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Development of Calculation Method for Full-Time Equivalent Workers per Man-Year to Improve Fatality Rate Estimation

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Abstract: The fatality rate in the construction industry is a key indicator for assessing safety management, with the number of workers being a critical factor in its estimation. Many countries rely on sampling inspections or assumptions to determine the number of workers, which can lead to inaccuracies in evaluating the fatality rate. In this study, we developed a method to calculate the full-time equivalent workers per man-year ($FTEW_{m\cdot y}$) to more accurately estimate the fatality rate, taking into account building and work types using daily work reports (DWRs). The research process included six steps: (i) selecting a target project; (ii) establishing a database; (iii) developing the $FTEW_{m\cdot y}$ framework based on the DWR; (iv) validating the framework; (v) calculating the $FTEW_{m\cdot y}$ for residential building projects in the Republic of Korea; and (vi) applying the framework. The key findings included the following: the $FTEW_{m\cdot y}$/USD for residential projects was 1.1×10^{-3} $FTEW_{m\cdot y}$/USD, with the framework achieving an accuracy of 85.30% and an R^2 value of 92.92% through five-fold cross-validation. The $FTEW_{m\cdot y}$ for residential buildings in the Republic of Korea was 4.5×10^{7} $FTEW_{m\cdot y}$, and the fatality rate was 0.011‰. This framework offers a more precise way of evaluating fatality rates by considering specific building and work types, improving safety management practices in the construction industry.

Keywords: fatality rate; full-time equivalent worker; construction man-year; construction daily work report; K-fold cross validation

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1. Introduction

The construction industry has the highest injury and fatality rates compared to other industries [1]. According to the '2022 Industrial Accident Statistics' report from the Ministry of Employment and Labor in Republic of Korea (MOEL), there were 27,432 injuries and 402 fatal accidents in the construction industry, accounting for 25.6% and 46.0% of all industrial accidents, respectively [2]. Thus, because the construction industry's risk level is higher than that of other industries, it is necessary to evaluate these rates and manage them completely [3]. Every year, the fatality rate is investigated and reported to identify and manage high risk levels worldwide. It is estimated using the number of fatal accidents and annual full-time equivalent workers (AFTEW) [3–7]. The number of fatal accidents is investigated according to the total number of inspections for each country, whereas the AFTEW is investigated and determined by sampling inspections in the United States, Japan, China, Singapore, Mexico, and the United Kingdom and the ratio of labor cost

to revenue in the Republic of Korea [8–14]. For example, two-step sampling inspection is conducted by the Ministry of Health, Labor and Welfare in Japan. The first step is location selection through a sampling inspection, and the second step, AFTEW, relies on the sampling inspection [10]. In addition, other countries estimate the AFTEW by considering their own standards. Therefore, the estimation of the AFTEW differs with regard to the fatality rate for each country.

Unlike other countries, the AFTEW in the Republic of Korea is estimated using construction revenue and the ratio of labor cost to revenue as a top-down method [15,16]. The ratio of labor cost to revenue is the ratio used in the Republic of Korea, referring to the ratio of wages paid to construction workers out of construction revenue. Therefore, the AFTEW is determined using the ratio of labor cost to revenue and construction workers' wage in the Republic of Korea [15,16]. However, there are several problems with the method of estimating the AFTEW. First, if the AFTEW is determined using the ratio of labor cost to revenue, it will differ from the actual AFTEW [16]. Second, only the AFTEW in the entire construction industry is estimated, although this figure does not consider building or work types [3]. However, the fatality rate also differs when the building and work types are considered because the intensity of labor differs when these factors are considered in the construction industry [17,18]. This makes it difficult to manage the risk level considering the building and work types [17]. The AFTEW should be estimated to manage the risk level in terms of both building and work types. Third, it is assumed that construction workers work 50 w per year and 40 h per week in the estimations of the AFTEW [3,7]. Because many construction workers work as non-regulars, few construction workers work all year [19]. Therefore, if the AFTEW is assumed based on working hours per year, the value will differ from the actual AFTEW.

Various previous studies have estimated the fatality rate using the AFTEW. Jo et al. [6] analyzed and evaluated accident data from 2011 to 2015 in the Republic of Korea. They analyzed the number of injuries and fatal accidents by sex, age, company size, and accident type. In addition, the injury and fatality rates were evaluated using the AFTEW provided by MOEL. They established that the average fatality rate in the construction industry of the Republic of Korea is 17.93 per 100,000 FTEW for five years. Konda et al. [7] analyzed the data of 2210 traumatic brain injuries (TBIs) from 2003 to 2010 in the construction industry in the USA. They presented a fatal TBI rate using the AFTEW from the Bureau of Labor Statistics. They established that the fatal TBI rate in the construction industry of the USA is 2.6 per 100,000 FTEW. Li et al. [20] analyzed and compared the fatality rates between Shanghai and Wuhan in China. The fatality rate was calculated using the AFTEW from the National Bureau of Statistics of China. They established that the fatality rates are 0.35 and 0.49 per 100,000 FTEW in Shanghai and Wuhan, respectively.

However, the AFTEW in previous studies were estimated through sampling inspections or the ratio of the labor cost to revenue. Therefore, the fatality rate appears to be different from the actual value. Proper safety management cannot be conducted when using different values of fatality rate and using the AFTEW. Furthermore, it is difficult to evaluate the fatality rate depending on the building and work types.

To solve these problems, construction workers can be estimated using daily work reports (DWRs). The number of full-time equivalent workers per man-day ($FTEW_{m \cdot d}$) was recorded through DWRs in the construction industry. The fatality rate (unit: year) should be estimated using the number of full-time equivalent workers per man·year ($FTEW_{m \cdot y}$) instead of the AFTEW to accurately represent the fatality rate [21]. However, there is no method for estimating $FTEW_{m \cdot y}$ in terms of the building type and/or work type in the construction industry.

Owing to these problems with estimating the AFTEW by using sampling inspection and the ratio of the labor cost to revenue, it is necessary to develop a calculation method for estimating the $FTEW_{m \cdot y}$. If a method of estimating $FTEW_{m \cdot y}$ is developed, it will be possible to calculate an accurate fatality rate according to the work type and building type and perform accurate safety management. DWRs record the number of construction

workers per day [22]. Specifically, the actual number of construction workers engaged in construction projects is recorded in DWRs by work type. Consequently, the $FTEW_{m \cdot y}$ can be estimated in terms of both building and work types [21]. In this study, we developed a framework based on DWRs for calculating the $FTEW_{m \cdot y}$ in the construction industry. The developed framework can estimate the $FTEW_{m \cdot y}$ accurately in terms of the building and work types, leading to accurate evaluations of fatality rates.

In this study, there are several words to express the number of construction workers, such as AFTEW, $FTEW_{m \cdot d}$ and $FTEW_{m \cdot y}$. The relationship between the AFTEW, $FTEW_{m \cdot d}$ and $FTEW_{m \cdot y}$ is as follows. First, the AFTEW is the number of construction workers estimated through sampling inspection. So, this cannot be an exact number. Second, the $FTEW_{m \cdot d}$ is the actual number of construction workers recorded in DWRs. Unlike the AFTEW, this is the actual number of construction workers, so it can be used for accurate statistics, such as calculating the fatality rate. Third, the $FTEW_{m \cdot y}$ is the $FTEW_{m \cdot d}$ converted to an annual value. Since the fatality rate is calculated on an annual basis, the $FTEW_{m \cdot d}$ needs to be converted.

There is a need for the accurate estimation of fatality rates due to the limitations of current methods, such as sampling and assumptions based on construction revenue. This study aims to provide a more precise method using DWRs to address these inaccuracies. For this, this study develops a framework that calculates an accurate $FTEW_{m \cdot y}$ using DWRs to calculate the correct fatality rate and ensure proper safety management.

2. Materials and Methods

As shown in Figure 1, this study was conducted in six steps: (1) the selection of the target project; (2) the establishment of the database; (3) the development of the proposed $FTEW_{m \cdot y}$ framework based on the DWR; (4) the validation of the framework based on the DWR; (5) the calculation of the $FTEW_{m \cdot y}$ for residential building projects in the Republic of Korea; and (6) the utilization of the framework based on the DWR.

2.1. Selection of the Target Project

In this study, a target project was selected to establish a database for the proposed framework based on DWRs. The number of fatal accidents and the scale of construction revenue in the Republic of Korea were considered when selecting the target project. With regard to building projects, there are many fatalities and injuries caused by accidents during residential building projects [18,23–25]. In addition, residential building projects account for 40% of the total construction revenue in the Republic of Korea [26]. Therefore, the $FTEW_{m \cdot y}$ for a residential building project should first be estimated considering the work type, and then the fatality rate can be evaluated to manage the risk level. Therefore, before developing the framework based on DWRs, the DWRs for the residential building project were collected for the establishment of the database. The database was utilized to develop the framework based on the DWRs ultimately to estimate the $FTEW_{m \cdot y}$ for each work type. The fatality rate can be calculated using the $FTEW_{m \cdot y}$.

2.2. Establishment of the Database

To ensure data reliability, 11 residential building projects, representative of the Republic of Korea market, were selected based on building type and scale. Related data, including the DWRs from these projects, were collected to develop the framework, as shown in Table 1. The construction revenue was as high as USD 211 million and as low as USD 11 million, with an average of USD 111 million. The construction period lasted as long as 1064 days and as few as 525 days, with an average of 843 days. The $FTEW_{m \cdot d}$ can be as high as 287,864 $FTEW_{m \cdot d}$ and as low as 21,594 $FTEW_{m \cdot d}$, with an average 124,346 $FTEW_{m \cdot d}$. Second, the construction revenue and number of fatal accidents for the residential building project from 2007 to 2019 in the Republic of Korea were collected. The details of this information are presented in Table 2. After developing the framework based on the DWR, validation was conducted, and the $FTEW_{m \cdot y}$ was estimated in terms of the work type from

2007 to 2019. Subsequently, using the $FTEW_{m \cdot y}$, the fatality rate for the residential building project was calculated.

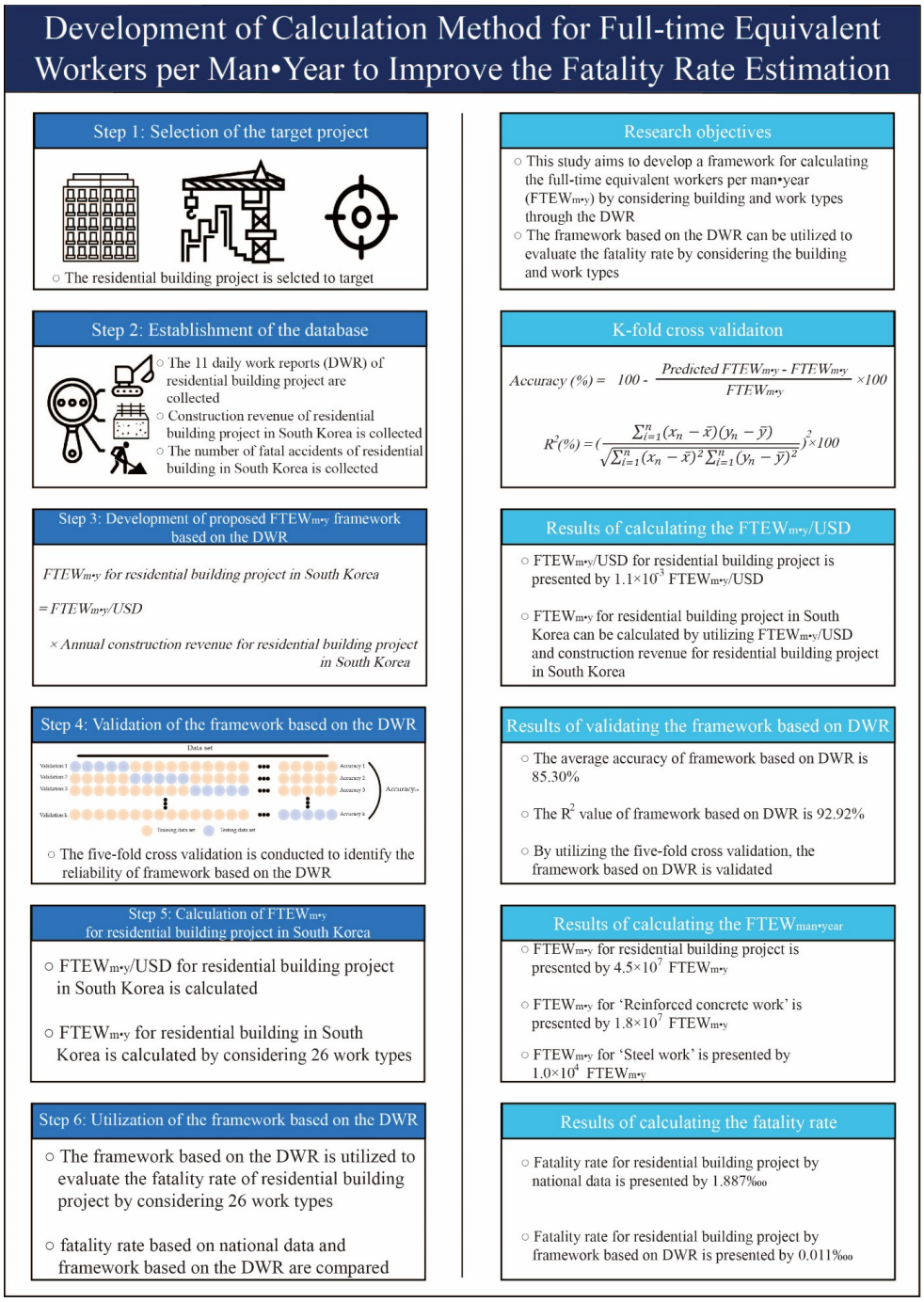


Figure 1. Research framework.

For the entire construction industry, the AFTEW is provided by the Korean Statistical Information Service (KOSIS) of the Republic of Korea. However, the risk level in the construction industry is different when considering different building and work types. Accordingly, when considering building and work types, proper risk management should be conducted. Therefore, this study presents the $FTEW_{m \cdot y}$ for a residential building project by considering the work type. Further research on the fatality rate during the residential building project is provided for each work type. The work types for the residential building projects are categorized into 26 types from 'Temporary work' to 'Information and telecom-

munication facilities installation work', referring to the Korea Construction Standards Center and to previous research, to calculate the $FTEW_{m \cdot y}$ and fatality rate [27,28]. The average number of fatal accidents in residential building projects for the 26 work types is presented in Table 3.

Table 1. Information about the 11 collected DWRs for residential building projects.

Site Number	Construction Revenue (USD)	Construction Period (Day)	$FTEW_{m \cdot d}$
1	200,948,341	890	195,035
2	122,692,510	804	118,774
3	95,934,606	945	106,904
4	104,537,794	834	110,774
5	118,555,903	829	136,078
6	54,671,154	806	77,123
7	11,235,010	525	21,594
8	38,482,123	792	55,774
9	184,448,798	1064	146,760
10	211,165,123	956	287,864
11	79,618,186	823	111,129
Average	111,117,232	843	124,346

Table 2. Construction revenue and number of fatal accidents for the residential building projects in the Republic of Korea from 2007 to 2019.

Year	Construction Revenue (USD)	The Number of Fatal Accidents for Residential Building Projects in the Republic of Korea
2007	35,295,980,609	57
2008	37,850,169,189	70
2009	36,629,828,511	82
2010	28,679,101,553	52
2011	24,142,238,775	47
2012	25,679,581,916	27
2013	32,159,296,529	52
2014	36,251,758,014	33
2015	42,853,315,876	41
2016	53,271,732,448	49
2017	65,544,849,367	51
2018	63,962,559,105	57
2019	57,472,866,564	41
Average	40,193,367,658	50.69

Table 3. Classification of work types and the average number of fatal accidents for residential building projects.

Unit: $FTEW_{m \cdot y}$					
Work type	**Temporary work**	**Earth work**	**Landscaping work**	**Foundation work**	**Stone work**
The average number of fatal accidents	6.92	1.92	1.77	1.92	0.62

Table 3. *Cont.*

Unit: $FTEW_{m \cdot y}$					
Work type	**Road pavement work**	**Pipe installation and joint work**	**Reinforced concrete work**	**Steel work**	**Masonry work**
The average number of fatal accidents	0.46	1.23	11.92	1.23	0.46
Work type	**Tile work**	**Interior finishing work**	**Waterproof work**	**Metal work**	**Plaster work**
The average number of fatal accidents	0.62	0.69	2.08	0.54	1.92
Work type	**Window and glass work**	**Paint work**	**Maintenance work (including demolition)**	**Plumbing work**	**Insulation work**
The average number of fatal accidents	2.08	6.46	2.23	1.62	0.08
Work type	**Sanitation work**	**Air handler work**		**Fire protection work**	**Gas service line and meter installation work**
The average number of fatal accidents	0.08	0.38		0.46	0.38
Work type	**Electric wiring work**	**Information and telecommunication facilities installation work**			**Total**
The average number of fatal accidents	1.92	0.69			50.69

2.3. Development of the Proposed $FTEW_{m \cdot y}$ Framework Based on the DWR

As mentioned above, the AFTEW is determined through sampling inspection and the ratio of labor cost to revenue worldwide [15,16]. The AFTEW is investigated according to the total inspection as a bottom-up method for accurate determination. However, total inspection requires considerable time and money [29]. Therefore, the AFTEW is determined according to the construction revenue, the ratio of labor cost to revenue, and the daily construction workers' wage in the Republic of Korea. The AFTEW in the Republic of Korea was determined using Equation (1).

$$\text{AFTEW} = \frac{\text{Annual construction revenue} \times \text{Ratio of the labor cost to revenue}}{\text{Daily wages of construction workers} \times 22 \times 12} \quad (1)$$

In Equation (1), the ratio of labor cost to revenue, noted by the MOEL every year, is the ratio of construction workers' wage to the construction revenue [12]. However, because construction workers' wages differ according to the job type and career level of each construction worker, it is difficult to estimate the AFTEW accurately [16]. Moreover, construction workers' wages and material costs can differ when considering building and work types. Therefore, when applying the ratio of labor cost to revenue and considering the building and work types, the AFTEW can be estimated precisely [17,18]. However, MOEL notes the ratio of labor cost to revenue for the entire construction industry. In addition, the AFTEW cannot accurately estimate the number of construction workers because it assumes that they work 2000 h per year. Therefore, when the AFTEW is estimated using Equation (1), the fatality rate cannot be estimated in terms of the building and work types. Therefore, the $FTEW_{m \cdot y}$ as recorded in the DWRs can be accurately estimated [21]. To resolve these issues, a framework based on DWRs is proposed to estimate the $FTEW_{m \cdot y}$ by considering the building and work types.

The proposed framework based on the DWRs is developed according to Equations (2)–(8) to estimate the $FTEW_{m\cdot y}$ for residential building projects in the Republic of Korea. In Equations (2)–(8), the abbreviation CR means "Construction Revenue" and RBP means "Residential Building Project".

$$FTEW_{m\cdot di} = \frac{\text{The number of construction worker}_i \text{ for construction period}_i}{\text{Construction period}_i} \quad (2)$$

$$FTEW_{m\cdot yi} = FTEW_{m\cdot di} \times 365\ (\text{year/day}) \quad (3)$$

$$FTEW_{m\cdot y} = \sum_{i=1}^{n} FTEW_{m\cdot yi} \quad (4)$$

$$\text{Annual CR for RBP}_i\ (\text{USD \$}) = \text{CR for RBP}_i \times \frac{365}{\text{Construction period}_i} \quad (5)$$

$$\text{Annual CR for RBP}\ (\text{USD \$}) = \sum_{i=1}^{n} \text{Annual CR for}RBP_i \quad (6)$$

$$FTEW_{m\cdot y}/\text{USD} = \frac{FTEW_{m\cdot y}}{\text{Annual CR for RBP}\ (\text{USD \$})} \quad (7)$$

$$\begin{aligned} &FTEW_{m\cdot y} \text{ for RBP in South Korea} \\ &= FTEW_{m\cdot y}/\text{USD} \times \text{Annual CR for the RBP in South Korea} \end{aligned} \quad (8)$$

The $FTEW_{m\cdot y}$/USD is calculated from Equations (2)–(7) based on the collected DWRs; when the $FTEW_{m\cdot y}$/USD is multiplied by the construction revenue for the residential building project using Equation (8), the $FTEW_{m\cdot y}$ can be estimated from the scale of a single residential building project to the scale of a residential building project in the country.

2.4. Validation of the Proposed Framework Based on the DWR

This study presents a framework based on DWRs to estimate the $FTEW_{m\cdot y}$ for a residential building project. However, several problems remain to be solved. First, the validation of the framework based on DWRs is needed to ensure accuracy. Second, the resolution of the overfitting problem is required for the framework based on DWRs. Overfitting is a problem in which a high forecast rate is presented when using an existing dataset, whereas a low forecast rate is presented with a new dataset [30,31]. Therefore, k-ford cross validation (CV) was used to perform the performance evaluation and avoid overfitting.

In this study, k-fold CV was used to validate the framework based on the DWR. Before machine learning, the dataset was divided into two datasets, namely the training and test datasets. The training dataset was used to train the model. The test dataset was used to evaluate the capacity of the model [30,31]. However, there are various problems. First, if the available data are subdivided into training and test datasets, some relevant trends may be omitted from the training dataset. Second, prediction errors in the training dataset can be reduced; however, errors in the test dataset can be high owing to the variability of the sample. Third, overfitting can occur because the dataset is divided into training and test datasets [30–34].

K-fold CV can be used to compensate for the problems of the machine learning model and identify overfitting [30–34]. CV divides the available dataset into k folds. One of the fold was used as the test dataset to validate the performance of the model, and the other folds were used as the training dataset to train the model. The process of CV is presented in Figure 2. CV was performed by conducting the procedure k times for training and testing. In particular, CV can be accurately evaluated for a small dataset [30,34]. In previous research, the k value was set to 5 to maximize the performance of CV [35]. Accordingly, k was set to 5 in this study, and the collected data of the 11 DWRs were divided into five groups. In each CV test, four groups were used to train the model and one group was used to test the model. The predicted performance of the model was validated by

calculating the average accuracy and coefficient of determination (R^2) for the test dataset. Accuracy is a measure of the difference between the $FTEW_{m\cdot y}$ of the test dataset and the predicted $FTEW_{m\cdot y}$ of the training dataset. The accuracy rate was calculated according to Equation (9).

$$\text{Accuracy}(\%) = 100 - \frac{\text{Predicted FTEW}_{m\cdot y} - \text{FTEW}_{m\cdot y}}{\text{FTEW}_{m\cdot y}} \times 100 \quad (9)$$

where $FTEW_{m\cdot y}$ is obtained using the test dataset and the predicted $FTEW_{m\cdot y}$ is obtained from the training dataset.

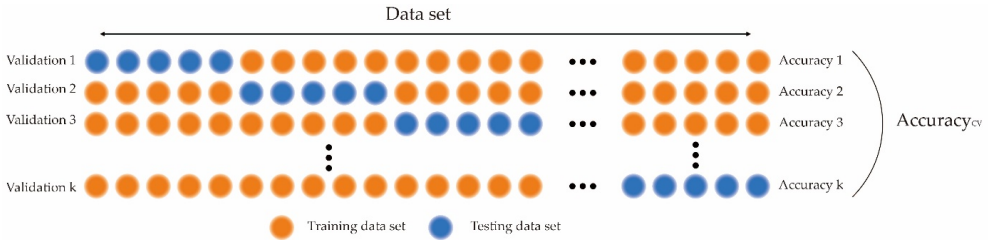


Figure 2. Example of the CV process.

R^2 is a measure of the correlation between the $FTEW_{m\cdot y}$ and the predicted $FTEW_{m\cdot y}$ [36–38]. If R^2 is close to 100%, the framework based on the DWR could predict the $FTEW_{m\cdot y}$ well [36–38]. The R^2 value is calculated according to Equation (10).

$$R^2(\%) = \left(\frac{\sum_{i=1}^{n}(x_n - \bar{x})(y_n - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_n - \bar{x})^2 \sum_{i=1}^{n}(y_n - \bar{y})^2}}\right)^2 \times 100 \quad (10)$$

where $\bar{x}$ denotes the average value of the $FTEW_{m\cdot y}$ and $\bar{y}$ is the average value of the predicted $FTEW_{m\cdot y}$.

2.5. Calculation of $FTEW_{m\cdot y}$ for Residential Building Project in Republic of Korea

A case study was conducted to estimate the $FTEW_{m\cdot y}$ for a residential building project in the Republic of Korea using the proposed framework based on DWRs. The case study was conducted as follows. First, 11 DWRs for the residential building project were utilized in the framework based on DWRs to estimate the $FTEW_{m\cdot y}$/USD. Second, the $FTEW_{m\cdot y}$ was estimated using the construction revenue for residential building projects in the Republic of Korea in terms of the 26 work types for residential building projects.

2.6. Utilization of the Proposed Framework Based on the DWR

Here, the fatality rate can be accurately estimated using the proposed framework based on the DWRs in terms of the building and work types. The fatality rate was estimated using the $FTEW_{m\cdot y}$ by considering the 26 work types for the residential building project. In addition, the result of the fatality rate is compared with national data to prove the superiority of the proposed framework based on the DWRs. The fatality rate was calculated according to Equation (11) [12].

$$\text{Fatality rate}(‰) = \frac{\text{The number of fatal accidents}}{\text{FTEW}_{m\cdot y}} \times 10,000 \quad (11)$$

3. Results and Discussion

3.1. Calculation of the $FTEW_{m\cdot y}$/USD

The $FTEW_{m\cdot y}$/USD for the residential building project was estimated using DWRs. The $FTEW_{m\cdot y}$/USD was calculated according to Equations (2)–(7). The $FTEW_{m\cdot y}$/USD was presented in terms of the 26 work types for the residential building project. The

$FTEW_{m\cdot y}$/USD for the residential building project was 1.1 × 10^{-3} $FTEW_{m\cdot y}$ /USD, indicating the $FTEW_{m\cdot y}$ amount invested per USD 1 of construction revenue based on the 11 residential building projects. The $FTEW_{m\cdot y}$/USD was estimated to be as high as 4.4 × 10^{-4} $FTEW_{m\cdot y}$/USD and as low as 2.6 × 10^{-7} $FTEW_{m\cdot y}$/USD, according to the work type. The $FTEW_{m\cdot y}$ for residential building projects in the Republic of Korea can be estimated using the $FTEW_{m\cdot y}$/USD and construction revenue for residential building projects in the Republic of Korea. Apart from the residential building project, the $FTEW_{m\cdot y}$ can be estimated using the proposed framework based on the DWRs for other building and work types. The $FTEW_{m\cdot y}$/USD values are presented in Table 4 and Figure 3.

Table 4. $FTEW_{m\cdot y}$/USD of the 26 work types for the residential building project.

Work type	**Temporary work**	**Earth work**	**Landscaping work**	**Foundation work**	**Stonework**
$FTEW_{m\cdot y}$/USD	1.4× 10^{-5}	2.3× 10^{-5}	2.4× 10^{-5}	3.3× 10^{-6}	2.5× 10^{-5}
Work type	**Road pavement work**	**Pipe installation and joint work**	**Reinforced concrete work**	**Steel work**	**Masonry work**
$FTEW_{m\cdot y}$/USD	7.7× 10^{-6}	9.9× 10^{-6}	4.4× 10^{-4}	2.6× 10^{-7}	2.1× 10^{-5}
Work type	**Tile work**	**Interior finishing work**	**Waterproof work**	**Metal work**	**Plaster work**
$FTEW_{m\cdot y}$/USD	2.6× 10^{-5}	1.2× 10^{-4}	3.7× 10^{-5}	1.2× 10^{-5}	4.9× 10^{-5}
Work type	**Window and glass work**	**Paint work**	**Maintenance work (including demolition)**	**Plumbing work**	**Insulation work**
$FTEW_{m\cdot y}$/USD	2.4× 10^{-5}	7.8× 10^{-5}	1.3× 10^{-5}	9.5× 10^{-5}	1.4× 10^{-5}
Work type	**Sanitation work**		**Air handler work**	**Fire protection work**	**Gas service line and meter installation work**
$FTEW_{m\cdot y}$/USD	1.0× 10^{-5}		4.5× 10^{-6}	8.8× 10^{-6}	2.7× 10^{-6}
Work type	**Electric wiring work**		**Information and telecommunication facilities installation work**		**Total**
$FTEW_{m\cdot y}$/USD	7.7× 10^{-5}		2.3× 10^{-6}		1.1× 10^{-3}

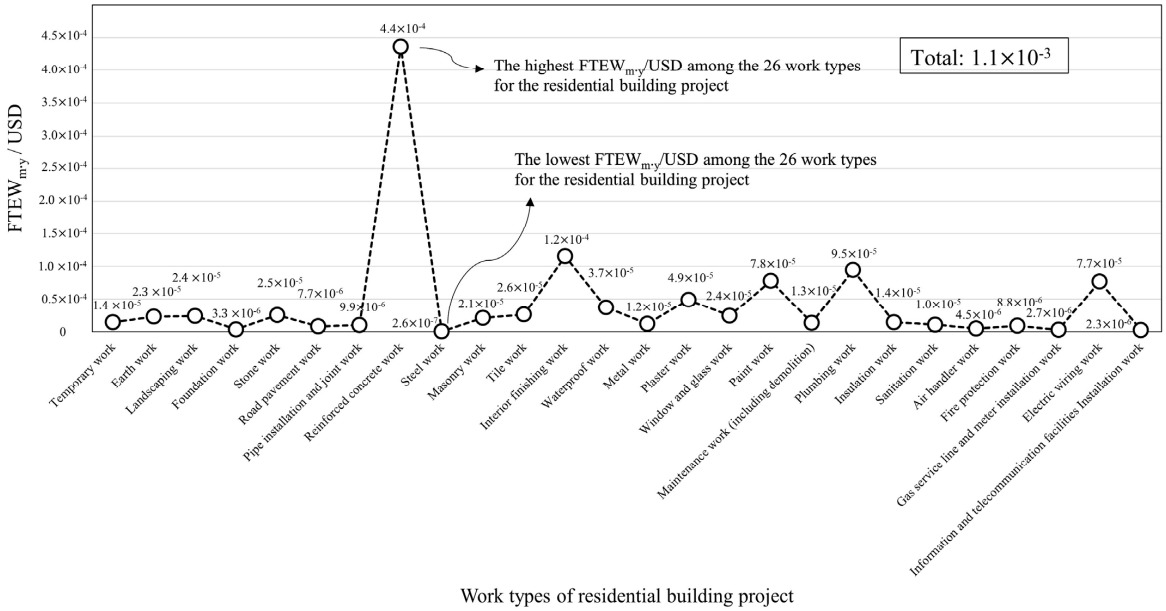


Figure 3. Comparison of $FTEW_{m\cdot y}$/USD by the 26 work types for the residential building project.

3.2. Validation of the Proposed Framework Based on the DWR

Five-fold CV was conducted to analyze the accuracy of the proposed framework based on the DWRs. The 11 DWRs of the residential building project were divided into five groups. The average accuracy of each of the five validations and the R^2 value were used to verify the reliability of the framework based on the DWRs. The results of CV are presented in Table 5 and Figure 4. The accuracy of the framework based on the DWRs ranged from 69.44% to 95.00%. The accuracy of Group 4 was the lowest at 69.44%. The $FTEW_{m\cdot y}$ and the predicted $FTEW_{m\cdot y}$ were 40,717 $FTEW_{m\cdot y}$ and 28,275 $FTEW_{m\cdot y}$, respectively, and the difference was 12,442 $FTEW_{m\cdot y}$, indicating a large error. The accuracy of Group 5 was the highest at 95.00%. The $FTEW_{m\cdot y}$ and the predicted $FTEW_{m\cdot y}$ were 209,537 $FTEW_{m\cdot y}$ and 199,053 $FTEW_{m\cdot y}$, respectively, with a difference of 10,484 $FTEW_{m\cdot y}$. The results of the differences were similar to each other; however, the accuracy of Group 5 was higher than that of Group 4. Projects with longer durations and larger scales tended to have more consistent data, leading to higher accuracy. In contrast, smaller projects or those with incomplete DWRs faced greater variability, which contributed to the lower accuracy rates. The average accuracy of the framework based on the DWRs was 85.30%, which was high. The R^2 value in the five groups was 92.92%, indicating that the framework based on DWRs could estimate the $FTEW_{m\cdot y}$ well. As shown in Table 6, if R^2 exceeds 0.7, it can be considered a strong effect size [39,40]. As shown in Table 6, the results of the five-fold CV indicated that the framework based on DWRs can estimate the $FTEW_{m\cdot y}$ with high accuracy and a high R^2. This verifies the reliability of the framework based on DWRs and shows that the overfitting problem does not exist.

Table 5. Results of CV.

	Group 1	Group 2	Group 3	Group 4	Group 5
$FTEW_{m\cdot y}$	133,907	89,771	94,839	40,717	209,537
Predicted $FTEW_{m\cdot y}$	164,766	94,477	85,682	28,275	199,053
Accuracy (%)	76.96	94.76	90.34	69.44	95.00
Average of accuracy (%)			85.30		
R^2 (%)			92.92		

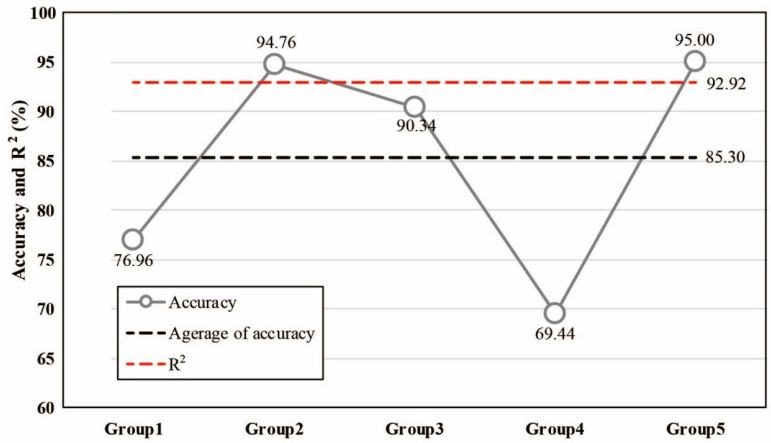


Figure 4. Results of five-fold CV for the proposed framework based on DWRs.

Table 6. Effect size of the R^2 value.

R^2 Value	Effect Size
$R^2 < 0.3$	It is generally regarded to be either zero or very low
$0.3 \leq R^2 < 0.5$	It is generally regarded to be a low effect size
$0.5 \leq R^2 < 0.7$	It is generally regarded to be a moderate effect size
$0.7 \leq R^2$	It is generally regarded to be a strong effect size

3.3. Calculation of FTEW$_{m\cdot y}$ for Residential Building Project in Republic of Korea

After identifying the reliability of the proposed framework based on DWRs, the FTEW$_{m\cdot y}$ for the residential building project in the Republic of Korea was estimated using FTEW$_{m\cdot y}$/USD and the construction revenue of the residential building project from 2007 to 2019. The average FTEW$_{m\cdot y}$ was estimated for 13 years. As shown in Table 7 and Figure 5, the FTEW$_{m\cdot y}$ was presented by considering 26 work types for the residential building project. The average FTEW$_{m\cdot y}$ was 4.5×10^7 FTEW$_{m\cdot y}$, which can be regarded as 4.5×10^7 FTEW$_{m\cdot y}$ for working in a residential building project each year.

Table 7. FTEW$_{m\cdot y}$ of 26 work types for the residential building project in the Republic of Korea.

Work Type	**Temporary Work**	**Earth Work**	**Landscaping Work**	**Foundation Work**	**Stonework**
FTEW$_{m\cdot y}$	566,676	912,030	949,876	133,088	1,005,055
Work type	**Road pavement work**	**Pipe installation and joint work**	**Reinforced concrete work**	**Steel work**	**Masonry work**
FTEW$_{m\cdot y}$	309,586	398,506	17,536,943	10,505	834,863
Work type	**Tile work**	**Interior finishing work**	**Waterproof work**	**Metal work**	**Plaster work**
FTEW$_{m\cdot y}$	1,044,459	4,640,473	1,480,292	474,209	1,962,022
Work type	**Window and glass work**	**Paint work**	**Maintenance work (including demolition)**	**Plumbing work**	**Insulation work**
FTEW$_{m\cdot y}$	961,411	3,136,259	521,648	3,798,647	558,603
Work type	**Sanitation work**		**Air handler work**	**Fire protection work**	**Gas service line and meter installation work**
FTEW$_{m\cdot y}$	419,687		181,199	355,002	107,677
Work type	**Electric wiring work**		**Information and telecommunication facilities installation work**		**Total**
FTEW$_{m\cdot y}$	3,090,225		93,819		45,482,759

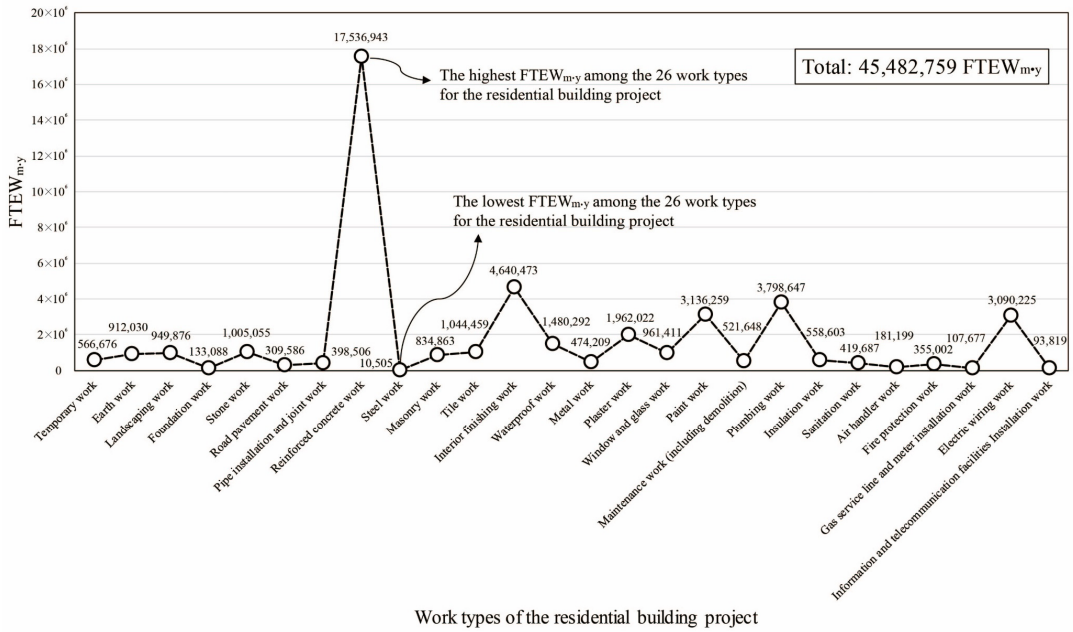


Figure 5. Comparison of FTEW$_{m\cdot y}$ by the 26 work types for the residential building project.

THE $FTEW_{m \cdot y}$ was analyzed by work type in detail. The result indicated that the $FTEW_{m \cdot y}$ for 'Reinforced concrete work' was 1.8×10^7 $FTEW_{m \cdot y}$, which was the highest number of construction workers among the 26 work types. Because 'reinforced concrete work' is the main type of structural work, the construction period accounts for 50% of the total duration of residential building projects [41]. Therefore, reinforced concrete work has the highest $FTEW_{m \cdot y}$ because it requires the longest construction period and a considerable amount of work [18,24]. Additionally, 4.6×10^6 $FTEW_{m \cdot y}$ for interior finishing work was the second highest work type in the residential building project. Interior finishing work requires much work compared to other work types. Accordingly, three to five subcontractors are generally employed [42]. Therefore, many construction workers are necessary for interior finishing work owing to the multiple sub-contractors employed. In contrast, the $FTEW_{m \cdot y}$ for steel work was 1.0×10^4 $FTEW_{m \cdot y}$, which is related to the lowest number of construction workers among the 26 work types. Steel work is not considered a main type of construction work and is not included in most residential building projects. Therefore, there were low $FTEW_{m \cdot y}$ results for steel work [43]. As shown in the results, there are major differences in the $FTEW_{m \cdot y}$ outcomes according to the 26 work types for the residential building project. The $FTEW_{m \cdot y}$ should be estimated accurately to manage the fatality rate in the construction industry.

3.4. Utilization of the Proposed Framework Based on the DWR

In Chapter 3.3, the $FTEW_{m \cdot y}$ for a residential building project was estimated using the proposed framework. As shown in Table 8 and Figure 6, the fatality rate was calculated using the $FTEW_{m \cdot y}$ (Table 7) and the average number of fatal accidents (Table 3) in terms of the 26 work types for the residential building project. The calculated fatality rate was compared to national data showing the average fatality rate for 13 years [12]. National data are only provided for fatality rates in the construction industry.

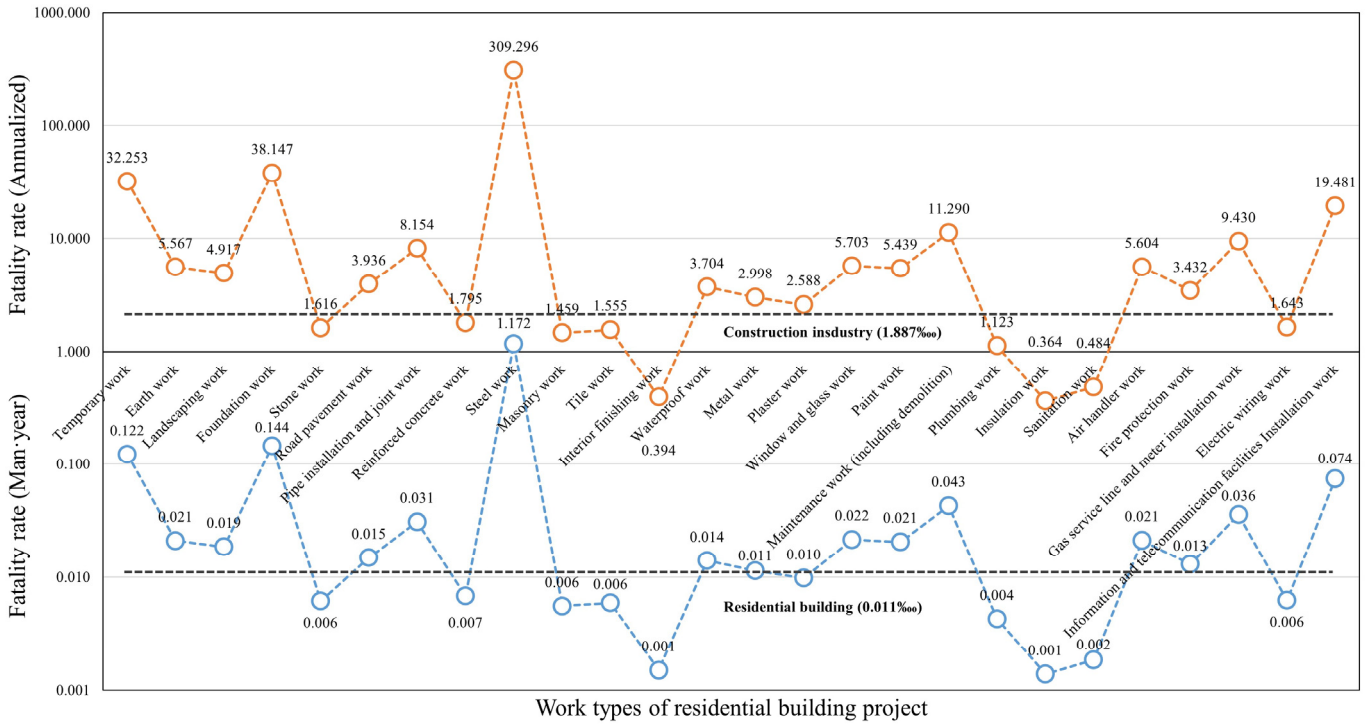


Figure 6. Comparison of fatality rate according to national data and the proposed framework based on the DWRs.

Table 8. Fatality rate according to national data and the proposed framework based on the DWRs (average from 2013 to 2019).

Calculation Method	Criteria of Classification		Fatality Rate (‰) (Man-Year)	Fatality Rate (‰) (Annualized)
Existing National data [1] (AFTEW)	Construction industry		-	1.887
Proposed framework based on DWR [2] ($FTEW_{m \cdot y}$)	Building type	Residential building	0.011	2.942
	Work type	Temporary work	0.122	32.253
		Earth work	0.021	5.567
		Landscaping work	0.019	4.917
		Foundation work	0.144	38.147
		Stone work	0.006	1.616
		Road pavement work	0.015	3.936
		Pipe installation and joint work	0.031	8.154
		Reinforced concrete work	0.007	1.795
		Steel work	1.172	309.296
		Masonry work	0.006	1.459
		Tile work	0.006	1.555
		Interior finishing work	0.001	0.394
		Waterproof work	0.014	3.704
		Metal work	0.011	2.998
		Plaster work	0.010	2.588
		Window and glass work	0.022	5.703
		Paint work	0.021	5.439
		Maintenance work (including demolition)	0.043	11.290
		Plumbing work	0.004	1.123
		Insulation work	0.001	0.364
		Sanitation work	0.002	0.484
		Air handler work	0.021	5.604
		Fire protection work	0.013	3.432
		Gas service line and meter installation work	0.036	9.430
		Electric wiring work	0.006	1.643
		Information and telecommunication facilities Installation work	0.074	19.481

[1] The fatality rate using the national data is calculated by dividing the number of fatal accidents by AFTEW and multiplying it by 10,000 (Unit: ‰). [2] The fatality rate using the framework based on the DWRs is calculated by dividing the number of fatal accidents by the $FTEW_{m \cdot y}$ and multiplying it by 10,000 (Unit: ‰).

In the national data, the average fatality rate for 13 years was 1.887‰ in the construction industry. Because the fatality rates in the national data are only provided for the construction industry, risk management cannot be performed in terms of building or work types. Moreover, the fatality rate was calculated using the AFTEW (Equation (1)) instead of the $FTEW_{m \cdot y}$. Because the AFTEW is determined according to the ratio of labor cost to revenue, it was difficult to calculate the fatality rate precisely.

For the proposed framework based on the DWRs, the average fatality rate for 13 years was 0.011‰ in the residential building project. The fatality rate ranged from 0.001‰ to 1.172‰ when considering the aforementioned 26 work types in detail. Because the fatality rate was accurately calculated by the $FTEW_{m \cdot y}$, as estimated through the DWR, risk management could be performed by considering the fatality rate of the 26 work types for residential building projects in detail.

Because the fatality rates based on national data and the proposed framework have different units, they cannot be compared. From Table 8, the fatality rate based on national data was calculated by dividing the number of fatal accidents by the AFTEW and then multiplying it by 10,000. The AFTEW is presumed to be the sum of the number of construction workers who worked full time for a year. The number of working days for a construction worker is 264 per year [44]. In contrast, the fatality rate based on the proposed framework was calculated by dividing the number of fatal accidents by the $FTEW_{m \cdot y}$ and multiplying it by 10,000 (Equation (11)). The $FTEW_{m \cdot y}$ is calculated as the sum of the construction workers who have worked a day, and the sum of the construction workers who have worked for a day is converted to an annualized value. Therefore, it is difficult to compare the fatality rate between the national data and the proposed framework. To compare the fatality rates within the same unit, the fatality rate based on the proposed framework should be multiplied by 264 days to annualize the $FTEW_{m \cdot y}$ [44]. In Table 8, the annualized fatality rate was calculated according to Equation (12).

$$\begin{aligned} &\text{Annualized fatality rate}(‰) \\ &= \frac{\text{The number of fatal accidents}}{FTEW_{m \cdot y}} \times 10,000 \times 264 \end{aligned} \quad (12)$$

The fatality rate based on the national data was 1.887‰ in the construction industry, whereas the average fatality rate in relation to the annualized value was 2.942‰ in the residential building project. The level of risk for residential building projects seems to be high among the building types in the construction industry. Hatipkarasulu [18] explained that the number of fatal and injury accidents in residential building projects is higher than in other building types.

However, the application of the same working days to different buildings and work types is limited. Therefore, further research is necessary to estimate the working days according to the building and work types.

Given the results of this study, risk management can be conducted considering the fatality rate for residential building projects and for other building and work types using the developed framework based on the DWRs.

3.5. Discussion

The fatality rate in the construction industry is evaluated based on the number of construction workers and fatal accidents worldwide. However, because the AFTEW, which is put to the construction project, is estimated through sampling inspection or the ratio of labor cost to revenue, there is a difference in the actual number of workers. The AFTEW in the entire construction industry is estimated, although it does not consider the building and work types [3]. When evaluating the fatality rate considering the AFTEW, the fatality rate cannot be evaluated by considering the building and work types. Moreover, it is inaccurate for the entire construction industry.

This study aims to develop a calculation method for the $FTEW_{m \cdot y}$ to evaluate the fatality rate accurately in terms of both building and work types. The proposed framework based on DWRs is developed by using the actual number of construction workers for the residential building project; hence, it can analyze precision with an assessment of the risk level rather than the AFTEW. To demonstrate the excellence of the fatality rate based on national data, the fatality rate based on the proposed framework can be annualized by multiplying it with 264 days. From Table 8, the results of the fatality rate between national data and the proposed framework were compared. In terms of national data, the national

data only provide the fatality rate in the construction industry as a whole. Therefore, the fatality rate based on national data cannot be presented according to the building and work types. The result of the fatality rate based on national data was 1.887‰. However, because the working days of construction workers are assumed to be 264 per year in the national data, the fatality rate cannot be evaluated when construction workers are put into the construction site for a day. The proposed framework can be utilized by evaluating the fatality rate based on man-days considering the building and work types. First, the fatality rate considering the building type was assessed as 0.011‰ when construction workers were put into the construction site for a day in the residential building project. When converting the units, the fatality rate was assessed as 2.942‰ when the value was multiplied by 264 days. When construction workers are put into the construction site for a day and a year, respectively, the fatality rate can be evaluated by considering the work types in the residential building project (Table 8). For instance, when considering construction workers' work per day, the fatality rate of temporary work was evaluated as 0.122‰. By multiplying this with 264 days, the fatality rate was evaluated as 32.253‰ when considering workers' work per year. Using this result, for the fatality rate of steel work, foundation work, and temporary work for the residential building project are higher than other work types, the risk level can be managed intensively. The proposed framework based on the DWRs can contribute to proactive safety management by presenting the risk level in terms of each building type and work type.

In this study, we developed a method to calculate the $FTEW_{m \cdot y}$ and presented the results by applying it to residential buildings in the Republic of Korea. Through this, we can see that the method developed in our study can contribute economically and socially. First, from an economic perspective, the proposed framework for calculating the $FTEW_{m \cdot y}$ enables the accurate evaluation of fatality rates in construction projects. By providing a precise estimation of labor inputs, companies can optimize resource allocation and improve safety management, which in turn reduces the costs associated with accidents and inefficiencies. This contributes to more sustainable economic practices in the construction industry by enhancing operational efficiency and reducing financial losses due to workplace accidents. Second, from a social perspective, our method emphasizes improving worker safety, a critical social sustainability factor. By refining the estimation of fatality rates and enabling better risk management based on building and work types, we aim to protect workers' health and well-being, contributing to safer and more socially sustainable workplaces.

The $FTEW_{m \cdot y}$ framework not only contributes to economic and social sustainability, but also significantly enhances the precision of safety assessments in construction projects. By offering a detailed estimation of labor exposure and the associated risks, this method enables the more effective identification of high-risk activities and work types. Consequently, project managers can implement targeted safety measures, proactively preventing accidents and reducing fatality rates. Moreover, this framework supports the continuous monitoring and adjustment of safety protocols throughout the project lifecycle, ensuring a dynamic, preventive approach to risk management and ultimately contributing to improved safety standards and safer working environments across the construction industry.

As shown in Figure 7, an example is given to better understand how to use the findings from this study. The number of reinforced concrete workers during the construction period at site 4 (Table 1) is presented. The number of reinforced concrete workers is put into the construction site differently from form installation work and form removal work. The construction period also differed according to each work type. In terms of the AFTEW, if was determined that 70 reinforced concrete workers worked in the reinforced concrete works during the entire construction period. However, 37,227 reinforced concrete workers worked in reinforced concrete construction during the entire construction period. The fatality rate based on national data cannot be evaluated accurately. Therefore, because it can reflect the actual number of construction workers during the construction period, it is necessary to evaluate the fatality rate based on man-days, which can express the actual number of construction workers. As shown in Figure 7, $FTEW_{m \cdot y}$ is the sum of the total

number of construction workers during the construction period. Additionally, the sum of the total area under the blue line was 37,227 $FTEW_{m \cdot y}$. Compared to the AFTEW and $FTEW_{m \cdot y}$, 70 construction workers have generally been used to calculate the fatality rate. However, based on the results of this study, 37,227 construction workers were considered to calculate the fatality rate accurately. Thus, the safety manager can plan risk management to reduce the fatality rate in the construction industry. Using the value of $FTEW_{m \cdot y}$, the fatality rate can be evaluated precisely by considering the actual number of workers and the construction period.

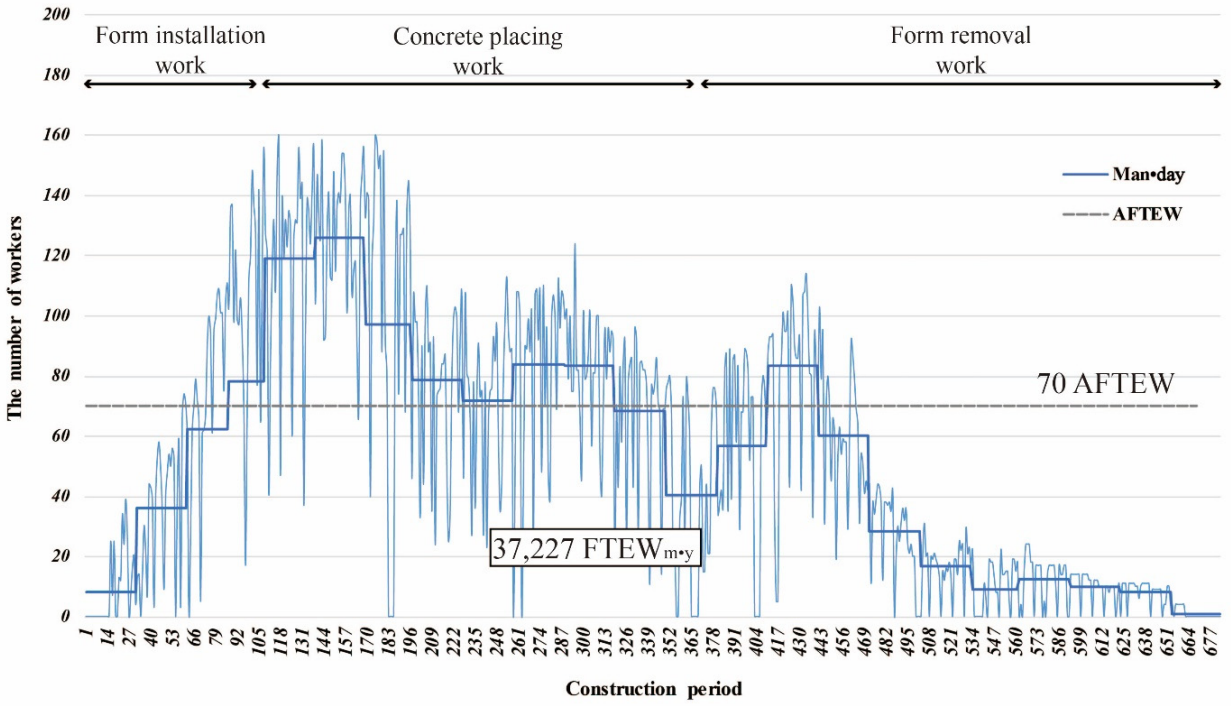


Figure 7. Comparison between $FTEW_{m \cdot y}$ and AFTEW for the reinforced concrete works.

This study developed a method to calculate the $FTEW_{m \cdot y}$ using DWRs and verified its applicability by applying it to residential building projects in the Republic of Korea. To further guide construction professionals, we have added a practical step-by-step process on how to integrate the $FTEW_{m \cdot y}$ framework into existing safety management practices. Additionally, the framework is adaptable to different regulatory frameworks and building environments worldwide, providing a practical and scalable solution for improving safety management and sustainability in the construction industry. We also now discuss the cost and time implications of implementing this method, highlighting how improved accuracy in labor input estimations can optimize resource allocation, reduce accident-related costs, and ultimately benefit project timelines and budgets. By delivering more precise data on worker safety and labor inputs, this framework can contribute significantly to international efforts to enhance construction safety standards and operational sustainability.

4. Conclusions

The risk level in the construction industry is extremely high compared to that in other industries. For a long time, the fatality rate has been used to evaluate risk levels worldwide, and the number of workers is an important factor in calculating the fatality rate. Safety management considering the building and work types is required to reduce the fatality rate. However, the number of construction workers is investigated by surveys, such as sampling inspection or the ratio of labor cost to revenue, in many countries. Moreover, only the number of construction workers in the construction industry is provided, without considering the building or work type. Thus, this study proposed a framework based on

DWRs to estimate the number of construction workers per man-year, which can calculate the fatality rate accurately.

This study was conducted in six steps: (1) the selection of the target project; (2) the establishment of the database; (3) the development of the proposed $FTEW_{m \cdot y}$ framework based on DWRs; (4) the validation of the framework based on DWRs; (5) the calculation of the $FTEW_{m \cdot y}$ for residential building projects in the Republic of Korea; and (6) the utilization of the proposed framework based on the DWR.

The framework was developed by utilizing 11 DWRs for residential building projects by considering the building and work types. Subsequently, k-fold CV was conducted to prove the validity of the framework based on the DWRs. The $FTEW_{m \cdot y}$ for the residential building project was estimated while considering 26 work types. Furthermore, the fatality rate for the residential building project was presented using the $FTEW_{m \cdot y}$.

The results of this study are as follows. First, the $FTEW_{m \cdot y}$/USD for the residential building project was 1.1×10^{-3} $FTEW_{m \cdot y}$ according to the 11 DWRs. Second, the results of CV indicated that the average accuracy was 85.30% and the R^2 value was 92.92%. The proposed framework based on the DWR was verified to have high accuracy and no problem with overfitting. Third, the $FTEW_{m \cdot y}$ for the residential building project was estimated using the framework based on DWRs in the Republic of Korea. From the calculation, it was identified that the $FTEW_{m \cdot y}$ for a residential building project was 4.5×10^7 $FTEW_{m \cdot y}$ in the Republic of Korea. In terms of the work type for residential building projects, the $FTEW_{m \cdot y}$ for 'reinforced concrete work' was 1.8×10^7 $FTEW_{m \cdot y}$, indicating the highest number of construction workers among the 26 work types. In contrast, the $FTEW_{m \cdot y}$ for 'steel work' was 1.0×10^4 $FTEW_{m \cdot y}$, which is related to the lowest number of construction workers for this work type. Fourth, the fatality rate for the work type during the residential building project was calculated using $FTEW_{m \cdot y}$ and the number of fatal accidents. From the calculations, the fatality rate for residential building projects was found to be $0.011‰$ over a period of 13 years.

The contributions of this study are as follows. First, a useful framework is presented for an accurate estimation of the number of construction workers per man-year compared to the sampling inspection or labor cost relative to revenue. Second, the $FTEW_{m \cdot y}$ and fatality rate can be estimated and calculated precisely using the proposed framework based on DWRs considering the building and work types. Using the framework, it is possible to determine a priority ranking for risk management according to the building and work types. Finally, using the framework developed in this study, the fatality rate can be calculated accurately. In addition, unlike the fatality rate, which was presented only for the entire construction industry, the fatality rate can be calculated by considering both the work and building types; thus, more detailed safety management can be performed.

The limitations of this study include the fact that the framework has only been applied to residential construction projects. While there are various types of construction projects, such as roads and plant projects, the current framework does not fully account for non-traditional work schedules, such as night shifts or part-time workers, which could influence fatality rate estimations. Future research should explore how these work patterns can be integrated into the $FTEW_{m \cdot y}$ framework to provide a more comprehensive analysis of labor inputs and associated risks across diverse construction environments.

Future research is as follows. First, we will aim to estimate the $FTEW_{m \cdot y}$ for different construction and work types and calculate fatality rates based on them. We also believe it is essential for future research to extend the application of this framework to other sectors, such as infrastructure and industrial projects. These sectors often have distinct risk profiles and labor inputs, and applying the $FTEW_{m \cdot y}$ framework in these settings can validate its adaptability and contribute to improving safety standards in a wider range of construction projects. Second, since there was some bias in CV due to variations in the project size, duration and geographical location, we can improve the accuracy of the developed framework by utilizing more DWRs. Third, we plan to compare and analyze the fatality rates calculated using the framework developed in this study with those of the

AFTEW across various countries. Through this, we aim to demonstrate the limitations of the existing AFTEW method.

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Conflicts of Interest: Author Jayho Soh was employed by the company Hyundai Engineering and Construction. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Abbreviations

AFTEW	'Annual Full-time Equivalent Workers' is defined as the number of workers, which is the estimated value using the ratio of labor cost and construction revenue
CV	K-fold Cross Validation.
DWR	Daily Work Report.
$FTEW_{m \cdot d}$	'Full-time Equivalent Workers per man·day' is defined as the number of construction workers daily, which is recorded through the DWR.
$FTEW_{m \cdot y}$	'Full-time Equivalent Workers per man·year' is defined as the number of construction workers yearly, which is recorded through the DWR.
KOSIS	Korean Statistical Information Service.
MOEL	Ministry of Employment and Labor.

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