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Analysis of the Impact of Building Shape on Safety Management Cost

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Abstract: Even if a building has the same building area or number of floors, the effect on construction safety varies depending on the building shape, and thus, safety management cost (SMC) should be calculated differently. If the effect of the building shape on the SMC is clearly analyzed and reflected, a reasonable SMC could be calculated. This study analyzes building shape's impact on SMC, including apartment buildings' impact. Following the data collection from 21 projects for this study, an analysis was conducted using the independent variables of the building perimeter (BP), building floor area (BA), and the building shape factor (BSF), and the dependent variable of SMC. As a result of analyzing the correlation between the three main factors and SMC, it was found that the BP, BSF, and BA have a very strong positive Pearson correlation coefficient of 0.876, 0.801, and 0.792, respectively. In the future, the results of this study can be used as supporting data for improving the safety management cost-related system and will develop into a more reliable model through continuous data accumulation and utility verification.

Keywords: building shape; building perimeter; building floor area; building shape factor; safety management cost

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1. Introduction

Despite ongoing attempts to reduce on-site safety accidents, the construction industry is still classified as a high-risk sector with a high fatal-accident rate [1]. According to the data from the Korean Ministry of Employment and Labor (MOEL, 2021), an analysis of accident status in 10 industries in 2019 showed that the construction industry had the highest work accident rate (26.9%) with 25,298 people, followed by the manufacturing industry (25.18%) with 23,684 people, and transportation, warehouse, and telecommunication industry (5.8%) with 5464 people. As per the mortality rate by industry, the construction industry had the highest mortality rate (50.1%) with 428 people, followed by manufacturing (24.1%) with 206 people and others (service) (13.8%) with 118 people. The death toll in construction sites worldwide is alarming as well [2]. In terms of the number of deaths per 100,000 workers on construction sites in Organization for Economic Co-operation and Development countries (International Labor Organization, 2016), Israel had the most at 24.8 people, followed by Mexico (19.5 people), Korea (17.6 people), and Portugal (15.6 people). Additionally, the building site in Israel had the highest mortality toll, with more than 2000 deaths per year when calculated with the whole population.

Design for Safety (DFS), a safety management system for preventing construction accidents by managing risk factors at all stages of construction activity, such as planning, design, construction, and project management, is being used to reduce the construction safety accident rate [3–5]. Many construction site safety accidents are related to design. Thus, the accident rate can be reduced if the degree of construction difficulty is accurately considered and reflected during the design stage [6–8]. Safety accidents can be decreased if

DFS is conducted on structures of varied shapes, and efforts are concentrated on reducing safety accidents at the construction stage. This is because there is a high incidence rate of safety accidents, including fatal accidents, during the construction stage. However, designers with inadequate knowledge of construction safety and site environment often fail to recognize how design might cause risks during the lifecycle of building facilities, including construction, operation, and maintenance [9]. Therefore, even if safety management is implemented using the DFS concept, there are limitations in lowering the safety accident rate during the construction stage [10–13]. The safety management cost (SMC) suitable for the characteristics of the construction site must be invested in for efficient construction site safety management. Even though structures have the same building area (BA), the cost of safety facilities such as fall prevention nets and safety fences, which account for most SMCs, will vary depending on the shape of the structure [14].

Tang et al. (1997) investigated 576 safety accidents at 18 sites. Therefore, they discovered that the amount of loss caused by accidents, including death at construction sites, exceeded the SMC used to prevent safety accidents [15]. Tam et al. (2004) investigated the safety management status of construction sites in China and concluded that the most influential factor affecting the safety of construction sites is the investment of SMCs suitable for the characteristics of construction sites so that factors related to safety management, such as the provision of personal protective devices, regular safety meetings, and safety education, can be properly implemented [16]. Ahn et al. (2021) identified a reason for the high disaster rate in the construction industry as SMCs that did not match the features of the construction site. They stated that the cost to strengthen safety management cannot be covered if the cost is calculated at a ratio derived in proportion to the overall construction cost without reflecting the characteristics of the building shape, number of floors, and construction period [17]. As such, various studies have been conducted on the importance of SMCs reflecting the characteristics of construction sites.

Therefore, the purpose of this study is to analyze the effect of the building shape on SMCs in the case of apartment buildings. Even if a building has the same BA or number of floors, the effect on construction safety varies depending on the building shape, and thus, SMCs should be calculated differently. If the effect of the building shape on the safety management cost is clearly analyzed and reflected, a reasonable SMC could be calculated. The result of this study could be used as a basis for calculating SMCs reflecting the characteristics of construction sites and will further contribute to lowering the safety accident of the construction industry.

2. Literature Review

2.1. Definition and Calculation Method of Safety Management Cost

The SMC for construction projects in Korea is the cost stipulated to activate safety and health management under the Occupational Safety and Health Act of the MOEL. Depending on the type of construction, a certain amount should separately be appropriated in the construction contract. The ordering body and the constructor will use it only for the safety of workers, such as safety facility expenses, safety-related personnel expenses, and safety reporting equipment. When calculating the construction cost, the direct construction cost is calculated by adding up the direct construction costs for each type of construction process. Afterward, the indirect construction cost is calculated by multiplying the direct construction cost by a certain ratio. One of the indirect construction cost items is the calculation standard of the SMC. Table 1 shows the appropriation standard of the SMC which is determined according to the standards based on the MOEL Occupational Safety and Health Act, Article 72-1 (Appropriation for Occupational Safety and Health Management Expenses of Construction Projects, etc.) [18].

Table 1. Safety management cost appropriation standard [18]. Unit: 1000 USD.

Division	Under 436	436~4360		4360 or More
		Ratio	Base Amount	
General construction (A)	2.93%	1.86%	4.67	1.97%
General construction (B)	3.09%	1.99%	4.75	2.10%
Heavy construction	3.43%	2.35%	4.71	2.44%
New railroad and track construction	2.45%	1.57%	3.85	1.66%
Special and other constructions	1.85%	1.20%	2.84	1.27%

Note: 1146 Won = 1 USD as of 30 March 2022 (Bank of Korea).

The problem with the SMC calculation method presented in Table 1 is that it is calculated by applying the same ratio to the construction cost once the project is classified, without reflecting the project characteristics such as the building perimeter (BP), building shape, and BA. When the SMC is calculated in this way, the installation cost of safety facilities varies depending on the building shape and the number of floors even for a construction project with the same total floor area. The more complex the building shape, the longer the construction period, increasing the labor cost of the safety manager as well. Under the current system, except for the SMCs calculated by the standard, the construction company must pay for the increased SMCs.

To examine the SMC calculation methods of foreign construction sites, the Labor Ministry's Labor and Technology Standards Bureau is committed to determining SMCs at overseas building sites in Japan, and it is comparable to the system used in Korea. SMC is included in the common temporary work cost, and safety evaluation is conducted in advance, but the characteristics of the project are not reflected [19]. In the case of Switzerland, as in Korea, SMC is appropriated according to the ratio for each construction type based on the total amount of construction, with no regard to project characteristics [20]. In contrast, the United Kingdom has the Health and Safety Executive which is an agency dedicated to determining time-specific risks under the Construction Design Management system and planning safety precautions to calculate the amount and quantity of safety management measures separately [21].

SMC on construction sites has the highest safety accident and mortality rates worldwide and is a crucial factor directly linked to safety accidents. Therefore, safe and sustainable site management cannot be achieved if the degree of construction difficulty, including the building shape, is not reflected and the SMC is uniformly calculated with a ratio of the construction amount [22–24].

2.2. Factors That Influence the Calculation of Safety Management Cost

The following review studies the calculation and influencing factors of SMC. Guha et al. (2013) stated that most of the construction industry's SMCs are set lower than the actual budget required. They also stated that since the budget for safety management is limited, SMCs should be appropriated based on reasonable standards [25].

Okoye et al. (2014) stated that a large portion of SMCs is safety facility and labor costs. They argued that the SMC must surely be preferentially allocated as per the site's characteristics for safety performance at construction sites. However, they mentioned that the smaller the construction company, the lower the set SMC than the necessary budget. Consequently, more investment is needed in terms of time and effort [26].

Jin (2011) stated that the most important factor in SMC is safety management labor cost. He stated that if the construction project is prolonged, the burden of labor costs for safety managers will increase, causing insufficient SMCs. In this case, he described that the cost of installing safety facilities such as safety nets to prevent accidents due to falls, etc. would become insufficient [27].

Smallwood (2004) mentioned the designer's influence on safety accidents at construction sites and said that the safety accident rate at construction sites might vary depending on the design of the building. He claimed that the designer is a critical factor that directly or indirectly affects safety management to lower the safety accident rate at construction sites. In addition, it is possible to improve the design and procurement stage for realistic safety management [28].

Choi et al. (2014) pointed out that SMC does not adequately protect workers from accidents because it is used more in the operation of safety managers than personal protective equipment. In other words, it is difficult to allocate a balanced budget because costs are allocated according to the reinforced regulations within the limited SMC. Thus, balanced safety management cannot be conducted [29].

Hamid (2012) investigated the importance of construction site safety management and the improvements to be made by collecting and analyzing the case data on construction site accidents from the Department of Occupational Safety and Health in Malaysia. He pointed out that unsystematic safety management and poor safety facilities and equipment resulting from inadequate SMCs are the main causes of safety accidents at construction sites. In addition, he said that the expenses paid due to safety accidents at construction sites are 10 times the SMC and that unreasonable SMC causes more expenditure [30].

Ahn et al. (2021) investigated and analyzed the actual spent SMCs for 23 high-rise residential building sites, considering the building shape, the number of floors, and the construction period, and presented an SMC calculation model reflecting the characteristics of the construction sites. According to the analysis of the actual SMC spent at the case sites, the items whose cumulative ratio satisfies more than 80% were facility and labor costs, with safety net installation costs accounting for the biggest percentage of facility costs [17].

As shown above, most studies cited safety-related facility costs, labor costs, and designer's influence as impacting factors in calculating SMCs. However, no studies have analyzed the direct correlation between building shape and SMCs. Suppose the correlation between the building shape and the SMC is verified. In that case, accurate and reasonable SMCs could be calculated via the building shape. Additionally, when accurate and reasonable SMCs can be calculated by reflecting the characteristics of construction sites, it will be possible to efficiently spend SMCs, such as investing in additional safety facilities or deploying additional safety management personnel. Therefore, this study analyzes the correlation between the building shape and SMC by collecting and analyzing the actual spent SMC data from 21 apartment building sites.

3. Methodology

3.1. Research Method

This study is conducted as shown in Figure 1. First, the existing safety management cost calculation process is investigated. Through this, the problem of the existing safety management cost calculation method is derived. Second, actual safety management cost data are collected for case sites. In addition, BP, BSF, and BA data at the case site are collected. Third, the correlation between the three main factors and SMC is analyzed. Finally, we discuss the results of the study.

3.2. Case Projects Overview

This study collected data on actual spent SMC and building shape factor (BSF) data for 33 apartment building construction sites completed in Korea. The survey period was for 13 months, from July 2020. As a result of reviewing the collected data, 12 sites were excluded because their data on personnel input to safety and the volume of safety nets were unreliable.

Table 2 shows the analyzed 21 sites. The 21 selected apartment building projects had an average construction duration of 33 months, an average of 8 buildings, a total floor area of 174,467 m^2, an average BA of 9866 m^2, and an average of 18 floors, most of which began to be constructed in 2016 and completed in 2020.

This study investigated the actual spent SMCs for each case project in Table 2. Furthermore, the correlations between the factors affecting the building shape and SMCs were analyzed. The factors for the building shape are discussed in detail in Section 3.3.

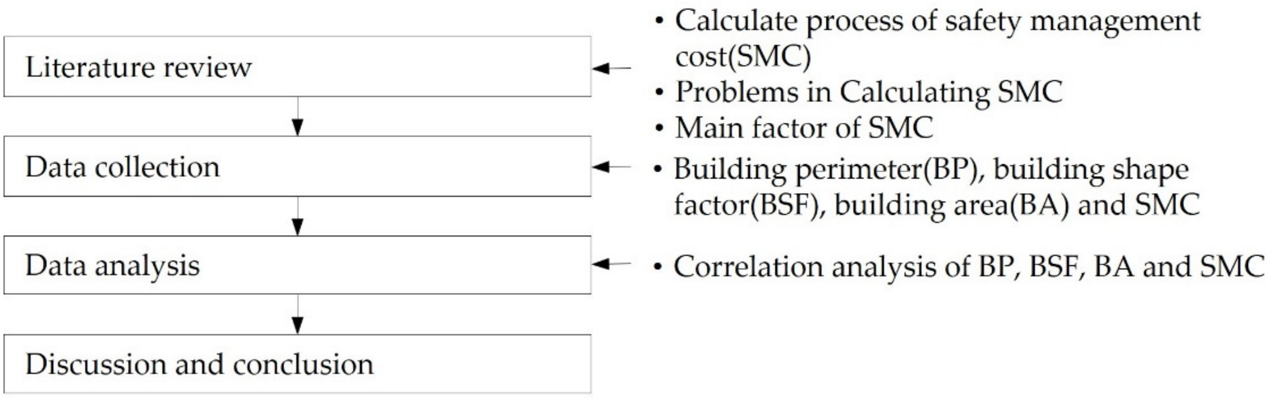


Figure 1. Research method.

Table 2. Brief description of the case projects.

No.	Duration (Months)	No. of Buildings	Highest Floor	Average Floor	Total Floor Area (m^2)	Building Area (m^2)	Total Const. Cost (1000 USD)
1	30	12	22	18	53,717	3025	62,553
2	29	5	23	21	63,423	2951	69,736
3	35	2	37	11	50,410	4581	72,412
4	27	1	15	7	56,358	7828	76,584
5	27	8	24	17	75,483	4554	78,361
6	27	7	27	20	102,252	5129	92,144
7	35	8	27	20	106,107	5356	92,301
8	42	2	49	16	91,274	5573	93,729
9	31	6	29	20	211,532	10,467	97,781
10	29	6	29	20	125,849	6325	120,475
11	29	7	22	17	143,044	8668	149,576
12	27	12	24	19	157,213	8436	153,364
13	41	5	49	18	146,552	8348	176,647
14	33	8	37	23	160,901	7127	184,028
15	32	18	20	13	241,068	18,242	205,560
16	31	1	15	14	270,406	19,536	214,903
17	33	10	35	22	195,603	8773	224,600
18	28	15	25	19	261,783	13,831	231,663
19	31	16	25	20	77,278	3936	240,964
20	36	12	43	25	293,555	11,653	283,148
21	36	17	35	19	811,619	42,902	377,505
Avg.	33	8	30	18	174,467	9866	157,133

Note: 1146 Won = 1 USD as of 30 July 2021 (Bank of Korea).

3.3. Data Collection for Case Projects

To analyze the correlation between the building shape and the SMC, the BP, BA, and SMC of the 21 construction sites were investigated, and the BSF was calculated based on the additionally investigated data. According to the study by Ahn et al. (2021), the change in the BP due to the building shape in the case of the same BA was described using the BSF. The BSF, which represents the complexity of the building shape, is calculated as shown in Equation (1) [17].

$$BSF = BP \div \left(\sqrt{BA} \times 4\right) \quad (1)$$

Here, *BSF*: building shape factor, *BP*: building perimeter, *BA*: building area.

As shown in Equation (1), the BSF is calculated by dividing the BP of the case building by the BP when it is squared. In other words, the BSF of the case building is determined by the relative ratio of the building when the BSF of the square building is set to 1.

Compared with a square-type building, the BP of a rectangular-type building increases by about 25%, and that of a polygonal-type building increases by about 67%. Figure 2 shows the difference in the BP compared to the similar BA at the case site. The BA of cases A and B are similar to 1050 and 1000 m^2, respectively. However, the BP of cases A and B are 170 and 130 m, respectively, showing a difference of about 24%. In other words, in the case of the same BA, if the BP is longer than that of a square building, SMCs increase due to installing fall-preventing nets and additional safety fences and the resulting increase in labor costs. Therefore, the building shape is a critical factor reflecting the characteristics of the construction.

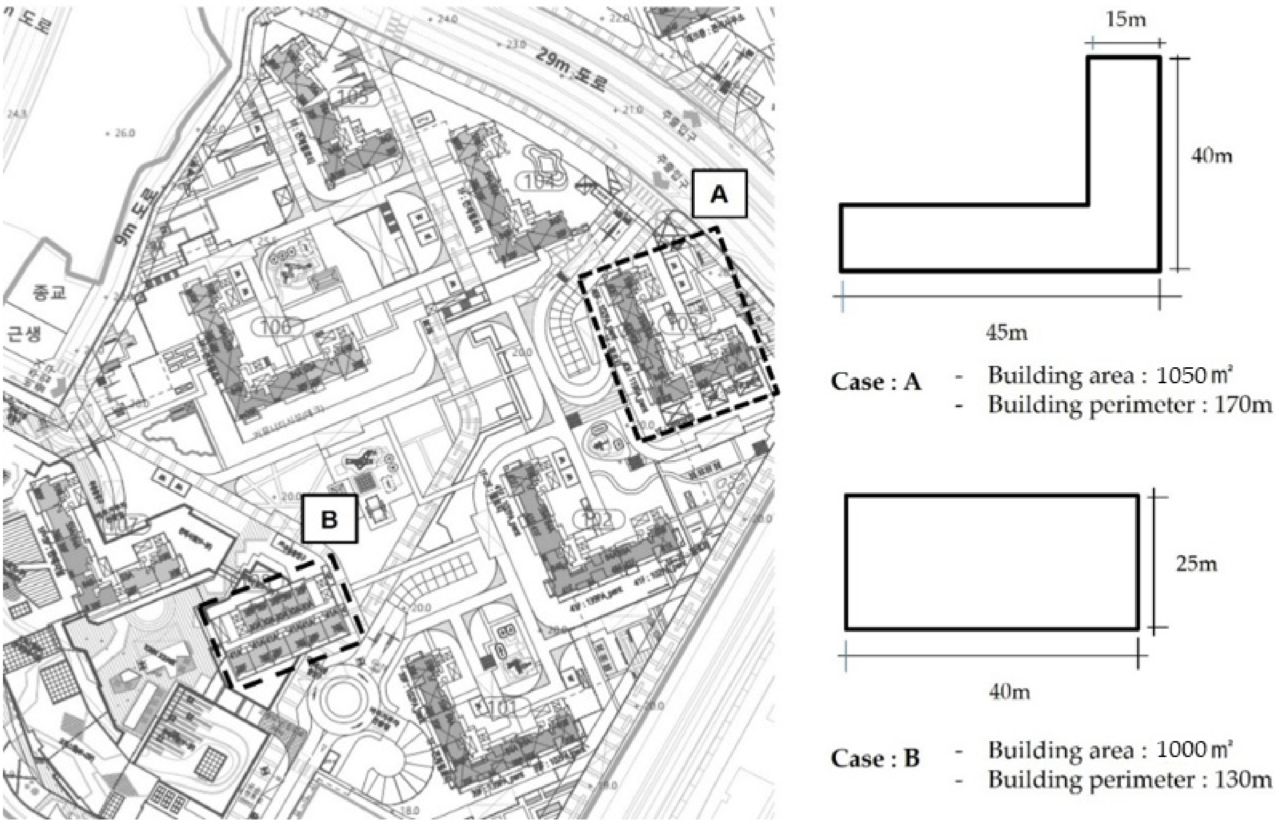


Figure 2. Comparison of building perimeter relative to building area.

The BP is the sum of the total BPs of the building for each case site. The SMC is calculated as the sum of eight costs: the safety manager's labor, safety facility, personal protection equipment, safety inspection, safety education, worker healthcare, construction disaster prevention guidance, and headquarters overhead. In this study, the building's BP, BSF, and BA were selected as the main factors, and the correlation between them and the actual SMC of the case project was analyzed. Through this, the impact of the BP, BSF, and BA on SMCs are to be confirmed. Table 3 shows the BP, BSF, BA, and SMC for each project.

Table 3. Actual BP, BSF, BA, and SMC of case projects. (Unit: 1000 USD).

No.	BP [(1)] (m)	BSF [(2)]	BA [(3)] (m^2)	SMC [(4)]
1	3759.2	17.1	3025	1089.1
2	5188.5	23.9	2951	1333.5
3	3291.8	12.2	4581	1095.1
4	916.0	2.6	7828	939.1
5	5766.0	21.4	4554	1200.6
6	7262.8	25.4	5129	1527.2
7	8528.0	29.1	5356	1338.3
8	1263.1	4.2	5573	1521.0
9	5795.2	14.2	10,467	1261.7
10	10,157.4	31.9	6325	2044.6
11	4459.9	11.9	8668	2064.3
12	8129.7	22.2	8390	2032.4
13	9748.0	26.7	8348	2482.8
14	7379.6	21.9	7127	2877.9
15	16,441.7	30.4	18,242	3217.3
16	9397.9	16.8	19,536	2726.2
17	17,305.3	46.2	8773	2761.6
18	23,590.7	50.2	13,831	3451.3
19	18,879.0	75.2	3936	3040.5
20	21,525.7	49.9	11,653	3627.9
21	23,284.0	80.0	42,902	5373.0

Note: [(1)] Building perimeter, [(2)] Building shape factor, [(3)] Building area, [(4)] Safety management cost. Exchange rate is 1146 Won/USD as of 30 July 2021 (Bank of Korea).

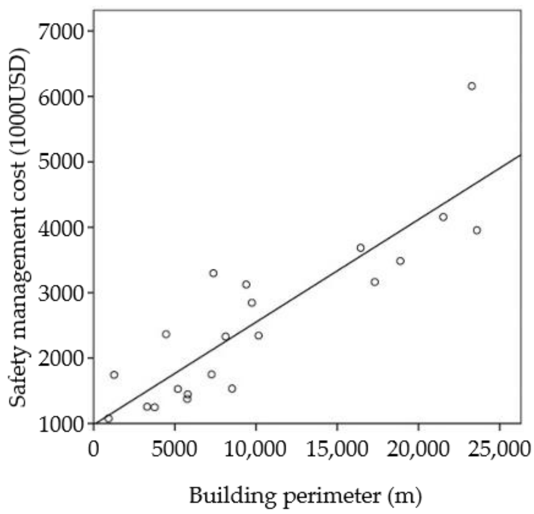
4. Result and Finding

When analyzing the correlation between the SMC and major factors using the data collected at the case site, the correlation coefficients between the SMC and the BP, BSF, and BA were relatively high, respectively at 0.876, 0.801, and 0.792, as shown in Table 4. These correlations are statistically significant because the p-values are less than 0.05. The one most closely related to SMC is the BP, followed by the BSF, and then the BA. In particular, the high correlation between SMC and BP implies that BP has a good influence on SMC.

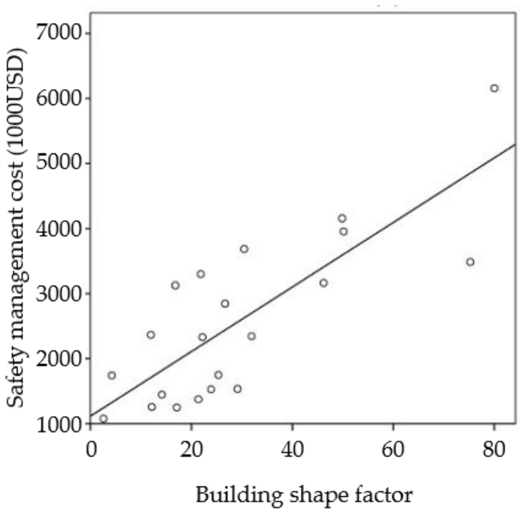
Table 4. Result of the correlation analysis.

	Description	BP	BSF	BA
SMC	Pearson correlation coefficient	0.876	0.801	0.792
	Significance probability (both)	0.000	0.000	0.000
	N	21	21	21

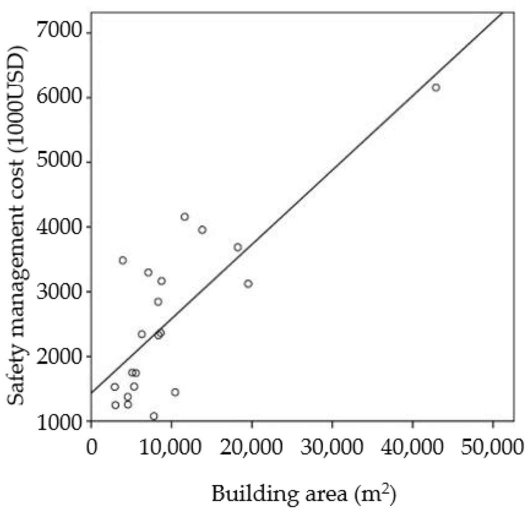
Additionally, as a result of regression analysis, a strong positive correlation between SMC and BP was established, as shown in Figure 3a. In addition, the regression model has a high explanation power (goodness of fit) with an R^2 value of 0.768. This indicates that SMC increases in proportion to the BP. As shown in Figure 3b, there is a strong positive correlation between SMC and BSF. As shown in Table 4, the R^2 value is 0.642, which has a relatively high explanation power (goodness of fit). This indicates that the BSF also affects the increase in SMC. As shown in Figure 3c, there is a strong positive correlation between SMC and BA, and the regression model has a high explanation power (goodness of fit) with an R^2 value of 0.627, as shown in Table 4. This represents that SMC increases in proportion to the BA. The results are shown in Table 5.



(a) Building perimeter



(b) Building shape factor



(c) Building area

Figure 3. Scatter diagram of SMC and influence factors.

Table 5. Results of regression analysis.

Model		**Unstandardized Coefficients**		**Standardized Coefficients**	**t**	**Sig.**	**R^2**
		B	**Std. Error**	**Beta**			
1	Constant	980.030	242.905		4.035	0.001	0.768
	BP	0.157	0.020	0.876	7.927	0.000	
2	Constant	1114.804	301.717		3.695	0.002	0.642
	BSF	49.654	8.505	0.801	5.838	0.000	
3	Constant	1430.657	266.193		5.375	0.000	0.627
	BA	0.115	0.020	0.792	5.651	0.000	

However, the SMC calculated at a legally determined ratio relative to the construction amount does not reflect these characteristics. Therefore, construction companies are paying safety facility expenses, safety manager labor costs, etc., in addition to the legally determined SMC. To meet the strengthened safety management standards, SMC that reflects the site's characteristics must be calculated.

5. Conclusions

This study used the actual data from 21 apartment construction sites and analyzed the correlation between the building's BP, BSF, BA, and SMC. However, in this study, only the correlation between the building shape and the safety management cost was analyzed due to the difficulty in data collection. In addition to the building shape, factors such as the number of floors, the number of buildings, the number of workers, and the difficulty of construction are expected to affect safety management costs. In the future, we plan to continuously collect data to prove the relationship between additional factors and safety management costs.

The results of this study are as follows:

First, the correlations between the SMC and the BP, BSF, and BA were analyzed based on the collected data. As a result of analyzing the correlation between the three main factors and SMC, it was found that the BP, BSF, and BA have a very strong positive Pearson correlation coefficient of 0.876, 0.801, and 0.792, respectively. The probability of significance obtained is 0.05 or less, which was statistically significant. The most closely related to SMC is BP, followed by BSF, and then BA. In particular, the high correlation between SMC and BP implies that BP has a good influence on SMC.

Second, the regression analysis showed a strong positive correlation between the SMC and the BP. The regression model had a high explanation power (goodness of fit) with an R^2 value of 0.768. This indicates that the SMC increases in proportion to the BP. It was analyzed that a strong positive correlation exists between the SMC and the BSF with an R^2 value of 0.642, which signifies a high explanation power (goodness of fit). This indicates that BSF also influences the increase in SMC. Finally, a strong positive correlation is established between the SMC and the BA, and the regression model has a high explanation power (goodness of fit) with an R^2 value of 0.627. This indicates that SMC increases in proportion to the BA.

As shown above, the SMC of the construction sites should be calculated by reflecting the characteristics of the construction site, such as the BP, BSF, and BA. Even with a similar residential building as in the case project, the BSF and BP are mostly different. Nevertheless, the same ratio is legally applied when calculating the SMC in the method under the current system. The existing method may cause an insufficient SMC and safety resources such as safety managers or safety facilities not being spent in accordance with the characteristics of the site. Therefore, the calculation method of the SMC must be improved urgently.

An SMC suitable for the characteristics of the construction site must be spent for the safe and efficient safety management of the construction site. Safety facilities such as fall prevention nets and safety fences, which account for the largest portion of SMC, will vary depending on the building shape, even for the same BA. Hence, SMC should be calculated according to the characteristics of the construction site, not the ratio of construction costs.

In the future, the results of this study can be used as supporting data for improving the safety management cost-related system and will develop into a more reliable model through continuous data accumulation and utility verification. In addition, it will be applied to the development of an appropriate safety management cost calculation model for other works such as general construction, civil engineering, and plants.

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