Activity-based Fatal Four Rate Assessment for Effective Safety Planning Utilizing 4D-BIM

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Index Terms: Fatal Four assessment (FFA), accident cases, 4D-BIM, temporary safety facility (TSF), safety management, safety prevention, real-time safety planning (RTSP).

Abstract: The unprecedented growth and integration of the innovative technologies in information and communication tech-nology (ICT) promotes rapid evolution of conventional construc-tion to smart construction. Advanced technology application brings impressive benefits such as time and cost reduction, especially safety management improvements in the construction where accidents and fatalities always happen due to the unsafe and risky working environment. In the sense that the fatality rate is one of the main quantitative measurements that reflects safety performance, numerous public agencies giving accident reports and safety standards to recommend for the construction stakeholders. However, incidents in workplace remain unin-terrupted because of the deficiency of safety information and understanding the root causes of accidents in specific conditions. Moreover, many construction companies do not have managers who have particularly technical and professional expertise related to safety area. It leads to pressures in controlling the whole process of construction within safety implementation, and so on, the workers face difficulties in approaching and understanding the complicated safety document. As a result, the manager's burden increase and sometimes vital information get ignored. To address this issue, this paper proposed a Real-Time Safety Planning (RTSP) System supported by 4-Dimensional Building Information Modeling (4D-BIM), which consist of risk severity assessment based on the temporal and spatial conditions before giving priorities of major hazard protection. To accomplish this, the study evaluated and distributed the severity of 320 fatalities cases in relation to Fatal Four (four major fatality causes in construction industry) reported from various public resources, which specifically illustrative of accident concentrate rate in an individual work task. A simulation of RTSP system for the Exterior building wall with major hazard consideration and designated Temporary Safety Facilities (TSF) utilizing 4D-BIM is presented as a proof of concept. It is expected that the novel approach could decrease the safety manager workload and will make the construction safety planning process more comprehensible.

1 INTRODUCTION

The dynamic unique and complex construction site en-vironment are the causes of the high fatal accident rate and safety risks for the jobsite worker. According to OSHA reports, worker fatalities in the construction industry in 2017, accounted for 20.7% with 971 cases, the higher rate than any sector. It is quite clear form the literature that four types of hazards are responsible for the majority of injury and death in the construction sites, what we called Fatal Four and that includes falls, struck-by-object, electrocutions, and caught-in-between (OSHA, 2014). By the US Bureau of Labor Statistics reports, these Fatal Four were responsible for more merely 60% among the construction worker deaths in 2017, and become the leading causes of accidents in construction. The fact that the construction working environment required labors haS to be well-equipped knowledge, professional experience, and skills, particularly in the safety aspect, immediately from pre-construction phase (Behm, 2005). Therefore, identify and eliminate root causes accidents for appropriate prevention decisions from early-stage play an essential role in the success of making project planning.

On the other hand, the high proportion of accidents have witnessed the ineffectiveness of safety planning provision. It should be emphasized that the actual health and safety implementation

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performance in the industry still inadequate and need strengthening. Explaining about causes, while some construction enterprises claimed that the biggest restricting factor for safety compliance was felt to be time constraints, others believed that cost was a problem prevent them (Chi, Chang, and Ting, 2005). Actually, when injuries and fatal accident occur, significant cost and time resources were lost because of rework and training for replacement personnel (Arboleda and Abraham, 2004). Moreover, accidents affect the quality of the project, increases direct and indi-rect costs for additional payments (Chi, Chang, and Ting, 2005). By enhancing safety planning and eliminating hazards factors, would not only save hundreds of worker's life but also reflect the sustainable development of construction companies, increasing working efficiency, competitiveness, and profitability project.

The research focuses on a visualization approach to improve safety planning and contribute towards a better understanding of the conditions and causes of accidents. Accordingly, the main goal was providing the severity of fatality in each work-ing activity and suggest preclusion measures respectively. The proposed system, hopefully, will effective assist construction managers, reduce the number of accidents, thus creating a safer environment for the labors working on construction projects.

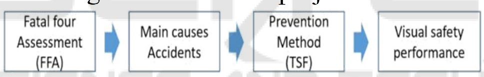

Figure 1: Effective safety planning development based on FFA.

2 MANUSCRIPT PREPARATION

2.1 Current Status of Safety Planning

Effective safety planning played a vital part in construction project success. Sufficient safety planning not only able to predict time and circumstance accidents occur on project but also develop adequate hazard mitigation plans (Choe and Leite, 2017). The best way to keep a safe construction workplace is by preventing hazards from the pre-arising period. Failing to identify risks from safety planning may increase significantly accidents and defections in Job-site (Chi,Chang, and Ting, 2005). However, conventional safety plan-ning accomplishing in the construction sector remains several drawbacks. Safety planning is still a shortage of specific information and separate among other planning functions, such as time, cost, and quality (Choe and Leite, 2017). Accordingly, construction safety analysis relies on manual efforts or individual experi-ence of safety managers to recognize potential hazards (Kim, Cho, and Zhang, 2016). Additionally, limited attention has been given to safety from the planning and design phase since the long-term impact was not considered or understand. Limited attention has been given to safety field from the planning and design phase since the long-term impact was not considered or understand (Zou, Kiviniemi, and Jones, 2017), (Wong, Wang, Law, and Lo, 2016). Furthermore, due to the overwhelming number of safety rules and the complexities inherent with them, detecting the appropriate safety contents and communicating them to the right person or the right working condition becomes a challenge. These problems require well-defined and structured safety information that can be identified and applied auto-matically by building models software with the least human interaction. Safety planning is obliged to instantly accessible, effortlessly; standardized and visualized input information; close communication with the routine works and workers (Choe and Leite, 2017).

2.2 Using BIM for Safety Planning

Even BIM is broadly used for design and monitoring, BIM is not yet widely applied for safety planning [9]. Zhang and Kim (Zhang et al, 2013), (Kim, Cho, and Kim, 2018) declared that most accidents could be decreased and prevented with the proper safety planning process that well planned by the integration of BIM. The innovation of BIM application has paved the way for safety performance by providing a rich profusion of information, reducing paper-based 2D drawing, improving realistic visualization of safety prevention (Zhang et al,2013), (Khan et al, 2019). In addition, 4D-BIM is known as a collaboration intelligent linking between 3D digital model, schedule-related information and safety contents (Kim, Cho, and Kim, 2018). The BIM environment accommodates visual information, a highly collaborative, and plentiful parameter that is an appropriate condition for simulation safety features. Prior involvement of safety leaders using BIM from the planning process made benefits to detect unsafe designs and risk factors (Kim, Cho, and Kim, 2018), (Hongling, Yantao, Weisheng, and Yan, 2016), provided necessary safety measures (Zhang et al, 2015).

2.3 Need for an Effective Activity-based Safety Planning

The investigated studies indicated that hazards identification and mitigation are necessary to enrich construction safety from planning to execution. Moreover, the application of BIM can overcome impediments in the traditional safety planning process. However, the literature revealed that the current integration of BIM merely provided subjective safety preven-tion without any authentic evidence. Hence, the provision of safety information in these cases seems more like passively memorized without foundation in reality. The objective of this study is to emphasize the main causes of accidents in each work task in order to enhance understanding of nature behind the reasons why safety protection needs to use in specific situations. This paper proposes an innovative approach which accommodated safety information including Fatal Four assessment (FFA) and TSF in specific conditions with spatial and temporal simulating in BIM environment. The process of developing RTSP based on FFA is illustrated in Fig. 1. The accident root causes are analyzed and evaluated by FFA process. Then, the virtual reality simulation for the prioritizing welfare facilities at work was designated and incorporated re-spectively. The visual-spatial environment including modeling components fastened on specific activities duration and real-time TSF collectively navigated. By developing Naviswork plugin that will allow intuitively distributing FFA and TSF, which will enhance safety planning by forecasting critical TSF that remind managers and simplify the access of other project participants.

3 DATA ANALYSIS AND ASSESSMENT

3.1 Current Status of Safety Planning

There are many methods available for collection and analy-sis of accidents and the purpose of such methods are clarifies the leading causes of the incident, the defection in working process from subjective aspects existences (such as organi-zational level, control measures, installation and maintenance, training, management factors) to objective existences problems like environmental issues (Hale et al, 2012). Relevant researches highlighted correlations among various accident characteristics with causes and construction stages (Betsis et al, 2019). Currently, the study found that fall-related hazards are major concerns (Chi, Chang, and Ting, 2005), (Wong et al, 2019), (Zhang et al, 2015), and most construction accidents and fatalities in small or medium firms (Betsis, Kalogirou, Aretoulis, and Pertzinidou, 2019). Therefore, the analysts collected and extracted critical information from available sources and classify it into the method formation. When analyzing fatal data, the literature methods cover different factors for specifying re-search contents. For illustration, the interviews for a human factors specialist were conducted by Hale (Hale et al, 2012) to classify and.

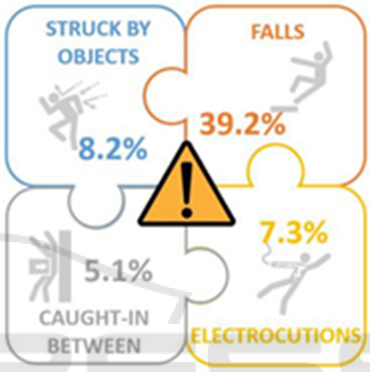

Figure 2: The proportion of fatal four in construction reported by OSHA.

Table 1: Partical references example of case databased.

No	No. Report	Accit case	Fatal Four type	Work activity	Main causes
1	13NY080	Two construction workers fatally crushed when ce-ment formwork collapsed.	Caught-in-Between	Concrete Work	1.Inadequate design of formwork 2.nonconformance of braced and tied 3.No proper training 4.No standard operating procedure
2	12NY018	Mechanicel ectrocuted when a mobile light tower contacted powerline.	Electrocutions	Electrical work	1.Lack of power lines hazards control 2.No training and education 3.No clear

					manual guide for the equipment operation
3	15MA037	Commercial roofer falls 30feet through a skylight while installing roof insulation	Falls	Roof Coatings	1. Ignoring job hazard analysis 2.No training for fall protection 3.No using fall protection
4	15MA037	Carpenterfatally injured after Falling from an extension ladder Massachusetts.	Falls	Roof Coatings	1. Ignoring job hazard analysis 2.No training for fall protection 3.No using fall protection
5	14NJ074	Day laborer, first day on the job, struck and killed by backhoe bucket.	Struck by an Ob-ject	Foundation	1. Lack of communication between the worker and operator 2.No personal protective equipment

underlying the levels of risk factors and their inter-relation associated with inadequacies in planning and risk assessment. Other research for the real causes behind Fatal Fall-from-Height in Hong Kong, (Wong et al, 2016) weigh all the inquest from the government agencies and witnesses involved in the accidents. Regarding the roots causes of fatalities in trenching operations, Arboleda (Arboleda and Abraham, 2004) established the major relationships between the condition and reason of the trenching fatalities.

By conducting the investigations of several public re-ports such as Occupational Safety and Health Administration (OSHA), Bureau of Labor and Statistics (BLS), the National Institute for Occupational Safety and Health (NIOSH), this study focuses on Fatal Four related fatalities which makes up a major proportion of worker death caused. In other words, FFA data provides a foundation for the development of effective intervention measures and subsequently minimizing the main causes of hazardous conditions in Jobsite. Fig. 2 shows the individual Fatal Four percentages. It is observed that the main cause belongs to Falls which occupies 39.2% of the total fatal causes while all others made up less than 10%. Internally, the OSHA and BLS data is gathered from the reports of employers or the news media while the figure of NIOSH depended on death certificate data. The investigated data consists of more than 300 fatalities reported cases of Fatal Four that were collected from OSHA website. In the reviewed OSHA fatalities reports for the last 3 years since 2017, the inspection report includes Case Status, Basic Information of victim, employer, working condition, Violation Summary, Violation Items, Investigation Summary.

3.2 FFA for Safety Planning

Safety planning is an essential part of the planning process, this stage aims at providing sufficient safety information and facilities for welfare of workers and working operations (Azhar, 2017). However, safety information is abstract and dynamic, it leads to a complicated accomplishing process consisted of various legal documents, regulations and accident records (Guo, Yu, and Skitmore, 2017). There is an abundance of hazards close implicated in each working activity. Meanwhile, conventional safety planning lack of in-tuitive method automatic exporting safety contents in chrono.

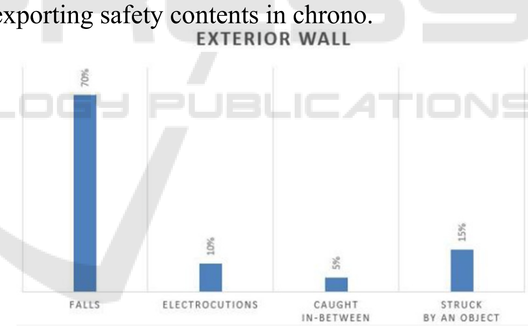

Figure 3: The severity of fatal four in boundary wall work.

logical order and hazardous priority. To solve these problems, FFA data was provided as a comprehensive explanation for prevention methods that required install in safety planning. The study focus on the evaluate the most frequent occurrences regarding construction Fatal Four and at the same time identify correlations among the various parameters associated with working activities.

Besides, Fatal Four occurred frequently in construction projects during many activities. To developing significance safety planning, the study considers broad reports of accidents in construction industry to indicate essential risks in each working stage. The evaluated information was taken verbatim from the initial report database held by OSHA covering the name of reports, the type of accident, time and location, age and employment status of the victim, the geographical region, size of Jobsite, nature of the project, the reason of incident and recommendation. The critical information was selected to input as initial data and display in excel format. Table. I presented a part of classification data for construction fatal cases that happened. More than 500 fatalities were analyzed and 320 Fatal Four related cases were evaluated and classified into four categories (Falls, Electrocutions, Struck by Objects, Caught-in-Between) with activity types (Excavation, Foun-dation, Concrete forming, Reinforcing, Masonry, etc.). After identifying the main causes of fatal in specific work conditions.

Figure 4: The 4D-BIM-based RTSP framework.

best-practice prevention was recommended. The results of FFA could impact the entire safety management process by what prime accident arrive and how they were eliminated during working stage. Each working activity was expressed FFA result in percentage (refer to Fig. 3). It can be seen that FFA information is useful to emphasize the hazardous factor and remind reasonable safety protection needs to be designated. In order to develop effective safety planning, FFA data, project schedule, and safety contents are required to identify and incorporate closely in a visual presentation.

4 RTSP SYSTEM FRAMEWORK

In order to reduce manager workload and enhance safety planning procedure, RTSP can be a useful alternative for traditional method of integrating reasonable safety protection with FFA-based. The term real-time is in the sense that the prevention methods were presented immediately to the dynamic changing of project in model environment. It means that when the schedule was integrated into 3D model, the real-time 4D simulations for working sequences were established with construction progress activity visualization. The develop-ment of RTSP based on 4D-BIM is automatically extracting reasonable safety contents in a visual-spatial environment, that encompassed the severity of accident and prioritizing safety prevention.

This can be achieved via five steps:

1) 4D-BIM preparation by integrating project schedule and digital 3D model.
2) Analysis FFA data.
3) TSF development based on FFA data.
4) RTSP collaborative simulation.
5) Data upload to BIM-cloud and User acquired RTSP data

The RTSP framework consists of four modules including Fatalities reports investigation, FFA, 4D-BIM simulation, Par-ticipants interaction are graphically presented in Fig. 4. In order to guarantee safely workplace, the participant including managers and workers has a responsibility to understand and complete many safety requirements. In particular, RTSP is purposely designed to help users understand the insight causes of accident and dangerous occurrence protection methods in Jobsite. Based on visualization material with prioritized prevention simulations, its easy approach, and flexible inter-actions. RTSP system potential to provides a better solution for preparing an effective and efficient safety planning to con-struction participants and creating critical safety data for local databased (project databased, contractor databased, company accident databased, agency databased, etc.).

5 4D-BIM-BASED RTSP DESIGN

4D-BIM-based RTSP aims to provide visualizations of construction sites through an innovative digital approach. To accomplish this, a combination of FFA data, project schedule, Temporary safety facility (TSF) and 3D building model plays a vital role in the success of the entire system. Fig. 5 illustrates the 4D-BIM-based RTSP architecture in detail.

5.1 4D-BIM Preparation

Spatial environment in BIM becomes an effective commu-nication and management method where critical information (dimension, quantity, quality, schedule, safety) and temporary facilities could be linked that enable visualized, distributed and addressed safety contents (Hossain et al, 2018). By embedding schedule information in a digital model, a 4D-BIM simulation was developed. In this section, a three months schedule for the residential project was created in MS project and a 3D digital model was developed simultaneously in Revit environment. After that, Navisworks was chosen to implement

4D-BIM collaboration. The 4D-BIM solution contains parametric at-tributes that offer several interesting opportunities to indicate safety contents in the safety planning process. Especially, in order to mitigating risk in construction site, the Family Editor tools in Revit enables to create prevention facilities data.

5.2 TSF Development

Temporary safety facility (TSF) system is the provision of temporary welfare facilities for employees in each work task in Jobsite. After identifying important risk factors along with each activity based on FFA (mentioned in the previous section), TSF positively influences construction safety by focusing on best practices prevention. With an abundance of safety contents in construction, workers or even designers or contractors possibly are unaware or ignore some requirements in non-typical conditions or in a short period, and so accident appears in the scenario. For instance, normally, in the pri-vate residential construction, Exterior wall work task at each building level often complete for 1 or 2 days. FFA result showed that the highest fatality proportion in the Exterior wall.

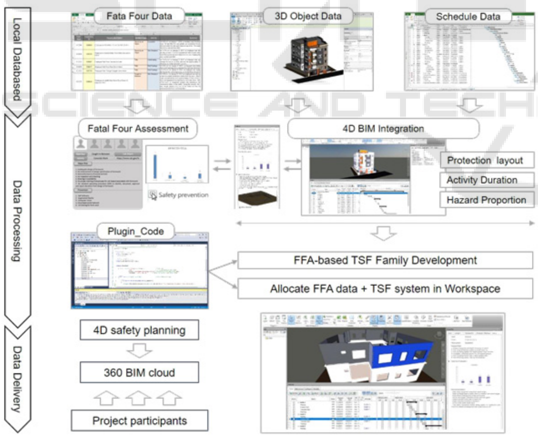

Figure 5: 4D-BIM-based RTSP system architecture.

work is Falls, as illustrated in Fig. 6. Consider risk factors of Exterior wall work such as floor level height, bounding space is sheltering or empty, materials or equipment delivering, framing and erecting walls, etc. The TSF priority needed to implement in this work should be the guardrail system. The place needs to install is the un-build exterior wall spaces or opening on the built wall.

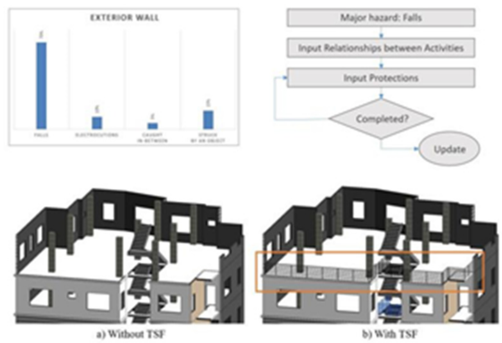

Figure 6: TSF for exterior wall work.

5.3 RTSP System Simulation

The main objective of this research is to develop com-prehensive FFA data and recommend TSF (or best practices prevention) which enhance the RTSP system in order to eliminate hazards and show activity-based TSF automatically. The RTSP development is detailed described as follows:

1) Non-model accident severity data were collected and analyzed then converted to the bar chart diagram to make it visualized graphically. When appended safety contents in the Naviswork environment, the FFA categories need clearly linked to explicit models of how and when po-tential hazards can occur. This process has been done in Construction safety information Tab with the help of Data Tools from Navisworks.
2) Using the API .NET programming interface offered by Navisworks. The custom plug-ins drive the safety pre-vention products in construction safety tab and create the connection access to model and schedule task. A navigate plugin is developed based on Application Programming Interface (API) provided by Naviswork Platforms. This plugin will be integrated into Navisworks environment and show the safety information as well as prevention products according to 3D digital model and work tasks.
3) Whenever a new TSF is created, RTSP system imple-ments the time for installation and removal of all TSF into the schedule. After that, it can be added to the TSF
Fmily. All the safety issues related to FFA data always updated to suggest and install TSF appropriately.
4) Finally, the 4D-BIM-based TSF can be coordinated and made available to users (workers, managers, owners, and

stakeholders) for simple approach, understandable safety planning, and other advanced communication purposes.

6 DISCUSSION AND CONCLUSION

This paper proposes an innovative approach based on the severity of fatalities, construction activities for constructing a 4D-BIM-based RTSP to provide adequate TSF recommenda-tion in specific spatial and temporal simulation. The studied approach has the potential to identify the most dangerous risk factors among fatality causes, corresponding prioritize providing safety prevention automatically. The system en-ables to update the best practice safety measures in order of importance, improve safety management process, and finally reducing errors in searching and using safety data. To fulfill the objective, the various accident reports associated with Fatal Four were analyzed and carefully evaluated. Based on this investigation, scenario of the unsafe conditions were identified for the purpose of providing TSF simulation. By taking advantage of 4D-BIM, a plugin was built to allow upload and navigate FFA data and TSF system in an intuitive way.

Proposed system able to enhance safety management, re-duce manager responsibility, and simplify worker's approach. It resulting in impressive efficiencies in reducing risks and accidents happening in construction. In the research, there are multiple steps which were executed for developing RTSP system. This works also reveals some limitations that it is nec-essary for developing an ideal and accurate 4D-BIM platform to accomplish specific safety tasks and conditions update. The aim of the assessment method is Fatal four, the remaining factors that take part 40 percent of construction fatality cause would explore in further investigation. Agruablelly, the accu-rate of RTSP concept depends on the number of fatality cases evaluated in producing severity accident rate. Further research would be necessary to collect more fatalities data and scope down on fatalities rate in the small and medium enterprises (SMEs). Besides, the FFA-based computer vision application to remotely monitor calculate the severity of accident occur-rences of workers will be experimental perform. Additionally, it would also be worthwhile to consider the effect of utilizing Artificial intelligence (AI) to automatically complete FFA pro-cess and recommend accurately risk prevention. On the other hand, we also going to integrate the system with Augmented reality (AR) technologies to brings real experiences method to users. The experiment implementation will be evaluated in the real construction site in Viet Nam and South Korea to compare the practical application of this system in developing and developed country.

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