two-storey houses constructed by conventional system and precast technology;

3) To propose the guidelines for selecting the construction system for house construction, concerning its number of floors.

4. Scopes of Research

1) This research aimed to study the construction durations of the structural works of one or two floor houses built by conventional system and precast technology.

2) The precast houses studied in this study were constructed by panel system, which the walls and the floor members were built in precast panels.

3) In order to make the scope of works of the houses constructed by both construction systems (i.e. conventional system and precast system) comparable, the start and finish points for recording construction durations, costs, and defects (such as wall crack and missing line of beam and column as the quality indicators) for both systems were defined as follows:

(1) For conventional system houses, the construction durations were measured from starting ground beam construction to the finishing of wall plastering.

(2) For precast system houses, the construction durations were measured from starting precast member manufacturing to the finishing of all precast member installation.

4) Only the direct costs, acquired from the Bill of Quantities (BOQ), were used in analyzing the construction costs in this research.

5. Research Methodology

This research was done by observing the construction of eight houses and in-depth interview of three senior staffs of a housing project, i.e. project owner, project manager, and project engineer of the studied project. The detailed methodology comprised the following steps:

1) Review the literatures concerning construction systems (method, advantage, and disadvantage or limitation), schedule analysis technique, and the former research works concerning the performances, i.e. durations, costs, and quality, of house construction.

2) Select eight research samples by Purposive Sampling Technique. The samples consisted of two one-storey houses & two two-storey houses built by the conventional system and two one-storey houses & two two-storey houses built by precast technology. It should be noted that in order to control the external factors, the researchers had looked fora housing project where its developer mixed two construction systems, e.g. conventional system and precast system, and decided to develop both one-storey and two-storey types in the same project. In addition, the samples should be constructed by the same project team at the times not significantly different. Finally, a 389 unit project, located in Samutsakorn Province, was selected. The details of the samples used in this research were shown in Table 1 below.

The one-storey samples have three bedrooms, two bathrooms, one living room, one kitchen, and one parking lot. They have 105.00 square meters overall usable area, which can be further divided into 85.00 square meters on-beam slab structure and 20.00 square meters on-ground slab structure, and 247.95 square meters floor and wall areas. The conventional type samples have seventeen 20 x 20 centimeter columns and 80.5 meters of 20 x 30 and 20 x 40 centimeter beams, depending on their transferred loads. The majority of slabs are pre-stressed plank slabs and the walls were built by lightweight-block bricklaying and plastering. On the other hand, the precast samples have five precast ground beams, eight precast slabs, and 22 precast walls. The perspective and floor plan of one-storey samples are shown in Figure 1 and Figure 2, respectively.

As to the two-storey samples, they have three bedrooms, three bathrooms, one living room, one kitchen, and two parking lots. They have 175.00 square meters overall usable areas, divided into 138.00 square meter on-beam slabs (59.6 square meter on first floor and 78.4 square meter on second floor) and 37.00 on-ground slabs, while the total areas of slabs and walls are 410.67 square meters. The conventional samples have thirty 20 x 20 centimeter columns and 140.5 meters of 20 x 30 and 20 x 40 centimeter beams. The slabs are pre-stress plank slabs and the walls are built by lightweight-block bricklaying and plastering. According to the precast samples, they have ten precast ground beams, fifteen precast slabs, three members of precast stair, 44 precast wall members. The perspective and floor plans of two-storey samples are shown in Figure 3 and Figure 4, respectively.

3) Prepare the research tools,

3.1) Construction process recording form The researchers designed this form in order to record the construction process, as well as the number or labors, headmen, materials, and equipment consumed and the problems found in the observation of the samples' daily construction processes.

3.2) Interview form This form was designed for collecting the data from the project owner, project manager, and project engineer of the selected project. The acquired data were the explanation of the project, construction processes, problems and suggestions, and confirmation of the acquired observation data. These data will be used in analyzing and discussing the acquired data from observation. In addition, the researchers also requested the bill of quantities of the houses from the interviewees during the interviews, in order to use in analyzing the construction cost of the samples.

Sample No.	Structural System	Number of Floors	Usable Area (Sq.m.)	Total Floor & Wall Area (Sq.m.)	Beam Length (m.)		Number of Column (column)	
					1st Floor	2nd Floor	1st Floor	2nd Floor
1	Conventional	1	85.00	247.95	80.5 (included roof beams)	N/A	17	N/A
2	Conventional	1						
3	Precast	1						
4	Precast	1						
5	Conventional	2	138.00	410.67	67.9 (ground beams)	72.6 (included roof beams)	16	14
6	Conventional	2						
7	Precast	2				28.6	N/A	N/A
8	Precast	2						

Table 1. Details of the Samples Used in This Research.

Figure 1. Perspective of One-storey Samples.

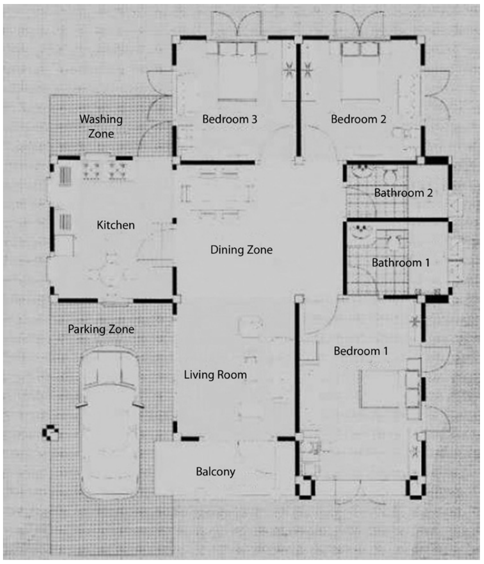

Figure 2. Floor Plan of One-storey Samples.

Figure 3. Perspective of Two-storey Samples.

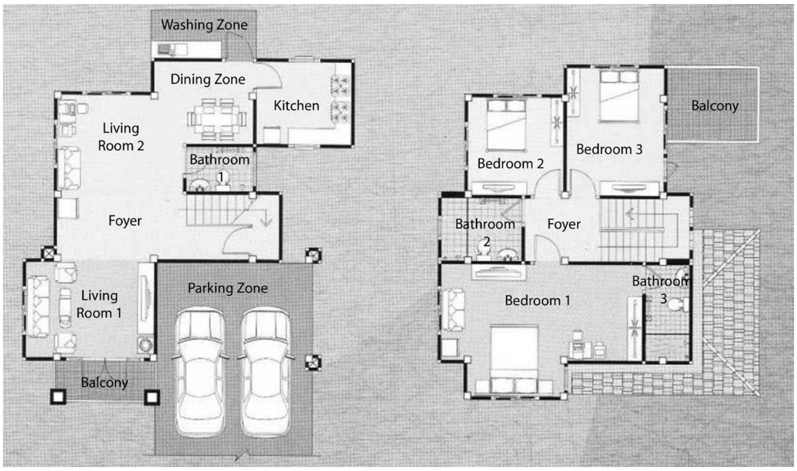

Figure 4. Floor Plans of Two-storey Samples.

4) Collect data by record the construction processes, durations, defects of the samples. Photographs were taken for the processes and the defects. Then, the acquired data were confirmed with the senior staffs. In addition, the project and samples' data, e.g. house catalogues and their bill of quantities, were requested.

5) Analyze the acquired data by:

5.1) Descriptive Statistics for the quantitative data such as the average construction durations, unit costs of construction, and numbers of defects per areas.

5.2) Content Analysis for the qualitative data such as the explanation of the project, construction processes, problems and suggestions, and confirmation of the acquired observation data.

6) Conclude the guidelines for selecting the construction systems, concerning the number of floors.

6. Results

6.1 Construction Processes of One- and Two-storey Houses

6.1.1 Conventional Houses

From the observation and confirmed by interviewing, the construction process of one-storey houses built by conventional system consists of seven steps: (1) foundation works, (2) cast-in-place (CIP) ground beam works, (3) CIP column works, (4) precast floor plank with concrete topping works, (5) bricklaying works, (6) roof works, and (7) plastering works, respectively. In addition, the construction process of two-storey houses built by the same system consist of twelve steps: (1) foundation works, (2) CIP ground beam works, (3) CIP first-floor column works, (4) precast plank first-floor with concrete topping works, (5) CIP second-floor beam works, (6) CIP second-floor column works, (7) precast plank second-floor with concrete topping works, (8) stair works, (9) first-floor bricklaying works, (10) roof works, (11) second-floor bricklaying works, and (12) first-floor and second-floor plastering works, respectively.

6.1.2 Precast Houses

On the other hand, the construction process of the precast one-storey samples comprises: (1) casting of precast members, (2) curing of precast members and storing, (3) transportation, (4) precast ground beam works, (5) precast slab works, (6) precast wall works, and (7) roof works, respectively. As to two-storey precast samples, the construction process comprises: (1) casting of precast members, (2) curing precast members and storing, (3) transportation, (4) precast ground beam works, (5) precast first-floor slab works, (6) precast first-floor wall works, (7) precast second-floor slab works, (8) stair works, (9) precast second-floor wall works, (10) roof works, and (11) first-floor and second floor skim-coat works, respectively.

6.2 Construction Durations of One- and Two-storey Houses

From observation and confirmed by interviewing, the construction durations of eight samples are shown in Table 2.

Sample No.	Structural System	Number of Floors	Durations		Construction Speed (Sq.m./ Day)
			Duration (Days)	Average Duration (Days)	
1	Conventional	1	36.00	38.00	2.24
2	Conventional	1	40.00		
3	Precast	1	18.00	20.00	4.25
4	Precast	1	22.00		
5	Conventional	2	83.00	87.50	1.58
6	Conventional	2	92.00		
7	Precast	2	28.00	31.00	4.45
8	Precast	2	34.00		

Table 2. Construction Durations of the Samples.

From Table 2, the construction durations of conventional two-storey, conventional one-storey, precast two-storey, and precast one-storey samples are 87.50, 38.00, 31.00, and 20.00 days, respectively. Dividing the areas of the houses (85 square meter for one-storey houses and 138 square meter for two-storey houses respectively) with the average duration of the houses, it was found that the construction speeds are 1.58, 2.24, 4.45, and 4.25 square meter per day for conventional two-storey, conventional one-storey, precast two-storey, and precast one-storey samples, respectively. It can be notified that the construction durations of the precast houses are much shorter than that of the conventional ones, as shown from the result that the average duration of the precast two-storey samples is shorter than the average duration of conventional one-storey samples. This finding confirmed the explanation of National Precast Concrete Association [NPCA] (2006) and Limthongthang (2005).

Comparing the average construction durations, acquired in Table 2, among groups of samples, the difference between the samples with different construction system and different number of storey are summarized in Table 3.

	One-storey	Two-storey	Increasing Duration
Conventional System	38.00 Days	87.50 Days	49.50 Days (130.26%)
Precast System	20.00 Days	31.00 Days	11 Days (55.00%)
Decreasing Duration	18 Days (47.37%)	56.50 Days (64.57%)	

Table 3. Construction Duration Comparison.

When the number of floors increases from one storey to two storeys, the durations are increased 130.26% for the samples with conventional system and 55.00% for the samples with precast system, respectively. Comparing with the increasing area of slabs and walls from 247.95 to 410.67 square meters (65.63% increase), the duration change of the conventional samples are much higher while the duration change of the precast samples are less. The reason that the duration increases very high when comparing between one-storey and two-storey conventional houses is the more complex construction works required to be done for the conventional houses (i.e. cast-in-place second-floor beam works, cast-in-place second-floor column works, precast plank second-floor with concrete topping works, stair works, roof works, second-floor bricklaying works, and second-floor plastering works), compared to the second-floor works of the precast houses (i.e. precast second-floor slab works, stair works, precast second-floor wall works, roof works, and second floor skim-coat works). Moreover, the interview results showed that the increasing second-floor beam work of conventional system consumes a lot of times to prepare the formworks and to cure the concrete until its strength reaches the required number. For precast houses, the construction duration increasing rate is less than the floor and wall area increasing rate because the times used in casting and transportation of precast elements and roof works are not significantly different.

As to the difference between two structural systems, the construction duration decreases 47.37% when an one-storey house is built by precast while it decreases 64.57% for two-storey house case. The reasons are that the precast system can save the time used in casting columns and beams, wall bricklaying, and plastering. It should be notified that, because the times used in roof construction are nearly the same for both structural systems, the percentage of the reducing time for two-storey house is higher than the reducing time for one-storey house.

6.3 Construction Costs of One- and Two-storey Houses

From the interview of senior staffs and analyzing the acquired bills of quantities (BOQ), the construction unit costs of the samples, categorized into the groups by the construction works are shown in Table 4.

The cost per area of the samples can be ascending sorted as: (1) one-storey conventional houses, (2) two-storey conventional houses, (3) two-storey precast houses, and (4) one-storey precast houses, respectively. It can be notified that the precast houses seem to have higher unit costs than the conventional houses. This finding supports the results of Limthongthang (2005) that the direct cost of precast load-bearing-wall system is higher than that of conventional system.

As to the effects of the number of floor on the construction cost per area, there are two interesting findings need to be discussed. Firstly, the ratio between the construction costs per area of precast samples and conventional samples are 136.55% (3,902.98 / 2,858.25 = 1.3655) and 124.65% (3,762.07 /3,018.19 = 1.2465) for one-storey and two-storey samples, respectively. The incremental percentages are decreased when the number of floors is increased because the unit cost of the conventional houses increases significantly faster than the unit cost of the precast houses (71.44% that is from 173,559 /242,951 = 0.7144 for conventional houses compared to 56.49% that is from 187,413/331,753 = 0.5649 for precast houses), when the number of floors are increased from one-storey to two-storey. This phenomenon can be explained by the more difficult structural works of the conventional houses, i.e. second floor beams, columns, and slabs, which have to be casted in the high level comparing to the first floor structural works that are casted at the ground level while the construction processes of the first floor and second floor are not much different for precast houses. Secondly, the unit cost of precast houses is decreased when the number of floor is increased while that of conventional houses is increased. This can be explained from the fact that the second-floor works of the precast houses are less complex than the first-floor works.

Table 4. Construction Unit Costs Analysis.

Cost Category	Conventional System (Baht)			Precast System (Baht)		
	1-storey	2-storey	Diff.	1-storey	2-storey	Diff.
1. Structure (Not Included Foundation)	101,468 (1,193.74)	237,233 (1,719.08)	135,765 (525.34)	224,758 (2,644.21)	389,360 (2,821.45)	164,602 (177.24)
2. Wall Bricklaying and Plastering	56,353 (662.98)	85,794 (621.70)	29,441 (-41.28)	21,865 (257.24)	36,323 (263.21)	14,458 (5.97)
3. Roof System	85,130 (1,001.53)	93,483 (677.41)	8,353 (-324.12)	85,130 (1,001.53)	93,483 (677.41)	8,353 (-324.12)
Total	242,951 (2,858.25)	416,510 (3,018.19)	173,559 (159.94)	331,753 (3,902.98)	519,166 (3,762.07)	187,413 (-140.91)

Remarks: Numbers in ( ) show the construction unit costs (Baht per square meter).

6.4 Construction Quality of One- and Two-storey Houses

In order to compare the quality of the samples, the numbers of defects were used as the indicators. The researchers recorded the types and the numbers of defects found in the house structures within a few days after the contractor finished the construction of the structural and wall works and confirmed with the interviewees. It should be noted that even some defects such as cracks on conventional walls may be happened from several factors and not be directly caused by house structure, they seems to be happened from the different material or construction details of the different construction system, e.g. brick is used in conventional system but not in precast system. The types and the numbers of defects were shown in Table 5, Figure 5, and Table 6, respectively:

Sample	Defect Position	Type of Defects
1. Conventional Samples	1.1 First Floor	Crack on Wall / Missing Line of Beam and Column
	1.2 Second Floor	Crack on Wall / Missing Line of Beam and Column
2. Precast Samples	2.1 First Floor	Crack on Wall
	2.2 Second Floor	Crack on Wall

Table 5. Types of Defects Found in the Samples.

(a) (b) (c)

Figure 5. Types of Defects Found in the Samples:
(a) Crack on Wall in Conventional Samples
(b) Missing Line of Beam and Column in Conventional Samples
(c) Crack on Wall in Precast Samples

According to Table 6, it should be noted that the numbers of defects of precast samples were much less than the number of defects of conventional ones, accordance with National Precast Concrete Association [NPCA] (2006), which implied workmanships of the contractors had less impact on the precast samples. As to the effects of the number of floors, the number of defects found in the precast samples seems to directly vary with the amount of works, as shown from the constant number of defects per area when the number of floor changed from one storey to two storeys. The interview results showed that most of the defects were the cracks on walls, which occurred in some specific weak-points, e.g. the narrow panels nearby door or window openings or the joints of wall members, during the transportation or erection processes.

On the other hand, the number of defects per area in the conventional samples seems to be increased when the number of floor increases. This can be explained by the fact that the second floor elements are difficult to build than that of the first floor, leading to more defects occurred.

Sample No.	Sample Type	Number of Defects	Average Number of Defects	Number of Defects / Sq.m.
1	Conventional One-storey House Unit#1	14	12	0.14
2	Conventional One-storey House Unit#2	10		
3	Precast One-storey House Unit#1	1	2	0.02
4	Precast One-storey House Unit#2	3		
5	Conventional Two-storey House Unit#1	24	25	0.18
6	Conventional Two-storey House Unit#2	26		
7	Precast Two-storey House Unit#1	6	3	0.02
8	Precast Two-storey House Unit#2	0		

Table 6. Numbers of Defects Found in the Samples.

It should be noted that the types of defects found in each sample seems to be similar for same construction system. This finding came from the fact that the samples were constructed from the same contractor for each construction system.

7. Conclusion and Suggestions.

In this article, the authors observed the construction durations, costs, and quality and analyzed the effects of the number of floors on one-storey and two-storey houses, built by conventional and precast systems. The results showed that:

(1) The construction durations will be much longer for the conventional houses comparing to the precast ones when the number of floor increases from one to two. As to the effects of the construction systems, two-storey houses can save more duration, compared in percentage, than one-storey houses, if developers change the construction system from conventional system to precast system. From the findings, precast system prevails conventional system concerning the increasing rate of construction when the number of floors is increased from one-storey to two-stories.

(2) The construction costs per square meter of precast houses are higher than the costs per area of conventional houses. However, the increasing percentages will be decreased when the number of floors is increased. From the findings, two-storey houses are more interesting for developers to apply the precast system than one-storey houses.

(3) As to the quality of construction works, precast houses have significantly higher quality than conventional ones. The number of defects found in the precast houses will directly vary with the amount of works while the number of defects per area will be increased for conventional ones.

The research results seem to support the application of precast system to two-storey single-detached house (SDH) projects, concerning the durations, costs, and quality per-spective. For one-storey SDH projects, developers need to trade-off between the shorter construction durations & higher quality and the increased costs. However, in order to make the effective and practical decisions, developers should take into account of some other concerns as men-tioned in several articles such as Walailaksanaporn (2014), Kineesee (2006), Maleerak (2013), and Wankanaporn, Chindapol and Tantasavasdi (2013) e.g. number of units in project, skills of staff and contractors, perceptions of customers through the new construction system, and environment impact, which were not in the scope of this research.

For the other types of buildings or the houses with different usable areas, developers may apply the rates of construction per area, construction costs per area, and the numbers of defects per area from this artcle to the first floor and the other higher floors, concerning their areas and construction systems, in order to estimate the speed, cost, and quality of the building construction process. However, it is recom-mended that the interested researchers should perform further studies about the effects of the number of floors on the other types of residential buildings or compare among the effects on houses with various usable areas, in order to confirm the authors' assumptions.

There are some limitations of this research which need to be addressed: (1) Because the research was designed to compare between the houses with the same design but different construction system, the samples were selected from only one housing project which the researchers found there were two construction systems implemented. Even though this research design can control some factors, e.g. size, design, and material, but it leads to the questions concerning its lack of variety of some factors such as workmanship and quality control process. (2) Avoiding the effects of business disturbance, the researchers were allowed to collect data from eight samples. Even though the interviewees confirmed that the construction processes and the bill of quantities of all units in the project were consistent, this may lead to the question of the ability to be representatives of the research results. However, the detailed findings are valuable for further construction studies.

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