Master of Science in Engineering

Analysis of Safety Risk Factors to Prevent Accidents in Modular Construction

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Abstract

Analysis of Safety Risk Factors to Prevent Accidents in Modular Construction

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Modular Construction is regarded as having enhanced safety compared to traditional construction since most of modular manufacturing process is conducted in plants. Unlike general perception of safety in modular construction, several industrial accident data and researches have pointed out that the accident rate of modular construction is not enough less as much as the experts have expected. It means that there is a clear need for improvement of safety management in modular construction. Since the modular construction industry is drawing attention and many projects are being tried, safety management suitable for modular construction is essential. To enhance safety of modular construction, the safety risk factors should be identified first. It is necessary to identify types and causes of accident through accident cases in order to prevent safety accident in advance.

To solve this problem, firstly, this study investigates accident cases related to modular construction and identifies safety risk factors. The study collects accident cases that occurred in the United states between 2000 to 2018 and analyzes safety risk factors such as types and causes of accidents with accident cases. The analysis is carried out by classifying the manufacturing process and the construction process, and the identification of casual factors is carried out in advance for the cause analysis. The analysis results are expressed in tables and cause map. The results of analysis show the major accident types and causes of accidents occurring in each activities.

Secondly, this study compares safety risk factors and characteristics of accidents between general construction and modular construction. By comparative analysis, it is possible to identify differences in accident factors, and to confirm requirements of safety management in modular construction projects. Also, this study suggest prevention method to reduce safety accidents in modular construction project. Based on this, a safety checklist for each activities of modular architecture is presented.

This study contributes that the result can be used as the basic safety management in the manufacturing and construction process of modular construction. Outcomes can also assist safety managers to understand safety risk factor and to make prompt safety decisions.

Keyword : Modular Construction, Safety Accidents, Safety Risk Factors, Cause Analysis, Safety Checklist

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Chapter 1. Introduction

1.1. Research Background

Modular construction has recently been concentrated as a rising industry, and many construction companies are making attempts to build with modular construction technique (Innella et al., 2019). According to the report by Modular building institute (2019), market share of modular construction in 2018 was 3.67% of all new construction in North American. This modular construction has been applied to a variety of applications such as dormitory and hotel construction and it has been also applied to residential facilities as a solution to urban housing shortages (Smith, 2011). Modular construction is growing because it has advantages in various areas compared to general construction. It is less affected by the external environment, with 70-80% of the work done in the manufacturing plant (Fard, et al., 2017; Smith, 2011). In particular, it is possible to reduce vertical work at on-site and the work can be conducted on the ground in manufacturing factory. Modular construction also can reduce input of field workers, shorten construction duration, save energy and improve quality of buildings (Gibb., 1999). Thus, modular construction is considered a sustainable construction method and the market is growing (Lee et al., 2019).

There is also an opportunity to reduce the safety accidents because it is less affected by external environmental factors such as rainfall and wind. Workers can become familiar with work space and work because they perform repetitive tasks in manufacturing factory (O’Connor et al., 2015). Also, as the amount of on-site work decreases, there are fewer workers required, and it is convenient to manage them (Smith, 2011). Therefore, modular construction is generally regarded as safer than traditional construction methods (Becker et al., 2003).

Contrary to this general perception, however, the US Bureau of Labor Statistics reports that accident rates in modular and prefabricated buildings are much higher than in general construction and manufacture industries (Bureau of Labor Statistics, 2017). Figure 1-1 shows the injury and illness rate per 100 full time works for all industries, construction, manufacturing and prefabricated wood building manufacturing industry in the USA from 2002 to 2017. Furthermore, McGraw's report found that there were no significant changes in safety in a survey of modular construction workers (McGraw, 2011). These results raise doubts about the general perception of safety in relation to construction accidents in modular construction.

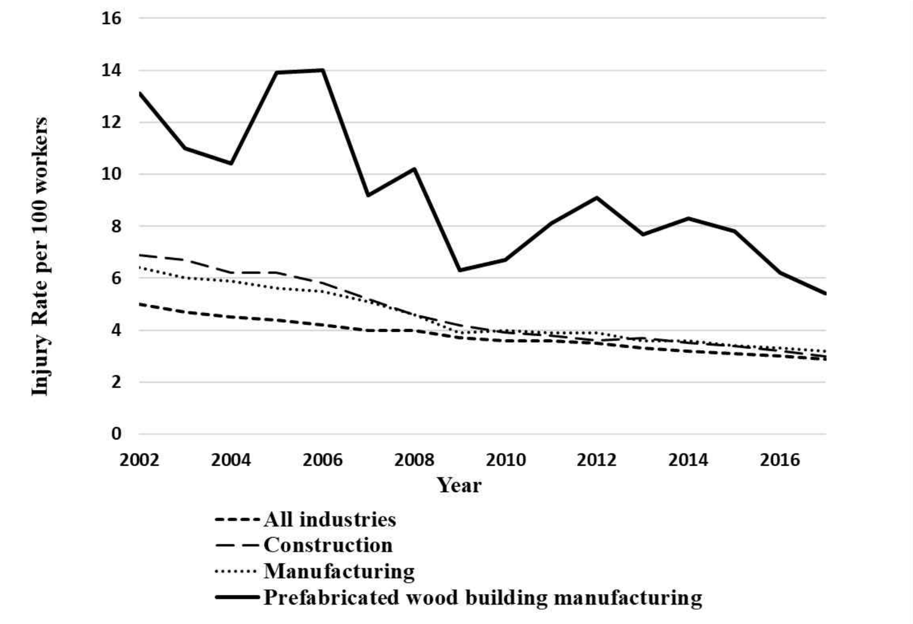

Figure 1-1. Injury and illness rate per 100 full time workers

In construction projects, safety accidents not only cause human casualties, but also greatly affect the construction duration and cost. Due to the general perception that modular construction is safer than general construction, safety management for modular construction is insufficient to prevent accidents. However, there are still some activities that pose a risk of safety accidents, and risk factors due to the work characteristics of modular construction. In a modular construction project aimed at reducing construction period, the occurrence of safety accidents can affect the entire construction schedule and cause incidental financial damage. Therefore, safety management in modular construction is a priority and critical issue over other management factors.

As modular construction project increased, it is needed more trained workers and skilled managers who are familiar to safety risk to complete the projects successfully (Fard et al., 2017). Nevertheless, existing construction companies, managers and employees who are working on general construction are participating in the modular construction project and there is a lack of capable contractors which have adopted modular construction (Blismas, 2006), so that safety management is being applied in a similar way of general construction project without additional conditions.

There is a limitation to the application of safety management of general construction to that of modular construction because there are different activities from general construction in the modular construction process (Ikuma et al., 2011). And since modular construction has a large proportion of manufacturing processes, project participants should understand both management of manufacturing process(off-site) and construction process(on-site). Therefore, there is a clear need of reflecting the characteristics of modular construction in safety management, and this requires detailed analysis of safety risk factors in modular construction. In this consideration, it would provide an opportunity to understand and improve safety management of modular construction by comparing how it differs from risk factors of general construction. The differences could ensure the primary targets of modular construction in terms of safety and accident occurrences.

1.2. Problem Statement

Modular construction has recently come into the spotlight and safety management of modular construction is needed to carry out successful projects. In construction projects, safety accidents not only cause human casualties, but also greatly affect the construction duration and construction cost. In modular construction project aimed at reducing construction duration, the occurrence of safety accidents can affect the entire construction schedule and cause incidental financial damage. Therefore, safety management in modular construction is a critical issue and must be considered at the same time as other management factors. In addition, excessive safety management can rather increase construction costs and reduce the efficiency of installation and work of safety devices. This is why proper safety management is needed to minimize the impact on other factors in modular building projects.

Modular construction is generally known to be safer than general construction methods. However, there are barely researches to improve modular safety, and existing researches have evaluated safety of modular construction with a focus on only at on-site work. However, both the manufacturing process and the construction process still have hazardous activities at risk for safety accidents. There are still risks of accidents, according to various statistics and reports.

Currently, the modular project has the same safety management used in general construction projects. However, given the characteristics of modular construction, existing safety management for general construction is not appropriate to modular construction and additional considerations is necessary. Therefore, safety management of modular construction is a critical issue that must be considered for the success of the project, and research on safety management for modular construction is needed because there is currently a lack of fit on it.

In order to solve this problem, it is necessary to identify safety risk factors in modular construction to check the current degree of safety risk. It is necessary to check the safety risk factors of modular construction by checking how many safety accidents have occurred in modular construction project, and it can be conducted by analyzing accident cases. Characteristics of the results have should be reviewed and a corresponding safety management system should be introduced.

In addition, safety accident factors in modular construction needs to be compared with those in general construction. Based on the results of identifying the current trend of modular construction safety accidents, it is necessary to analyze the differences from general construction. Since there is a limit to reflecting the existing safety management system, an analysis of the differences is needed and safety management measures should be devised to compensate for them. For the growth and development of modular construction, a safety management system that reflects the characteristics of modular construction is essential. This study currently takes issue with the status of modular construction safety management, and conducts analysis of safety risk factors in modular construction to improve safety management.

1.3. Research Objective and Scope

This study investigates safety risk factors with accident cases in modular construction and discuss several findings to understand the trend of safety accident occurring during modular projects.

First of all, the study conducts analysis of major accident factors with accident cases recorded in the Occupational safety and health administration(OSHA) in U.S. To investigate various characteristics of accidents, this study collects modular construction-related accident cases using web crawling and analyze in each cases including type of accident, cause of accident and activity in which an accident occurred. And to investigate the significance of the analysis results, statistical analyses including cross-analysis and Fisher's exact test are used to analyze relationships between accident type and cause for modular activities.

Secondly, the study compares safety risk factors and characteristics of accidents between general construction and modular construction. These include accident rates, project cost, fall location, and fall height. With the results of comparative analysis, this study identifies trends of safety accidents and discusses the differences that may be disregarded in the safety management of modular construction.

Finally, the study proposes some suggestion to prevent accidents in main activity in modular construction. Also it suggests a safety checklist which is suitable for activities in modular construction.

The scope of this study is as follows. This study deals with safety accidents that occur in activity during manufacturing and construction processes of the modular construction project. For construction process, only work such as unit transportation, module unit lifting, unit installation, and finishing activities are targeted because these activities characterized the modular project. Foundation work and temporary work are excluded from the scope of this study because there are same works in general construction and it is hard to distinguishing project types when collecting data. The accident cases used in this study selects related to modular construction recorded in the Occupational safety and health administration(OSHA) occurring from 2000 to 2018. Outcomes of the study can be a basis research for safety management guidelines in modular construction. And it will also assist safety managers to understand and pay more attention to make prompt safety decision by presenting major risk factors for each activities in the modular construction process. Comparative analysis is conducted by comparing some of safety risk factors analyzed in the study of Kang et al. (2017). Kang compiled the trend of construction accidents, especially falls, with data from OSHA's database related to construction in U.S. from 1997 to 2012. By comparing the risk factors analyzed through accident cases in modular construction with the research of Kang, it is possible to check whether the trend of accident in modular construction differs from general construction. Factors to compare are accident ratio, project cost, fall height, and fall location.

1.4. Research Process

The analysis process is shown in Figure 1-2, and the contents at each step are as follows.

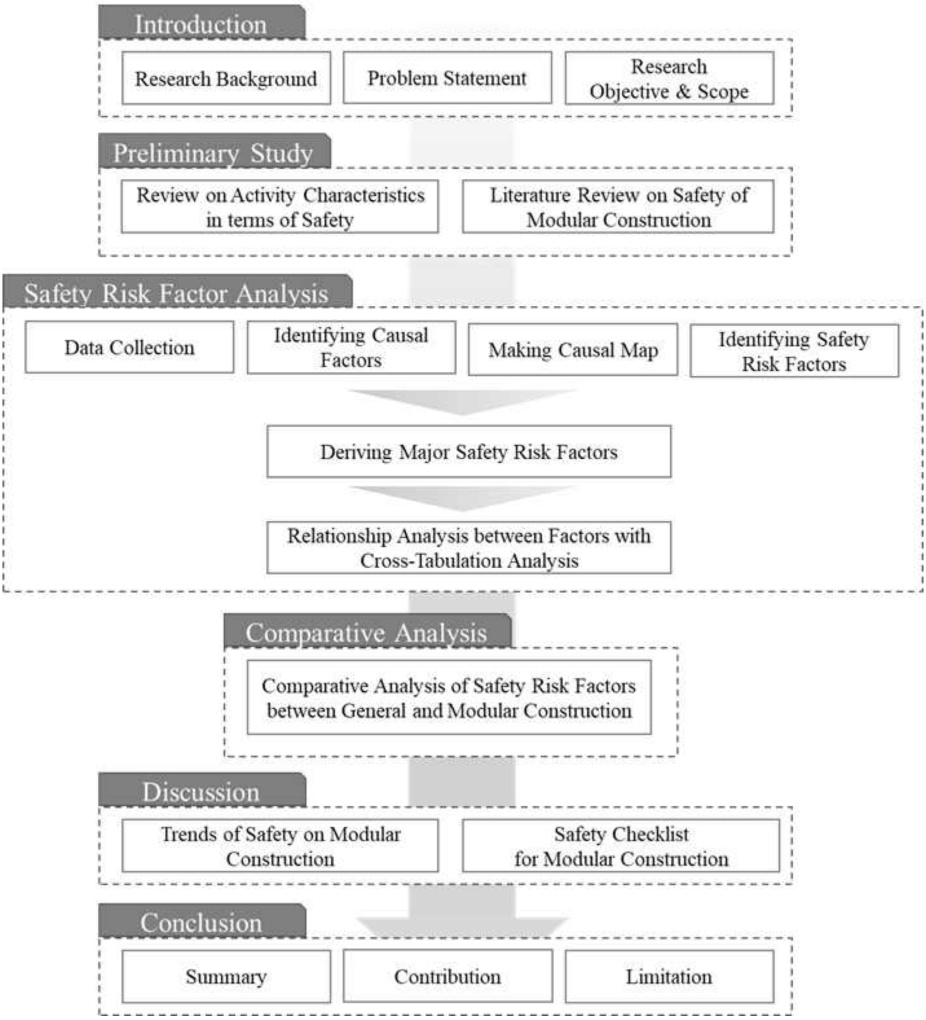

Figure 1-2. Research process to identify safety risk factors to prevent accidents in modular construction

In part of safety risk factor analysis, firstly, data collection is conducted. The data includes safety accident cases which occurred in modular construction in U.S. Second, the study identify causal factors and make a reference table from some agencies related to construction industry. Third, the study makes a causal map to use for deriving cause of accidents based on causal factors reference table. Fourth, safety risk factors such as type of accident, cause of accident, and activity of accident of each accident cases are derived and results are databased. To confirm the significant of the results, cross-tabulation analysis is conducted to find the relationship between results.

After analysis of risk factors of modular construction, comparative analysis is conducted between modular construction and general construction. Some contents such as accident ratio, project cost, fall height, and fall location are included. From the results of analysis, the study discuss about the trend of accidents in modular construction compared to general construction and suggest prevention method to reduce accidents. Also the study present safety checklist for modular construction project.

Chapter 2. Preliminary Study

2.1. Researches on Safety Management in Modular

The existing literature has been many efforts to identify accident types by investigating accident cases to establish a safety management system and to classify how and why these accidents occurred (Fullman, 1984; Goldsmith, 1987). Some previous researches have made efforts to manage the safety of modular construction. Becker et al. (2003) conducted a survey to identify possible hazards to workers when installing modular units at on-site. Based on the survey results, major risk tasks and accident types are analyzed in modular construction site. This research only focused on on-site activities excluding off-site activities. McGraw Hill Construction (2013) conducted a survey to derive three reasons that modular construction is safe. According to the result, modular construction is safe because complex work is done on the ground and off-site, there are fewer workers on the field, and it less need to work on high ground (McGrow, 2013). James et al. (2012) conducted a research on the application of the lean construction method to some of the operations in the modular manufacturing plant, and showed that the lean method could reduce the risk exposure of workers. There was also a research dealing with accident cases occurring at the modular and prefabricated construction process as documented in OSHA (Fard et al.2017). However, it was only a summary of the recorded case data, and the cause of the accident was not analyzed in detail. And also this research did not take into account the characteristics of risk factors through comparison with general construction.

As a result of review of previous researches, there are researches related to safety management of modular construction, but most of them were conducted only to find some hazardous factors by survey or to arrange statistical date. And most of them were focused only on construction work at on-site. The accident rate at off-site plant is also high, and accidents occur frequently during the manufacturing process (James et al., 2012). Therefore, for the safety management of modular construction, it is necessary to study not only the construction process but also the accidents that occur during the manufacturing process.

In this research, accident cases are analyzed to derive safety risk factors and also conduct comparative analysis with accidents in general construction to find characteristics. This research is different from previous researches in that it is analyzed through actual accident cases and identifies safety management targets by addressing the characteristics of activities in modular construction.

2.2. Characteristics of Activities in Modular Construction

Modular construction differs from general construction and manufacturing in various ways (Smith, 2011). There are differences in production methods, and differences occur due to various characteristics such as scheduling, work, quality, and risk of modular construction project. According to the study of Smith, characteristics of modular construction could also affect to safety management. Among these characteristics, this study selects those that could affect safety accidents. It investigates some factors such as workplace, workers, high-place work and lifting work that could have a significant impact on safety accidents. Through this, the characteristics that need to be managed in order to improve the safety of modular construction can be identified in advance. Table 2-1 shows characteristics of modular construction.

Table 2-1. Characteristics of modular construction
(Modified from Smith's comparative table)

Characteristics	General Construction vs Modular On-site	General Manufacturing vs Modular Off-site
Workplace	- Less impact of weather - Familiar workplace to workers	- Risk factors resulting from differences in production process
Workers	- Low input personnel - Less workers to manage	- Lack of proficiency in work - Absence of experts
High Place Work	- Less high place work - Additional works (unit installation, external finishing)	- Some high place work during unit assembly or finishing - Insufficient fall prevention devices
Lifting	- Need high performance crane for unit weight - Friction of the workplace	- More use of overhead crane - Heavy members and insufficient work space

The first characteristic is the workspace. In modular construction, workers could have a high understanding of space to perform repetitive tasks in the same workspace even if the project changes (Smith, 2011). In addition, because external environmental factors do not act as variables in terms of a fixed indoor environment, there is less change in the workspace itself (Isabelina, 2012). In this respect, considering the overall workspace, understanding of workers is relatively higher than that of workers in general construction. In the aspect of manufacturing process, conveyor systems, a production process in general manufacturing plants, have been introduced, but in modular unit production there is a lot of work done by workers moving around (Bae et al., 2012). This increases the frequency with which work positions are not fixed, resulting in complex work flow and worker exposure to risk.

The second characteristic is input manpower for work experience level of workers. Modular construction has relatively few inputs due to its introduction of automation and its simplicity and repeatability (Smith, 2011). Therefore, safety management can be more efficient with fewer objects to be managed. On the other hand, the number of workers who have experienced it is small due to the low number of modular construction and construction cases, and there is also a lack of experts who can teach their skills to other workers (Joshua, 2016). There is a limit to the operator's ability to identify and recognize hazards that may arise from the work, so it is necessary to improve capabilities through prior safety education.

The third characteristic is different type of high-place work. By converting the vertical working form of the general construction project into the horizontal working form of the production line of the fabrication plant, the work of constructing the building is done on the ground. However, there are still high-place work to do, such as installing and roofing modular units, and finishing the exterior (Lawson et al., 2010). Although the proportion of falls is relatively small in general manufacturing, it is possible during the Modular Unit production phase to be caused by suing on unit structures or using ladders and mobile scaffolding (Fard et al., 2017). Therefore, a management system is needed to prevent falls during work.

The last characteristic is increase of lifting work and risk of it. Modular construction requires a high-performance crane to lift and install a module unit of approximately 20 tons, and uses additional equipment to prevent damage and distortion when the unit is lifted (Lawson et al., 2011). In addition, when the unit is hanged by crane, the worker below it might adjust the unit's position or perform operations such as jointing work. Therefore, it is important to plan cranes and to secure safety of workers, and to manage management systems such as securing work lines and work spaces.

This study investigates that the characteristics of safety-related in modular construction, such as work spaces, workers, high-place work, and lifting work, are different from those of general construction and general manufacturing. While there are characteristics that can be advantage to reduce accident, there are additional management target that need to be considered through the application of modular construction. These differences in characteristics have a direct effect on the actions of the workers and can cause safety accidents (Oliver, 1986). Therefore, this research analyzes the characteristics of the accident through modular accident cases and identify the relationship with the activity characteristics. It is also used for comparative analysis with accidents in general construction.

2.3. General Construction Safety Accident

In spite of many researches sin the construction industry, safety accidents still occur. Before analyzing safety accidents in modular architecture, it is necessary to identify the characteristics of safety accidents occurring in general construction. According to the U.S OSHA’s report, it represents four major types of accidents in construction industry in 2018. Falls are a leading type of accident, representing 33.5% of total accidents. Struck- by object(11.1%), electrocutions(8.6%) and caught-in/between(5.5%) follow after.

Falls is the main accident (Hinze et al.,2003; Bobick 2004) in the construction industry, and the falls is one of the most cost work-related hazards. Many researches have been conducted because of the heavy influence of falls on construction projects. In particular, there are many analyses through accident cases using OSHA database (Kang et al., 2017). In Fard et al.’s research, the rate of falls is also the highest in modular construction project. The main accident types have been drawn from the analysis of accident cases in this study, and more detailed identification of fall accidents is needed. In a similar way to analyzing modular accident cases in the United States in this research, there are some researches that analyzes general construction accident and crash accident cases in the United States.

Research of Kang et al. (2017) compiled the trend of construction accidents, especially falls, with data from OSHA's database related to construction in U.S. from 1997 to 2012. In the research, various factors such as the accident ratio, project cost, fall height, fall location, whether protective gear is worn or not were analyzed. After identification of accident factors in this research, it is necessary to compare them with those in general construction. In particular, if there is a difference, it is needed to understand what the characteristics of modular construction are. Comparative analysis targets are conducted by selecting some of the items analyzed in Kang's research.

Chapter 3. Accident Factor Analysis in Modular

3.1. Process of analysis

This study analyzes safety risk factors of modular construction in order to reduce safety accidents in modular construction projects. The construction industry uses various accident analysis models to classify the cause of the accident. However, in the case of modular construction, there are not many cases of construction and accidents, and researches on the cause of accidents has been barely handled. Therefore, there is a limit to analyze them through existing accident analysis models. Considering that the first step in resolving a safety accident is to identify the root cause of the accident (Wilson, 1993), it is necessary to identify firstly what is the root cause of the accident in modular construction. In this respect, this study applies root cause analysis process for accident case analysis.

Root cause analysis is the process of identifying the root cause of a problem in order to find an appropriate solution (Abdelhamid et al., 2000). Figure 3-1 shows the process of root cause analysis.

Step 1 is data collection. It is the stage of gathering data on how many problems or accidents have occurred during a certain period of time. Step 2 is identifying causal factors. It is to select and chart the causal factors for next step. Step 3 is identifying root causes. It is to find out the root cause of problem or accident. In this step, causal map is used to identify the causes. The final step 4 is to make recommendation and suggest implement solutions. Based on the root cause of each accident, a measure to reduce safety accidents is proposed to prevent accidents.

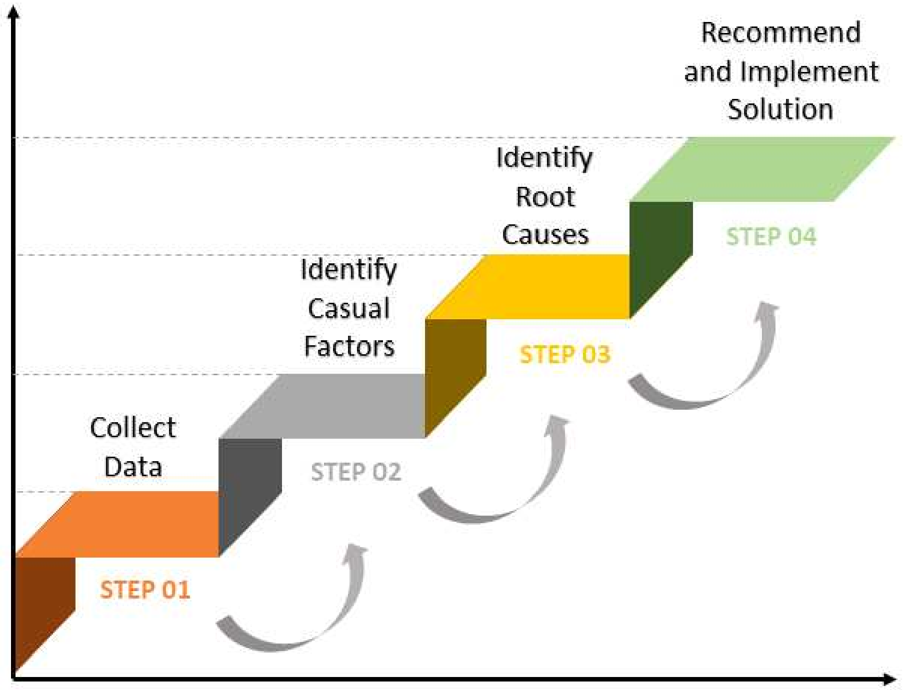

Figure 3-1. Process of root cause analysis

This study follows the process of root cause analysis to identify safety risk factors of modular construction. Firstly, data collection is conducted. The data includes safety accident cases which occurred in modular construction in U.S. Second, the study identify causal factors and make a reference table from some agencies related to construction industry. Third, the study makes a causal map to use for deriving cause of accidents based on causal factors reference table. Fourth, safety risk factors such as type of accident, cause of accident, and activity of accident of each accident cases are derived and results are databased. Finally, in chapter 5, the study suggest prevention methods to reduce accidents in modular construction and present safety checklist.

3.2. Data Collecting

To investigate accidents in modular construction, this research uses the OSHA's database. The accident information of the entire U.S. industry is recorded in OSHA and it provides summary of and detailed information for each accident cases. In order to obtain accident data for a specific industry or sector form OSHA, it can be classified using Standard industrial classification (SIC) or North American industry classification system (NAICS) codes. However, accident data are not usually separated between sectors associated with modular construction, so that there is a limit to search accidents related to modular construction through SIC and NAICS codes. Therefore, in this research, data collection is done through web crawling using Python 3.6. to extract only the desired accident data. By coding with Python, accident data including specific keywords related to modular construction is extracted. The keywords used in this research include modular, prefabricated, and mobile home. This research focuses on accidents occurred from 2000 to 2018 in U.S. There are 63 cases with keyword mobile, 75 with prefabricated, and 102 with mobile home, so that a total of 236 accident cases are collected except for 3 overlapping ones. Although the above keywords are included, some accident samples are collected that do not correspond to modular manufacturing process and construction process set to scope in this research. For example, some accident cases include the word modular, but these are accidents caused by modular boiler, modular conveyor belt, modular pipe, etc. And it also includes accidents caused by fire after completion of construction. Therefore, it is needed to be re-sorting because there are many accidents that are not related to modular construction. The re-sorting is conditional on the inclusion of several keywords related to work in modular construction, such as installing, lifting, assembly, panel, and unit. Among them, 107 cases of accidents that occurred in the work activity of manufacturing and construction process as the scope of this research are selected as the final data and used for the analysis of the research. The contents of the accident and the description are used in this research.

3.3. Identifying Casual Factors

Prior to analyzing the risk factor of each accident, it is necessary to identify casual factors for modular construction. The causes of each accident are determined based on the selected casual factors. In order to identify causal factors of the accident, this research lists and identifies the related causes of construction projects and modular construction in OHSA, Health and safety commission (HSE), Korea occupational safety and health agency (KOSHA) and Construction safety management information system(COSMIS). The causal factors were categorized into cause type and causal factors. Table 3-1 shows the cause types by each agencies and table 3-2 indicates causal factors for modular construction.

According to Heinrich's domino theory (Heinrich, 1959), the unsafe condition and unsafe action are the fundamental major factors of accidents and the emphasis of safety management should be placed on eliminating them. However, the content and description of accident cases used in this study are not specific and do not contain all information. In other words, determining the cause of an accident can be inaccurate because it has the risk of involving subjective views of researcher during identifying the cause of an accident as unsafe action and indirect cause. Therefore, this study limited the cause of the accident to only an unsafe condition that can be objectively identified. The cause types are selected based on the major categories used in the construction industry and these are material/equipment, safety protection device, personal protection equipment(PPE), site layout/space, and workplace.

Detailed cause types for material/equipment are slippery/pointed material, improper use of equipment, and defective material/equipment. There are no safety device, non-operating safety device, and absence of risk indication for safety protection device. Personal protective Equipment is divided into no PPE and defective PPE. Detailed cause types for site layout/space are improper arrangement of workplace, insufficient workplace, congested work areas, unstable work areas/platforms. And for workplace, detailed cause types are poor illumination/ventilation, excessive noise, unpredictable weather, and poor housekeeping. Based on the derived causal factors, the cause of the accident for cases is analyzed.

Table 3-1. Cause types by agencies

Cause Type	Detailed Cause Type	OSHA	HSE	KOSHA	COSMIS
Material/ Equipment	Slippery/ pointed material			*	
	Improper use of equipment	*	*	*	*
	Defective Material/Equipment	*	*		*
Safety Protection Device	No safety device	*	*	*	*
	Non-operating safety device	*	*		
	Absence of risk indication	*		*	
PPE	No PPE	*	*	*	*
	Defective PPE			*	
Site Layout/ Space	Improper workplace arrangement	*			*
	Insufficient workplace	*	*	*	
	Congested work areas	*	*	*	*
	Unstable work areas/platforms	*			*
Workplace	Poor illumination/ventilation	*	*	*	
	Excessive noise	*		*	
	Unpredictable weather	*	*		*
	Poor housekeeping	*	*	*	*

Table 3-2. Casual factors for modular construction(1)

Cause Type	**Detailed Cause Type**	**Casual Factors**
Material/ Equipment	Slippery/ pointed material	Slippery floor
	Improper use of equipment	Improper use of crane
		Improper use of forklift
	Defective Material/Equipment	Defective crane
		Defective equipment
		Defective jack
		Defective ladder
		Defective member
		Defective structure
Safety Protection Device	No safety device	Poor fall prevention
		Poor safety device for equipment
	Non-operating safety device	Non-operating safety device for equipment
		Non-operating safety device for lift
	Absence of risk indication	Lack of risk indication of equipment
		Lack of fall risk indication
Personal Protective Equipment (PPE)	No PPE	Failure to wear PPE
	Defective PPE	Defective PPE

Table 3-2. Casual factors for modular construction(2)

Cause Type	Detailed Cause Type	Casual Factors
Site Layout/ Space	Improper arrangement of workplace	Insufficient consideration of moving line
		Insufficient consideration of crane radius
		Ignore power line
	Insufficient workplace	Insufficient moving space
		Insufficient workplace for unit installation
	Congested work areas	Congested work areas
	Unstable work areas/platforms	Unstable floor
		Unstable support
		Unstable crane
		Unstable ladder
		Unstable unit structure
Workplace	Poor illumination/ventilation	Poor illumination/ventilation
	Excessive noise	Excessive noise
	Unpredictable weather	Unpredictable weather
	Poor housekeeping	Poor housekeeping

3.4. Identifying Accident Cause

To use the causal factor table made in previous chapter, this study creates a causal map that can visually represent the causal factor. Causal map in tree form is one of the most common methods used to describe the process of a problem and causes and to analyze the cause of accident (Abdelhamid et al., 2000). In the causal map, the decision for one accident is made by going down from the upper category to the lower category, and finally, the cause of the lowest level is determined. By creating and using this causal map, this study can make decisions at the stage of determining the cause of an accident in modular construction.

Causal map for modular construction is firstly divided into the manufacturing and on-site construction processes, and the accident type by the work activities for each process is presented. In the lower part, the causal factors of accidents derived previous are expressed in tree form. Figure 3-2 shows the cause map for modular construction.

By using causal map, based on the accident case information in the database, the study identifies the cause of accident by selecting each factor from the upper category to the lowest cause. To identify the cause of the accident, the study follows the procedure; the manufacturing and construction process, unit work activity, accident type, cause type, detailed cause type, and finally the causal factor. Each identified results are re-databased and used to produce results. Table 3-3 shows the result of cause analysis by activities in modular construction. It contains the number of accident cases in each activities and causes.

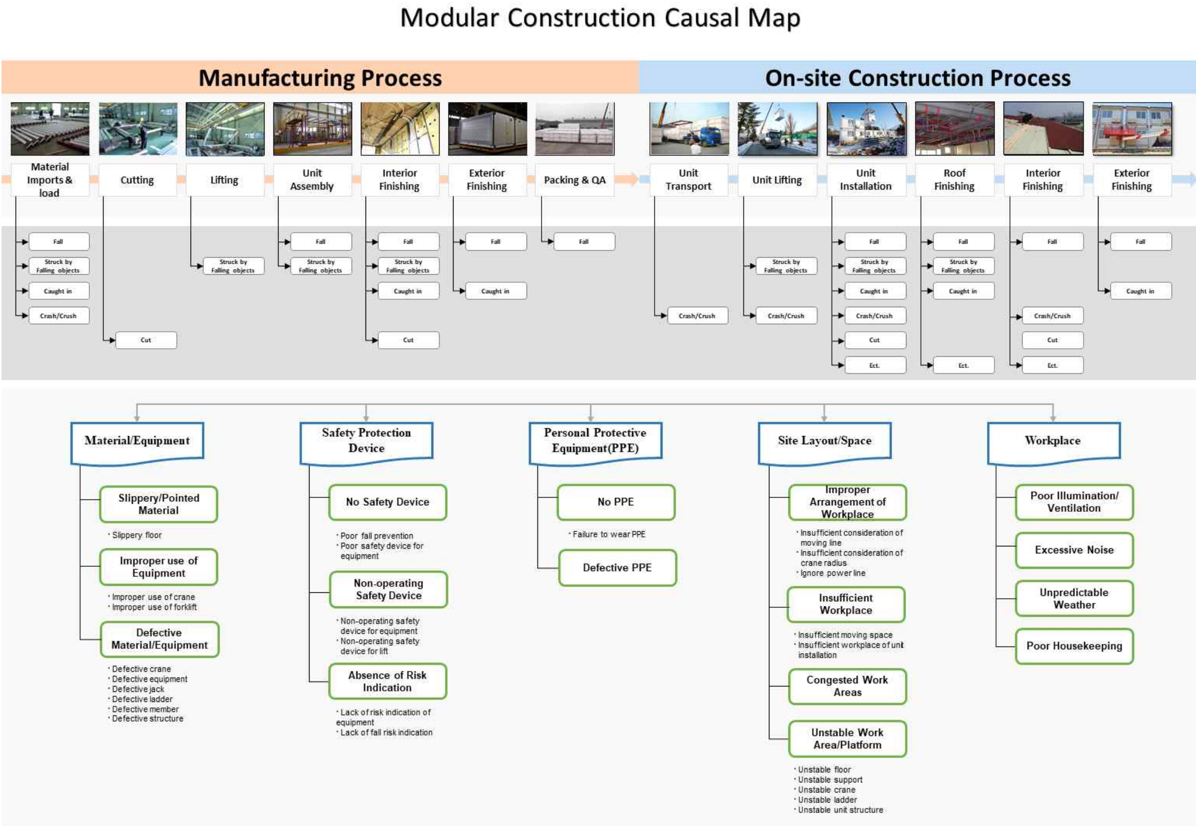

Figure 3-2. Causal map for modular construction

Table 3-3. Result of cause analysis in modular construction(1)

Cause Type	**Detailed Cause Type**	**Casual Factors**	**Manufacturing Process(Off-Site)**							**Construction Process(On-site)**						**Total**
			M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	
Material/ Equipment	Slippery/pointed material	Slippery floor					1					2	1		1	5
	Improper use of equipment	Improper use of crane					1					1		1		3
		Improper use of forklift	1													1
	Defective Material/ Equipment	Defective crane				1	1				1	1				4
		Defective equipment					1						1			2
		Defective jack	1								2	11				14
		Defective ladder													1	1
		Defective member									2	1			2	5
		Defective structure										4				4
	Subtotal		2	-	-	1	4	-	-	-	5	20	2	1	4	39

Table 3-3. Result of cause analysis in modular construction(2)

Cause Type	Detailed Cause Type	Casual Factors	Manufacturing Process(Off-Site)							Construction Process(On-site)						Total
			M1	M2	M3	M4	M5	M6	M7	C1	C2	C3	C4	C5	C6	
Safety Protection Device	No safety device	Poor fall prevention											1	2		3
		Poor safety device for equipment		2												2
	Non-operating safety device	Non-operating safety device for equipment		1												1
		Non-operating safety device for lift										1				1
	Absence of risk indication	Lack of risk indication of equipment										1		1		2
		Lack of fall risk indication	1									1				2
	Subtotal		1	3	-	-	-	-	-	-	-	3	1	3	-	11
PPE	No PPE	Failure to wear PPE				1			1			3	4		1	10
	Subtotal		-	-	-	1	-	-	1	-	-	3	4	-	1	10

Table 3-3. Result of cause analysis in modular construction(3)

Cause Type	**Detailed Cause Type**	**Casual Factors**	**Manufacturing Process(Off-Site)**							**Construction Process(On-site)**						**Total**
			M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	
Site Layout/ Space	Improper arrangement of workplace	Insufficient consideration of moving line	1					1		2		1				5
		Insufficient consideration of crane radius	1										1			2
		Ignore power line										1	3	1		5
	Insufficient workplace	Insufficient moving space						1		1						2
		Insufficient workplace for unit installation										4				4
	Unstable work areas/platforms	Unstable floor										2	2			4
		Unstable support	2								1					3
		Unstable crane										2				2
		Unstable ladder				1	1	1				2	1		1	7
		Unstable unit structure	1		1	2				2		4	1			11
	Subtotal		5	-	1	3	1	3	-	5	1	16	8	-	1	45

Table 3-3. Result of cause analysis in modular construction(4)

Cause Type	**Detailed Cause Type**	**Casual Factors**	**Manufacturing Process(Off-Site)**							**Construction Process(On-site)**						**Total**
			M1	**M2**	**M3**	**M4**	**M5**	**M6**	**M7**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	
Workplace	Unpredictable weather	Unpredictable weather											1			1
	Poor housekeeping	Poor housekeeping										1				1
	Subtotal		0	-	-	-	-	-	-	-	-	1	1	-	-	2
Total			8	3	1	5	5	3	1	5	6	43	16	5	6	107

M1 : Material Imports & Load
M2 : Member Cutting
M3 : Member Lifting
M4 : Unit Assembly
M5 : Interior Finishing
M6 : Exterior Finishing
M7 : Packing & QA

C1 : Unit Transportation
C2 : Unit Lifting
C3 : Unit Installation
C4 : Roof Finishing
C5 : Interior Finishing
C6 : Exterior Finishing

Chapter 4. Results of Accident Analysis

After identifying each accident cases, the results were analyzed are categorized. A total of 107 accident cases are used to analyze the cause of the accident and there are 26 accidents during the manufacturing process and 81 accidents during the construction process. In this section, the research summarizes the main factors among the results of the analysis of the accident cases in the previous section. Major hazardous activities, accident types and accident causes are derived.

4.1 Hazardous Activities

This section summarizes the main factors among the results of the analysis of the accident cases in the previous section. Major hazardous activities are derived during manufacturing and construction process. As table 4-1 indicates, in manufacturing process, there are total of 26 accident cases. 31% of the accidents are occurred during material imports & load activity and 19% are unit assembly and interior finishing. Unit assembly and exterior finishing accounts for 12% each.

The total number of accidents can be seen to have occurred much more during the construction process than during the production process. During construction process as table 4-2, the most noticeable result is that unit installation activity is most hazardous activity over 50%. Roof finishing is second at 20% and unit lifting and exterior finishing come next with 7%.

Table 4-1. Number of accident case by activity in manufacturing process

Process	Activity	Number of accident	Ratio
Manufacturing Process (Off-site)	Material Imports & Load	8	31%
	Member Cutting	3	12%
	Member Lifting	1	4%
	Unit Assembly	5	19%
	Interior Finishing	5	19%
	Exterior Finishing	3	12%
	Packing & QA	1	4%
Total		26	100%

Table 4-2. Number of accident case by activity in construction process

Process	Activity	Number of accident	Ratio
Construction Process (On-site)	Unit Transport	5	6%
	Unit Lifting	6	7%
	Unit Installation	43	53%
	Roof Finishing	16	20%
	Interior Finishing	5	6%
	Exterior Finishing	6	7%
Total		81	100%

4.2 Accident Types

Table 4-3 and 4-4 show the number of accident cases by types of accidents in manufacturing and construction process. As this table indicates, accidents caused by falls and struck-by falling objects are the major types of accident with 31% each during manufacturing process. And there are few accidents caused by caught in and cut at 15% each. In the case of construction process, falls account for 35%, which is the highest one in the percentage in the whole. 27% of accidents are occurred by crush/crash and 23% are by struck-by falling objective. In the entire modular construction process, fall accidents are the most major accident types, followed by struck-by falling objects and crush/crash.

Table 4-3. Number of accident case by accident type in manufacturing process

Process	Accident Type	Number of accident	Ratio
Manufacturing Process (Off-site)	Fall	8	31%
	Struck By Falling Object	8	31%
	Crush/Crash	2	8%
	Caught in	4	15%
	Cut	4	15%
	Etc.	0	0%
Total		26	100%

Table 4-4. Number of accident case by accident type in construction process

Process	Accident Type	Number of accident	Total
Construction Process (On-site)	Fall	29	36%
	Struck By Falling Object	19	23%
	Crush/Crash	22	27%
	Caught in	4	5%
	Cut	1	1%
	Etc.	6	7%
Total		81	100%

4.3 Accident Causes

Accidents have occurred due to various causes in modular construction, and this section mentions only a few of the major cause of accidents. Table 4-5 and 4-6 show the number of accident cases by accident cause in manufacturing and construction process. In manufacturing process, unstable work areas/platforms had a most high frequency rate with 35%. Defective material/equipment (15%) and improper arrangement of workplace (12%) have also high rate compared to the other causes. There are also accidents caused by improper use of equipment (8%) and no PPE (8%). During construction process, defective material/equipment accounts for 32% and it is the major accident cause. Unstable work area/platform is a second highest cause at 23%. No PPE and improper arrangement of workplace account for 10% each.

Table 4-5. Accident cause type in manufacturing process

Cause Type	**Detailed Cause Type**	**Number of Accident**		**Ratio**
Material/Equipment	Slippery/ pointed material	1	7	4%
	Improper use of equipment	2		8%
	Defective Material/Equipment	4		15%
Safety Protection Device	No safety device	2	4	8%
	Non-operating safety device	1		4%
	Absence of risk indication	1		4%
Personal Protective Equipment (PPE)	No PPE	2	2	8%
	Defective PPE	0		0%
Site Layout /Space	Improper arrangement of workplace	3	12	12%
	Insufficient of workplace	1		4%
	Congested work areas	0		0%
	Unstable work area/platforms	9		35%
Workplace	Poor illumination/ventilation	0	0	0%
	Excessive noise	0		0%
	Unpredictable weather	0		0%
	Poor housekeeping	0		0%
Total		26	26	100%

Table 4-6. Accident cause type in construction process

Cause Type	**Detailed Cause Type**	**Number of Accident**		**Ratio**
Material/Equipment	Slippery/ pointed material	4	31	5%
	Improper use of equipment	2		2%
	Defective Material/Equipment	26		32%
Safety Protection Device	No safety device	3	7	4%
	Non-operating safety device	1		1%
	Absence of risk indication	3		4%
Personal Protective Equipment (PPE)	No PPE	8	8	10%
	Defective PPE	0		0%
Site Layout /Space	Improper arrangement of workplace	8	32	10%
	Insufficient of workplace	5		6%
	Congested work areas	0		0%
	Unstable work area/platforms	19		23%
Workplace	Poor illumination/ventilation	0	2	0%
	Excessive noise	0		0%
	Unpredictable weather	1		1%
	Poor housekeeping	1		1%
Total		81	81	100%

4.4 Summary

As a summary of results during manufacturing process, one of the interesting features is high percentage of falls. There is a risk of falls when workers build or finish modular unit structure, or when using ladder or working above the structure. According to the National safety and health agency's industrial disaster statistics, 70% of falls occur at a low height of less than 3m (KOSHA, 2016). Considering that the height of the unit is less than 3m high, we can see that the hazard exists. Pre-measures can be identified in order to prevent falls. On the other hand, in aspect of construction process, the characteristics of safety accidents are the large number of accidents during lifting and installation of modular units. Modular units also account for a large proportion of original cause materials. In particular, various types of accidents occurred during the installation activity, because the workers' movements and space were not sufficiently considered and there were not sufficient falls prevention devices.

4.5 Relationship Analysis Between Accident Factors

This research is intended to verify that the results from the previous section are significant through statistical analysis. To validate the results of the previous analysis, it is necessary to verify that the working characteristics of the modular architecture have affected the type and cause of the accident. To explain the correlation, this research used statistical analyses, cross-tabulation analysis, a method for preparing and analyzing the association's cross-tables, is used. Cross-analysis is also called the Chi-square test. The chi-square is calculated by comparing observed and expected frequencies an it is possible to verify independence through it. The analysis calculates the difference between the observed actual frequency and expected frequency. The equation to calculate is shown as (1).

$$x^2 = \sum_i \sum_j \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \tag{1}$$

If cells with an expected frequency less than 5 are more than 20% of the total, the Fisher's exact test should be used (Fisher, 1954). The analysis is conducted through the use of IBM SPS Statistics 22.0 program and conducted on the relationship between activity-accident type and activity-accident cause in each manufacturing and construction process. Variables used in the analysis are limited to major factors for accuracy. A ρ-value indicates whether there is a significant relationship between the two variables. It is estimated by comparing the chi-square value to the predetermined chi-square distribution (Chi et al., 2013). If ρ-value is less than 0.050, relationship between two variables is in an acceptable significant level. Through the value of lamda(λ), the degree of relationship can be found. λ has a value from 0 through 1 and the closer to 1 the complete means that there is a relationship between the two variables. Table 4-7 shows the results of cross-tabulation analysis.

The analysis results show that activities of modular construction has a direct effect on the type of accident and the cause of the accident. However, due to the small number of samples, the data is not reliable. They also have significant relationships, but they are low. These results indicate the need to be presented in conjunction with activities when considering a safety management in modular construction. Statistical analysis is used to determine whether the type of accident and the cause of the accident are affected by the activity of modular construction. Through this, the results of the accident case analysis conducted in the previous section were shown to be significant. In the next section, this research compares the differences between accidents in modular architecture and general construction.

Table 4-7. Result of cross-tabulation analysis

Content of Result	Manufacturing Process		Construction Process	
	Activity - Accident Type	Activity - Cause	Activity - Accident Type	Activity - Cause
Chi-square (x^2 - test)	24.952	23.198	25.665	17.635
Degree of Freedom(df)	12	16	6	9
p-value	p1=0.008*	p2=0.094	p3=0.000*	p4=0.040*
Fisher's Exact Test	0.045	0.348	0	0.025
Lambda(λ)	0.296	0.211	0.143	0.111

Note: *p < 0.050 as an acceptable significance level

Chapter 5. Comparative Analysis with General Construction

Modular construction projects are carried out by existing construction companies, and the same safety management system of general construction is applied to modular construction. (Blismas, 2006). It is necessary to compare the trends and characteristics of safety accidents between modular construction and general construction to see if existing safety management can be applied. If there are differences, the cause should be identified and reflected in safety management of modular construction. This process can allow the establishment of safety management for modular construction.

Comparative analysis requires the results of analysis of general construction in a similar way of the modular construction analysis conducted in this study. Kang et al. (2017) collected 20,997 accident cases occurred in the construction industry that recorded in OSHA and identified various safety risk factors with accident cases. In particular, it indicated a detailed analysis of the trend of falls in the U.S. construction industry. According to the result of this study, the main type of accident that occurred in modular construction project is also the falls. It is judged to be suitable for comparison with the results of this study because of the similar scope of analysis results and the intensive analysis of falls. For this reason, this study conducted comparative analysis with Kang et al.'s study to identify trends of modular construction safety accidents.

This study selected four factors such as accident type ratio, project cost, fall height, and fall location and a comparative analysis is performed on these factors. The modular construction accident cases collected from OSHA have different information in each case. For example, some cases include information about fall protection, but most did not. This study selected factors that many accident cases commonly contain, and these are the four factors.

5.1. Accident Type Ratio

Table 5-1 shows the ratio of accident types between the result of this research for modular construction and general construction. Although slightly out of scope from the objectives of this study, the accident data from Korea occupational safety and health agency (KOSHA) are presented together to compare the accident type ratio in the manufacturing industry. Both general construction and modular construction account for the highest percentage of falls. The characteristic part is that the percentage of falls during manufacturing process is also high. In modular construction process, work is divided into manufacturing process(off-site) and construction process(on-site). And manufacturing rate is about 70~80% (Florida, 2004). Despite the reduced vertical work, falls account for the highest percentage in modular construction. Reviewing the manufacturing process, most of the work is done using ladders or scaffolding or building structures, except for floor concrete placement and flat paneling (Lawson et al., 2010; Fard et al. 2017).

Table 5-1. Ratio of accident type in modular and general construction

Accident Type	This research (Modular)		Kang et al. (2017)	KOSHA(2018)	
	Off-Site	On-Site	General Construction	Manufacture	General Construction
Fall	31%	36%	44.6%	8%	33%
Struck-by	31%	23%	22.8%	8%	11%
Caught in	15%	5%	11.1%	39%	18%
Crush/ crash	8%	27%	-	7%	17%
others	15%	9%	21.4%	38%	31%

5.2. Project Cost

Project cost means to the scale of the project. This study compares the accident rate by project scale and checks whether the accidents occurring in modular construction are affected by the scale of the project. Table 5-2 shows the ratio of accident by project cost in modular construction and general construction. Small companies are vulnerable to safety accident because they have less manpower and resources available for training (Dong et al., 2009; Olbina et al., 2011). Although much research is being conducted for safety management in small construction projects, many disasters still occur (Navon et al., 2007). The number of workers experienced in person is small, and there is also a shortage of experts who can transfer skills (Joshua et al., 2016). Not many large-scale modular projects have been carried out at home and abroad. Recently, the 44-story building in the United Kingdom has grown increasingly taller.

Table 5-2. Accidents by project cost in modular and general construction

Project Cost	This research (Modular)	Kang et al. (2017) General Construction
Under $50,000	22.73%	28.9%
$50,000 to $250,000	31.82%	18.8%
$250,000 to 500,000	9.09%	9.8%
$500,000 to $1,000,000	9.09%	11.0%
$1,000,000, to $5,000,000	22.73%	15.5%
$5,000,000 to $20,000,000	4.55%	9.6%
More than $20,000,000	0.00%	6.8%

5.3. Fall Location

According to the result of accident analysis in this research, falls is the major types of accident and it accounts more than 30% in each process. Falls is also the main accident in the general construction industry and comparative analysis is necessary in details. Table 5-3 shows the ratio of falls by location in modular construction and general construction. Both general and modular construction have the most frequent falls on the roof, followed by structures and ladders. Critical work in the modular project is lifting module units. Depending on the number of load per day, entire construction duration is affected (Lawson et al., 2010). Continuous lifting and installation of the unit requires minimum obstacles in the lifting radius and careful planning of the worker layout. Since the lifting and installation of the module unit is ongoing, safety net system and scaffold may not be installed for efficiency of work and shortening of construction duration. If the external finishing rate is low and the finishing work occurs on-site, scaffold is installed after completion of the unit lifting and installation (Kamali et al., 2016).

Table 5-3. Falls by location in modular and general construction

Fall Location	**This research (Modular)**	**Kang et al. (2017) General Construction**
Roof	34.5%	24.7%
Structure	25.5%	16.4%
Scaffold	3.6%	14.3%
Ladder	12.7%	16.0%
Floor opening	9.1%	5.6%
Vehicle	3.6%	3.2%
Platform	1.8%	5.2%

5.4. Fall Height

Table 5-4 shows the ratio of falls by height in modular construction and general construction. In general construction, more than 80% occurs below 9m. Safety net system and safety barriers may not be installed at low-rise construction site. And according to the standard for installation of a safety net, the first stage is to be installed at the position of 7~10m from ground (Hinze et al., 1997). In addition, the project type of accident data in the U.S. has a high percentage of housing and dwellings (Kang et al., 2017). The fall height in modular construction is related to the unit height. The average module unit is about 3m high. Falls in ladders and structures in the manufacturing process and fall in residential modular construction were affected to this result.

Table 5-4. Falls by height in modular and general construction

Fall Height(m)	**This research (Modular)**	**Kang et al. (2017) General Construction**
0-3	17.39%	22.1%
3-6.1	47.83%	42.5%
6.1-9.1	13.04%	19.9%
9.1-12.2	8.70%	6.8%
12.2-15.2	8.70%	2.3%
15.2-18.3	4.35%	1.5%
>18.3	0.00%	4.9%

Chapter 6. Discussion

6.1. Trends of Accidents in Modular Construction

Using the accident data of OSHA, this research analyzed the accident cases in modular construction and derived the major hazardous activities, types of accident and causes of accident. The analysis results were compared with accidents in general construction to identify the characteristics of safety accidents in modular construction. There are notable findings through analysis results. In the case of modular construction, falls account for 35%, struck-by falling objects 25%, crush/crash 22%. Because the number of accidents is very low compared to the general construction industry, it is impossible compare the number of accident directly. However, the results are similar to the major accident types in general construction. According to the ratio by accident type, it can still be seen that fall accidents account for a large portion, and that the proportion of accidents caused by struck-by falling objects and crush/crash is relatively high. In particular, it was confirmed that the rate of falls and struck-by falling object accidents was high during the modular manufacturing process. These results indicate that modular construction has somewhat different characteristics from general construction, and that safety management by modular activity is required accordingly.

6.2. Suggestions of Safety management

As a result of the analysis, it is deemed that intensive safety management is required for unit installation in the construction process with the highest accident rate. The main causes of falls during unit installation activity are the absence of personal safety equipment and unstable work space. Since pre-built units are installed in the field in a short period of time in modular construction, safety devices such as fall prevention nets are not performed as thoroughly as in general construction projects for the efficiency of work. In particular, personal safety devices may be neglected in consideration of workability, as the work of settling and joining units is long. Therefore, prior safety education should be thoroughly conducted to alert workers to falls on the educational side, and safety measures should be taken into account work efficiency on the technical side at the same time. In addition, in organizational terms, workers' movements are planned in advance for work at risk of falling, and safety managers' ability to manage at the site is important.

When installing the unit, there is a high risk of accidents caused by struck-by falling objects, and the modular unit itself is unstable or defective. In general, accidents caused by struck-by falling objects are caused by crane defects or poor driving by crane drivers, but in modular construction, there are many cases that the unit itself was defective. This may be due to improper welding or bonding during the unit's manufacturing process, or damage due to impact during transport to the site, or damage to the member due to distortion during crane lifting. Thus, from an organizational point of view, a systematic procedure for verifying confidentiality is needed in the manufacture of modular unit structures. The manager's role is important to check and evaluate whether the manufacturing has been carried out in accordance with the design. On the technical side, technologies such as vibration control systems should be installed to reduce impact in transportation that minimize shaking on the vehicle.

There have been many accidents caused by falls and falling objects in the modular manufacturing process, and safety management should also be considered for this purpose. When assembling the structure of the modular unit, accidents caused by falls and struck-by falling objects occurred. Modular manufacturing plants are mainly responsible for handling heavy loads and each member and modular unit is carried out using an overhead crane. In addition, work is carried out on the unit structure or by using a ladder or a movable scaffolding. In general manufacturing, high place work is rarely carried out, and there are insufficient devices to prevent falls at manufacturing plants. On the other hand, considering the height of the modulator unit, safety measures for preventing falls are insufficient, even though there is sufficient room for falls. Therefore, it is necessary to thoroughly conduct prior safety training on the handling of heavy objects and the use of cranes in educational aspects in the construction of structures. On the technical side, the fall prevention rope and device should be installed on the structure itself or on the production line to prevent falls.

It is certain that modular construction has many advantages in terms of safety by introducing manufacturing characteristics and performing most of the work in manufacturing plants. It is also an obvious fact to reduce safety accidents and improve workability at construction sites. However, as the result of this study, safety accidents are still occurring, and the characteristics of modular construction activity cause different types of accidents than those of general construction and manufacturing industries, and the causes are different. It is also confirmed that various accidents are occurring not only during the modular construction process but also during the manufacturing process because of activities for modular unit. In other words, modular construction is different in work characteristics from existing construction projects, so the types and causes of accidents are different, and therefore accident prevention measures are needed.

6.3. Safety Checklist for Modular Construction

In this study, safety risk factors are analyzed by collecting accident cases that occurred in modular construction in U.S, and the trend of modular building safety accidents is analyzed through comparison with safety accidents in general construction. It also suggest some prevention method to reduce major accidents in modular construction.

In order to prevent safety accidents in modular construction, it is necessary to deliver cautions in work more efficiently. In particular, a safety inspection checklist is required that presents the main inspection items for each type of activity. Therefore, through the results of the previous analysis, this study proposes a activity-specific safety checklist for rational safety management in modular construction projects.

Table 6-1 and 6-2 show safety checklist in the manufacturing(off-site) and construction(on-site) process in modular construction. The checklist is divided into each activities, and the main safety inspection items are presented. Each item that constitutes a checklist is based on the type of accident and cause of accident analyzed in Chapter 4. The checklist provides key management points with safety regulation to solve the causes of accidents identified for each activities.

This study also conducted risk assessment for the safety checklist by 5 experts in modular construction projects. The evaluation method applied a five-point scale of the Likert scale technique. Five points is assessed as very important, four points important, three points normal, two points not important, and one point not important at all. The results of risk assessment indicates the degree of importance for safety checklist and show priorities among the items. The degree of danger can help safety managers to make safety decisions when using the checklist.

The checklist presented in this study does not include all check points. Since it is based on accident cases in modular construction which are handled in this study, there should be many additional check points to be made. In particular, items on the existing safety checklist need to be added to supplement it. However, since the checklist considers causes of the actual accidents, it includes essential safety check items. Therefore, the checklist contains the most important points to prevent the occurrence of fatal accidents.

Table 6-1. Safety Checklist during manufacturing process (1)

Process	Activity	Checklist Suggestion	Degree of Danger
Off-Site	Material Imports & Load	Is the support for load place is fixed on the ground?	4.6
		Didn't the load exceed the proper height?	3.8
		Is there no worker in the crane's radius?	3.8
		Is there a support to prevent the load from being overturned?	3.8
		Hasn't the support exceeded the proper weight to withstand?	3.4
		have enough passageways for the lift been secured?	3.4
		Has the driver of forklift been trained?	3.2
	Member Cutting	Is a cutter safety device installed?	4.8
		is a cutter safety device working well?	4.6
	Member Lifting	Is there fault in hook when moving components using overhead crane?	4.0
	Unit Assembly	Is there a fall prevention device when assembling a unit?	4.8
		Is the bolt work of the unit structure as designed?	4.6
		When using an over-cran, doesn't the operator work under it?	4.6
		Is the ladder or scissor-lift fixed on the ground?	4.2

Table 6-1. Safety Checklist during manufacturing process(Off-Site) (2)

Process	Activity	Checklist Suggestion	Degree of Danger
Off-Site	Interior Finishing	Is the ladder fixed on the ground during interior finishing work?	4.2
		Is there a safety device for nail gun and does it work?	4.2
		Is there no fault in the hook when moving the components using an over-crane?	4.0
		Isn't the floor slippery?	3.2
	Exterior Finishing	Is the ladder fixed on the ground during exterior finishing work?	4.4
		Doesn't the space for the exterior finishing work overlap with other working lines?	4.2
		Is the working radius sufficient during exterior finishing work?	3.6
	Packing &QA	Is there fall prevention device during packing work?	3.8

Table 6-2. Safety Checklist during construction process(On-Site) (1)

Process	Activity	Checklist Suggestion	Degree of Danger
On-Site	Unit Transport	Is the modular unit tightly connected to the trailer?	3.8
		Does a fixed modulator unit not move during transport?	3.4
		Is there enough space for the trailer to move around?	3.4
		Is there any obstacle in the path of the trailer?	3.4
	Unit Lifting	Didn't the crane exceed the proper load?	4.8
		Is the unit balanced when lifting with the crane?	4.4
		Is the hook connecting the unit undamaged?	4.4
		Is there a risk of falling out of the components that make up the unit?	4.2
		Is the spreader bar to hang modular unit well fixed in the crane?	4.2
		Is it prohibited to enter other workers within the radius of the crane?	4.2
		Have proper jack been used to withstand enough load?	4.0

Table 6-2. Safety Checklist during construction process(On-Site) (2)

Process	Activity	Checklist Suggestion	Degree of Danger
On-Site	Unit Installation	Does the worker wear PPE to prevent falls?	4.8
		Is there enough work space for the worker when installing the unit?	4.8
		Is there enough work space for the worker when installing the unit?	4.6
		Is there fall prevention device during installation work?	4.2
		Isn't there a worker underneath the crane when it's lifting?	4.2
		Is there any obstacle that could interfere with the workplace?	4.0
		Is the support of the work plate installed as prescribed?	4.0
		Does the safety device work When working on a skycar or lift?	3.8
		Is the work plate fixed on the structure and safe enough?	3.6
		Isn't the floor slippery?	3.4
		Is there no defect in the joint of the unit structure?	3.4
		Is there no defect in the jack that support the unit?	3.2
		Is there work carried out between units or structures?	3.2

Table 6-2. Safety Checklist during construction process(On-Site) (3)

Process	Activity	Checklist Suggestion	Degree of Danger
On-Site	Roof Finishing	Is there a fall prevention device in the opening?	4.6
		Does the worker wear PPE to prevent falls?	4.4
		Is there enough work space for roof installation?	4.2
		Is there electric wire over the work space during roof finishing work?	4.2
		Isn't the floor slippery?	3.6
		Is the flooring member fixed to the structure?	3.4
		Is the ladder or scissor-lift fixed on the ground?	2.6
	Interior Finishing	Is there a fall prevention device in the opening inside the building?	2.8
		Doesn't the inner wall fall?	2.6
	Exterior Finishing	Does the worker wear PPE to prevent falls?	4.4
		Is the bolt of the member well fastened?	4.0
		Isn't the floor slippery?	3.6
		Is the ladder or scissor-lift fixed on the ground?	3.0

Chapter 7. Conclusion

Modular construction has various advantages in terms of safety, and has been applied in whole world recently. Although there have been studies related to modular safety management, these have rarely analyzed accident cases and identified characteristics. In addition, the focus of previous studies was on the work at on-site, and the unit manufacturing process is poorly considered. Therefore, this study investigated the accident case of modular construction and analyzed safety risk factors such as major accident type and the cause of accident. In addition, this study conducted comparative analysis between modular construction and general construction to identify differences of characteristics and to find trends of safety accident in modular construction. In this study, suggestions for reduction measures for accident prevention of modular construction are proposed, and a safety checklist is presented to be used in modular construction project.

Although there were limitations that the number of accident cases was small in the selection of major accident types and cause of the accident, the correlation with modular work characteristics was directly confirmed through cross-analysis. If the accident case is added and analyzed, the cause of the accident can be identified more accurately and it is believed to affect the establishment of safety management measures. Therefore, it is necessary to secure cases of safety accidents in modular construction and to analyze more detailed levels of activities.

Nevertheless, this study is meaningful in academically that safety management of modular construction is extended beyond the construction process to the manufacturing process and safety accident cases are analyzed for each activities at each process. This study also presents causal map for accidents in modular construction. The causal map can be used to make a decision what the cause of accident is. In addition, by comparing the accident trend in general construction, the characteristics of modular construction have been further identified, which can prove the need of specialized safety management in modular construction.

In practically, the safety checklist, presented in discussion part, suggests what needs to be managed with emphasis in modular construction project. And it can be used by the safety manager to prevent safety accidents. Findings in this research could contribute to diagnosing the current state of accident factors in modular construction industry in the United states. This can be used to predict the probability of accidents off-site and on-site, and to develop a strategy to reduce the number of accidents in modular construction project. Outcomes will assist safety managers to understand safety risk factor and to make prompt safety decisions. They also can prioritize risk factors and control unsafe condition in working place.

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Appendix

A. Web Crawling Code for Data Collecting

```
import re
import numpy as np
import pandas as pd
import requests
from datetime import datetime
from bs4 import BeautifulSoup

def OSHA_accident(word):
url2="https://www.osha.gov/pls/imis/accidentsearch.search?sic=&
sicgroup=&naics=&acc_description=&acc_abstract="+ word
+"&acc_keyword=&inspnr=&fatal=&officetype=All&office=All&startm
onth=08&startday=21&startyear=2020&endmonth=08&endday=21&e
ndyear=2000&keyword_list=&p_start=&p_finish=0&p_sort=&p_desc=
DESC&p_direction=Next&p_show=500"
    r2 = requests.get(url2).text
    soup2 = BeautifulSoup(r2, "html.parser")

    tables = soup2.find_all("table",{"class":"table table-bordered
table-striped"})
    table2 = tables[1]
    trs = table2.find_all("tr")

    list=[]
    for tr in trs[1::]:
        tds = tr.find_all("td")

        number = tds[2].find("a").get("title")
        event_date = tds[3].text
        reportID = tds[4].text
        maintitle = tds[7].text
```

```
        url =
"https://www.osha.gov/pls/imis/accidentsearch.accident_detail?id=
"+str(number)
         r = requests.get(url).text
         soup = BeautifulSoup(r, "html.parser")

         data1 =soup.find("div", {"id":"maincontain"})
         main = data1.find("div", {"class":"row-fluid"})

         data2 = soup.find_all("td",{"colspan":"8"})
         try:
             descript = data2[1].text.replace("\n", "").replace("'","")
         except:
             descript ="None"

         try:
             keyword=data2[2].text.replace("\n",
"").replace("Keywords:", "").replace("'","")
         except :
             keyword = "None"

         list.append([number, event_date, reportID, maintitle,
descript, keyword])

     cols = ["SummaryNr", "EventDate",
"ReportID","Title","Descrpit","Keyword"]
     df = pd.DataFrame(list, columns=cols)

     df.to_csv('%s.csv' % (word))
     print("Success Get Datafile and Save Data")
```

```
def Searching():
    while(1):
        kb=input("$ ")
        if kb == "exit":
            break
        elif kb == "crawling":
            word = input("Enter keyword : ")
            OSHA_accident(word)
        else:
            print("Error command")

Searching(keyword)
```

B. Samples of Accident Cases

1) Sample No.1

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

CONTACT US FAQ A TO Z INDEX ENGLISH ESPAÑOL

OSHA STANDARDS TOPICS HELP AND RESOURCES SEARCH OSHA

Return to Accident Search Results

Accident Report Detail

Accident: 201159837 - Employee Amputates Finger While Assembling Steel Modular

Accident: 201159837 -- Report ID: 0950633 -- Event Date: 06/08/2004

Inspection	Open Date	SIC	Establishment Name
307453738	07/08/2004	1541	Moreno Valley Const. Inc

At approximately 1:30 p.m. on June 8, 2004, an employee, a carpenter, was putting steel modular classroom buildings together on foundations at a school site. As a modular class room was being inched into its final position next to the adjacent building, the employee working in a crawl space under the structures placed his left hand on the metal frame and inserted his left index finger in a bolthole to check the final alignment of the structures. When the structure moved, the tip of his index finger was severed. Coworkers provided first aid. Paramedics took the injured employee to the Riverside County Regional Medical Center in Moreno Valley, where he was treated and released that evening.

Keywords: amputated, finger, construction, caught between

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Other building	New project or new addition	$500,000 to $1,000,000	1		

Employee #	Inspection	Age	Sex	Degree	Nature	Occupation	Construction
1	307453738			Non Hospitalized injury	Amputation	Construction laborers	**FallDist:** **FallHt:** **Cause:** Installing interior walls, ceilings, doors **FatCause:** Other

2) Sample No.2

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

CONTACT US FAQ A TO Z INDEX ENGLISH ESPAÑOL

OSHA STANDARDS TOPICS HELP AND RESOURCES SEARCH OSHA

Return to Accident Search Results

Accident Report Detail

Accident: 202486106 - Employee Killed When Modular Unit Falls During Transit

Accident: 202486106 -- Report ID: 0950621 -- Event Date: 01/03/2008

Inspection	Open Date	SIC	Establishment Name
125820779	01/04/2008	1522	Weed Construction

On January 3, 2008, Employee #1, a carpenter for a construction contractor that moved and installed modular structures, was moving a 65 ft long modular unit when it fell on top of him. He was crushed and killed.

Keywords: structure moving, unsecured, work rules, construction, crushed, mech mat handling, struck by, falling object, unstable position

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Commercial building	Alteration or rehabilitation	Under $50,000	1	10	X

Employee #	Inspection	Age	Sex	Degree	Nature	Occupation	Construction
1	125820779			Fatality	Other	Carpenters	**FallDist:** **FallHt:** **Cause:** Temporary work (buildings, facilities) **FatCause:** Collapse of structure

3) Sample No.3

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

CONTACT US FAQ A TO Z INDEX ENGLISH ESPAÑOL

OSHA STANDARDS TOPICS HELP AND RESOURCES SEARCH OSHA

Return to Accident Search Results

Accident Report Detail

Accident: 202508594 - Employee'S Hip Crushed By Modular Building

Accident: 202508594 -- Report ID: 0950622 -- Event Date: 04/14/2011

Inspection	Open Date	SIC	Establishment Name
314326695	04/21/2011	1541	Global Modular, Inc.

On April 14, 2011 at approximately 12:00 p.m. an employee suffered a crushed right hip while attempting to place springs and axels on a modular building being raised. Employee was a laborer tasked with placing the springs and axels under a modular building; upon placement and securing of the springs and axels, the building would then be transported on the roadway. While attempting to raise the modular building with lever jacks placed atop plastic padding, a jack slipped causing the modular building to fall and strike employee on the right acetabulum (hip joint). The building then landed on wood cribbing. Employee sustained a fractured right acetabulum (hip joint) requiring surgery and several days hospitalization. Emergency services were activated, and employee was transported via helicopter to the hospital for further treatment. Employee's employer is a modular building company whose main functions are the designing, building, installation and transportation of factory built modular structures. The lever jack and plastic padding being used for raising the building at the time of the accident were placed upon sand. The wood cribbing used at the time of the accident was placed at the front, center and back of the building on both sides, six total. Of this wood cribbing, one was placed upon asphalt and five were placed upon sand.

Keywords: building, crushed, jack, hip

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Other building	Other	Under $50,000	1	10	

Employee #	Inspection	Age	Sex	Degree	Nature	Occupation	Construction
1	314326695			Hospitalized injury	Fracture	Construction laborers	**FallDist:** **FallHt:** **Cause:** Demolition **FatCause:** Struck by falling object/projectile

4) Sample No.4

UNITED STATES DEPARTMENT OF LABOR

Occupational Safety and Health Administration

CONTACT US FAQ A TO Z INDEX ENGLISH ESPAÑOL

OSHA STANDARDS TOPICS HELP AND RESOURCES SEARCH OSHA

Return to Accident Search Results

Accident Report Detail

Accident: 109164.015 - Employee Is Struck By A Falling Load From A Crane And Is Cru

Accident: 109164.015 -- Report ID: 0352440 -- Event Date: 08/23/2018

Inspection	Open Date	SIC	Establishment Name
1344698.015	08/23/2018		Maxim Crane Works L.P.

At 8:30 a.m. on August 23, 2018, an employee was providing signals to a crane operator as they set a modular unit in place. The employee reached under the load and disconnected the ratchet strap that was being used as a tag line when the synthetic sling broke and struck him, crushing the employee.

Keywords: struck by, crane, crushed

End Use	Proj Type	Proj Cost	Stories	NonBldgHt	Fatality
Commercial building	New project or new addition		1		X

Employee #	Inspection	Age	Sex	Degree	Nature	Occupation	Construction
1	1344698.015	28	M	Fatality	Cut/Laceration	Operating engineers	**FallDist:** **FallHt:** **Cause:** **FatCause:** Heat/hypothermia

C. Results of Cross-Tabulation Analysis

1) Activity − Accident Type (Manufacturing Process)

단위작업 * 사고유형 교차표

			사고유형				
			Caught in	Cut	Fall	Struck By Falling Object	전체
단위작업	구조체 제작	빈도	0	0	2	3	5
		기대빈도	1,0	0,8	1,8	1,5	5,0
		단위작업 중 %	0,0%	0,0%	40,0%	60,0%	100,0%
		사고유형 중 %	0,0%	0,0%	28,6%	50,0%	25,0%
	부재 절단	빈도	0	3	0	0	3
		기대빈도	0,6	0,5	1,1	0,9	3,0
		단위작업 중 %	0,0%	100,0%	0,0%	0,0%	100,0%
		사고유형 중 %	0,0%	100,0%	0,0%	0,0%	15,0%
	석고보드 시공	빈도	1	0	1	1	3
		기대빈도	0,6	0,5	1,1	0,9	3,0
		단위작업 중 %	33,3%	0,0%	33,3%	33,3%	100,0%
		사고유형 중 %	25,0%	0,0%	14,3%	16,7%	15,0%
	외장 마감 작업	빈도	1	0	2	0	3
		기대빈도	0,6	0,5	1,1	0,9	3,0
		단위작업 중 %	33,3%	0,0%	66,7%	0,0%	100,0%
		사고유형 중 %	25,0%	0,0%	28,6%	0,0%	15,0%
	자재 반입 및 적재	빈도	2	0	2	2	6
		기대빈도	1,2	0,9	2,1	1,8	6,0
		단위작업 중 %	33,3%	0,0%	33,3%	33,3%	100,0%
		사고유형 중 %	50,0%	0,0%	28,6%	33,3%	30,0%
전체		빈도	4	3	7	6	20
		기대빈도	4,0	3,0	7,0	6,0	20,0
		단위작업 중 %	20,0%	15,0%	35,0%	30,0%	100,0%
		사고유형 중 %	100,0%	100,0%	100,0%	100,0%	100,0%

카이제곱 검정

	값	자유도	근사 유의확률 (양측검정)	정확 유의확률 (양측검정)
Pearson 카이제곱	24,952[a]	12	0,015	0,008
우도비	23,079	12	0,027	0,066
Fisher의 정확검정	15,020			0,088
유효 케이스 수	20			

a. 20 셀 (100,0%)은(는) 5보다 작은 기대 빈도를 가지는 셀입니다. 최소 기대빈도는 ,45 입니다.

방향성 측도

			값	근사 표준오차[a]	근사 T 값[b]	근사 유의확률	정확 유의확률
명목척도 대 명목척도	람다	대칭적	0,296	0,193	1,356	0,175	
		단위작업 종속	0,286	0,209	1,195	0,232	
		사고유형 종속	0,308	0,239	1,101	0,271	
	Goodman과 Kruskal 타우	단위작업 종속	0,275	0,043		,052[c]	0,032
		사고유형 종속	0,329	0,047		,095[c]	0,065

a. 영가설을 가정하지 않음.

b. 영가설을 가정하는 점근 표준오차 사용

c. 카이제곱 근사값을 기준으로

d. 카이제곱 근사값을 기준으로

2) Activity – Accident Cause (Manufacturing Process)

단위작업 * 사고의 근본원인 교차표

			사고의 근본원인					
			Defective Material/Equipment	Improper arrangement of workplace	Improper use of equipment	No safety device	Unstable work areas/platf	전체
단위작업	구조체 제작	빈도	1	0	0	0	3	4
		기대빈도	0.7	0.7	0.2	0.5	1.9	4.0
		단위작업 중 %	25.0%	0.0%	0.0%	0.0%	75.0%	100.0%
		사고의 근본원인 중 %	33.3%	0.0%	0.0%	0.0%	37.5%	23.5%
	부재 절단	빈도	0	0	0	2	0	2
		기대빈도	0.4	0.4	0.1	0.2	0.9	2.0
		단위작업 중 %	0.0%	0.0%	0.0%	100.0%	0.0%	100.0%
		사고의 근본원인 중 %	0.0%	0.0%	0.0%	100.0%	0.0%	11.8%
	석고보드 시공	빈도	1	0	0	0	1	2
		기대빈도	0.4	0.4	0.1	0.2	0.9	2.0
		단위작업 중 %	50.0%	0.0%	0.0%	0.0%	50.0%	100.0%
		사고의 근본원인 중 %	33.3%	0.0%	0.0%	0.0%	12.5%	11.8%
	외장 마감 작업	빈도	0	1	0	0	1	2
		기대빈도	0.4	0.4	0.1	0.2	0.9	2.0
		단위작업 중 %	0.0%	50.0%	0.0%	0.0%	50.0%	100.0%
		사고의 근본원인 중 %	0.0%	33.3%	0.0%	0.0%	12.5%	11.8%
	자재 반입 및 적재	빈도	1	2	1	0	3	7
		기대빈도	1.2	1.2	0.4	0.8	3.3	7.0
		단위작업 중 %	14.3%	28.6%	14.3%	0.0%	42.9%	100.0%
		사고의 근본원인 중 %	33.3%	66.7%	100.0%	0.0%	37.5%	41.2%
전체		빈도	3	3	1	2	8	17
		기대빈도	3.0	3.0	1.0	2.0	8.0	17.0
		단위작업 중 %	17.6%	17.6%	5.9%	11.8%	47.1%	100.0%
		사고의 근본원인 중 %	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

카이제곱 검정

	값	자유도	근사 유의확률 (양측검정)	정확 유의확률 (양측검정)
Pearson 카이제곱	23.198a	16	0.109	0.094
우도비	19.180	16	0.259	0.338
Fisher의 정확검정	16.687			0.348
유효 케이스 수	17			

a. 25 셀 (100.0%)은(는) 5보다 작은 기대 빈도를 가지는 셀입니다. 최소 기대빈도는 .12 입니다.

방향성 측도

			값	근사 표준오차a	근사 T 값b	근사 유의확률	정확 유의확률
명목척도 대 명목척도	람다	대칭적	0.211	0.206	0.916	0.360	
		단위작업 종속	0.200	0.283	0.640	0.522	
		사고의 근본원인 종속	0.222	0.240	0.833	0.405	
	Goodman과 Kruskal 타우	단위작업 종속	0.292	0.043		.286c	0.260
		사고의 근본원인 종속	0.297	0.059		.269c	0.254

a. 영가설을 가정하지 않음.

b. 영가설을 가정하는 점근 표준오차 사용

c. 카이제곱 근사값을 기준으로

d. 카이제곱 근사값을 기준으로

3) Activity – Accident Type (Construction Process)

단위작업 * 사고유형 교차표

			사고유형			
			Crush/Crash	Fall	Struck By Falling Object	전체
단위작업	외장 마감 작업	빈도	0	5	0	5
		기대빈도	1.3	2.1	1.6	5.0
		단위작업 중 %	0.0%	100.0%	0.0%	100.0%
		사고유형 중 %	0.0%	20.0%	0.0%	8.5%
	유닛 설치	빈도	12	10	15	37
		기대빈도	9.4	15.7	11.9	37.0
		단위작업 중 %	32.4%	27.0%	40.5%	100.0%
		사고유형 중 %	80.0%	40.0%	78.9%	62.7%
	유닛 양중	빈도	3	0	3	6
		기대빈도	1.5	2.5	1.9	6.0
		단위작업 중 %	50.0%	0.0%	50.0%	100.0%
		사고유형 중 %	20.0%	0.0%	15.8%	10.2%
	지붕 마감	빈도	0	10	1	11
		기대빈도	2.8	4.7	3.5	11.0
		단위작업 중 %	0.0%	90.9%	9.1%	100.0%
		사고유형 중 %	0.0%	40.0%	5.3%	18.6%
전체		빈도	15	25	19	59
		기대빈도	15.0	25.0	19.0	59.0
		단위작업 중 %	25.4%	42.4%	32.2%	100.0%
		사고유형 중 %	100.0%	100.0%	100.0%	100.0%

카이제곱 검정

	값	자유도	근사 유의확률 (양측검정)	정확 유의확률 (양측검정)
Pearson 카이제곱	25.665[a]	6	0.000	0.000
우도비	31.779	6	0.000	0.000
Fisher의 정확검정	23.507			0.000
유효 케이스 수	59			

a. 9 셀 (75.0%)은(는) 5보다 작은 기대 빈도를 가지는 셀입니다. 최소 기대빈도는 1.27 입니다.

방향성 측도

			값	근사 표준오차[a]	근사 T 값[b]	근사 유의확률	정확 유의확률
명목척도 대 명목 척도	람다	대칭적	0.143	0.086	1.542	0.123	
		단위작업 종속	0.000	0.000	.[c]	.[c]	
		사고유형 종속	0.235	0.136	1.542	0.123	
	Goodman과 Kruskal 타우	단위작업 종속	0.161	0.060		.000[d]	0.001
		사고유형 종속	0.243	0.046		.000[d]	0.000

a. 영가설을 가정하지 않음.

b. 영가설을 가정하는 점근 표준오차 사용

c. 점근 표준오차가 0이므로 계산할 수 없습니다.

d. 카이제곱 근사값을 기준으로

4) Activity - Accident Cause (Manufacturing Process)

단위작업 * 사고의 근본원인 교차표

			사고의 근본원인 Defective Material/Equipment	Improper arrangement of workplace	No PPE	Unstable work areas/platforms	전체
단위작업	외장 마감 작업	빈도	3	0	1	1	5
		기대빈도	2.3	0.5	0.7	1.4	5.0
		단위작업 중 %	60.0%	0.0%	20.0%	20.0%	100.0%
		사고의 근본원인 중 %	11.5%	0.0%	12.5%	6.3%	8.9%
	유닛 설치	빈도	17	2	3	10	32
		기대빈도	14.9	3.4	4.6	9.1	32.0
		단위작업 중 %	53.1%	6.3%	9.4%	31.3%	100.0%
		사고의 근본원인 중 %	65.4%	33.3%	37.5%	62.5%	57.1%
	유닛 양중	빈도	5	0	0	1	6
		기대빈도	2.8	0.6	0.9	1.7	6.0
		단위작업 중 %	83.3%	0.0%	0.0%	16.7%	100.0%
		사고의 근본원인 중 %	19.2%	0.0%	0.0%	6.3%	10.7%
	지붕 마감	빈도	1	4	4	4	13
		기대빈도	6.0	1.4	1.9	3.7	13.0
		단위작업 중 %	7.7%	30.8%	30.8%	30.8%	100.0%
		사고의 근본원인 중 %	3.8%	66.7%	50.0%	25.0%	23.2%
전체		빈도	26	6	8	16	56
		기대빈도	26.0	6.0	8.0	16.0	56.0
		단위작업 중 %	46.4%	10.7%	14.3%	28.6%	100.0%
		사고의 근본원인 중 %	100.0%	100.0%	100.0%	100.0%	100.0%

카이제곱 검정

	값	자유도	근사 유의확률 (양측검정)	정확 유의확률 (양측검정)
Pearson 카이제곱	17.635[a]	9	0.040	0.037
우도비	19.534	9	0.021	0.032
Fisher의 정확검정	15.771			0.025
유효 케이스 수	56			

a. 13 셀 (81.3%)은(는) 5보다 작은 기대 빈도를 가지는 셀입니다. 최소 기대빈도는 .54 입니다.

방향성 측도

			값	근사 표준오차[a]	근사 T 값[b]	근사 유의확률	정확 유의확률
명목척도 대 명목척도	람다	대칭적	0.111	0.089	1.192	0.233	
		단위작업 종속	0.125	0.141	0.837	0.402	
		사고의 근본원인 종속	0.100	0.071	1.364	0.173	
	Goodman과 Kruskal 타우	단위작업 종속	0.120	0.060		.019[c]	0.029
		사고의 근본원인 종속	0.118	0.042		.021[c]	0.025

a. 영가설을 가정하지 않음.

b. 영가설을 가정하는 점근 표준오차 사용

c. 카이제곱 근사값을 기준으로

d. 카이제곱 근사값을 기준으로

D. Survey Form for Safety Checklist

Modular Construction Safety Checklist

1: not important at all, 2: not important, 3: normal, 4: important, 5: very important

Process	Activity	Checklist Suggestion	Likert Sacle 1	2	3	4	5
Off-Site	Material Imports & Load	Is the support for load place is well fixed?					
		Didn't the load exceed the proper height?					
		Is there no worker in the crane's radius?					
		Has the driver of forklift been trained?					
		Is there a support to prevent the load from being overturned?					
		have enough passageways for the lift been secured?					
		Hasn't the support exceeded the proper weight to withstand?					
	Member Cutting	Is a cutter safety device installed?					
		is a cutter safety device working well?					
	Member Lifting	Is there no fault in the hook when moving the member using an overhead crane?					
	Unit Assembly	Is the ladder or scissor-lift fixed on the ground?					
		Is there a fall prevention device when assembling a unit?					
		Is the bolt work of the unit structure as designed?					
		When using an over-crane, doesn't the operator work under it?					
	Interior Finishing	Is the ladder fixed on the ground during interior finishing work?					
		Is there no fault in the hook when moving the member using an over-crane?					
		Isn't the floor slippery?					
		Is there a safety device for nail gun and does it work?					
	Exterior Finishing	Doesn't the space for the exterior finishing work overlap with other working lines?					
		Is the ladder fixed on the ground during exterior finishing work?					
		Is the working radius sufficient during exterior finishing work?					
	Packing &QA	Is there fall prevention device during packing work?					

Process	Activity	Checklist Suggestion	1	2	3	4	5
On-Site	Unit Transport	Is the modular unit tightly connected to the trailer?					
		Does a fixed modulator unit not move during transport?					
		Is there enough space for the trailer to move around?					
		Is there any obstacle in the path of the trailer?					
	Unit Lifting	Is the spreader bar to hang modular unit well fixed in the crane?					
		Is the unit balanced when lifting with the crane?					
		Is there a risk of falling out of the components that make up the unit?					
		Is the hook connecting the unit undamaged?					
		Didn't the crane exceed the proper load?					
		Is it prohibited to enter other workers within the radius of the crane?					
		Have proper jack been used to withstand enough load?					
	Unit Installation	Is there enough work space for the worker when installing the unit?					
		Is the work plate fixed on the structure and safe enough?					
		Isn't the floor slippery?					
		Is there any obstacle that could interfere with the workplace?					
		Does the safety device work When working on a skycar or lift?					
		Is there fall prevention device during installation work?					
		Does the worker wear PPE to prevent falls?					
		Is the support of the work plate installed as prescribed?					
		Isn't there a worker underneath the crane when it's lifting?					
		Is there enough work space for the worker when installing the unit?					
		Is there no defect in the joint of the unit structure?					
		Is there no defect in the jack that support the unit?					
		Is there work carried out between units or structures?					
	Roof Finishing	Is the ladder or scissor-lift fixed on the ground?					
		Is the flooring member fixed to the structure?					
		Isn't the floor slippery?					
		Is there a fall prevention device in the opening?					
		Does the worker wear PPE to prevent falls?					
		Is there enough work space for roof installation?					
		Is there no electric wire line in the work space during roof finishing work?					
	Interior Finishing	Is there a fall prevention device in the opening inside the building?					
		Doesn't the inner wall fall?					
	Exterior Finishing	Is the ladder or scissor-lift fixed on the ground?					
		Does the worker wear PPE to prevent falls?					
		Isn't the floor slippery?					
		Is the bolt of the member well fastened?					

국 문 초 록

모듈러 건축은 대부분의 제작 공정이 공장에서 수행됨으로써 일반 건설에 비해 안전하다고 여겨진다. 하지만 모듈러 건축의 일반적인 인식과는 달리, 일부 연구와 산업 데이터에 따르면 모듈러 건축의 사고율이 전문가의 기대만큼 낮지 않다고 지적하고 있다. 이러한 부분은 모듈러 건축의 안전성에 의구심을 가져다 주며 안전관리가 필요하다는 것을 나타낸다. 모듈러 건축이 최근 떠오르는 산업으로 주목받고 있고, 많은 프로젝트가 수행되는 시점에서, 모듈러 건축에 적합한 안전관리가 필요한 것이다.

모듈러 건축의 안전을 향상시키기 위해서는 우선 안전 리스크 요인들을 분석하여야 한다. 또한 안전 사고를 사전에 예방하기 위해서 기존의 사고 사례를 분석하여 사고 유형 및 사고 원인을 파악하여야 한다.

이러한 문제를 해결하기 위하여, 먼저, 본 연구는 모듈러 건축과 관련된 사고 사례를 조사하고, 안전 리스크 요인들을 분석한다. 본 연구는 2000년부터 2018년 사이에 미국에서 발생한 사고 사례를 수집하고, 각 사고 사례의 사고 유형과 사고 원인 등의 안전 리스크 요인 분석을 실시한다. 분석은 모듈러 전체 프로세스를 제작과정과 시공과정으로 나누어 실시하고, 건설 관련 원인 인자를 사전에 분석하여 사고 원인 분석에 적용한다. 분석 결과는 표와 동시에 원인 맵을 생성하여 나타낸다. 분석 결과로부터 각각의 작업에 따른 주요 사고 유형 및 사고 원인을 확인할 수 있다. 결과를 바탕으로, 교차분석이라는 통계적 분석을 실시하는데, 이를 통하여 모듈러

건축의 작업 특성이 안전 사고와 연관성이 있음을 통계적으로 확인한다.

모듈러 건축의 분석 이후에 본 연구는 모듈러 건축과 일반건축의 사고 리스크 요인과 특성의 비교분석을 실시한다. 비교 분석을 통하여, 사고 요인들에 차이점과 모듈러 프로젝트를 위한 안전 관리가 필요하다는 것을 확인할 수 있다.

최종적으로 모듈러 건축에서의 안전사고의 추이를 확인하고, 안전사고를 예방할 수 있는 저감방안을 제시한다. 이를 바탕으로 모듈러 건축의 작업별 안전 체크리스트를 제시한다.

본 연구는 모듈러 건축의 제작과정과 시공과정에서의 안전관리 기초자료로 사용될 수 있다. 또한 연구 결과는 안전 관리자가 안전 위험 요인을 이해하고, 적절한 의사결정을 하는데 도움을 줄 수 있다.

주요어: 모듈러 건축, 안전 사고, 안전 리스크 요인, 원인 분석, 안전 체크리스트

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