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HARNESSING BIM-BASED TECHNOLOGY WITH RISK ASSESSMENT TO IDENTIFY HAZARDS AND GENERATE AUTOMATED SAFETY SCHEDULE

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Abstract: In India, 24.20% of the accidents are construction related, causing nearly 38 deaths every day. Since every construction activity has some level of associated hazards, it often leads to either loss of lives, compensation loss, work delays, or various levels of ergonomic and Musculo-Skeletal Disorders (MSDs). Poor safety management at sites often leads to accidents and reduced worker's morale and productivity which ultimately increases indirect cost (4 times the direct cost). Safety planning also becomes necessary in Indian construction sector as it employs 51 million people but has only 4% formally skilled labours. Hence, safety planning is one of the aspects that should be paid much attention to in project management. The current study harnesses risk assessment using Failure Mode and Effect Analysis (FMEA) method to identify and rank major hazards and associated risks. A safety database was prepared from applicable safety codes. Risk assessment data and safety database were integrated using Visual Scripting in Dynamo v.2.10 and exported to BIM environment of Autodesk Revit to generate a 'Safety Schedule' along with safety measures, which is a state-of-the-art approach in the domain of safety planning. A case study demonstrates the applicability and effectiveness of the proposed method. The proposed approach can be used by designers, site project managers, safety engineers, and other participants as a tool to foresee and predict hazards. As a result, accidents can be avoided by making timely decisions and proactive actions.

Keywords: Construction safety, Risk assessment, Failure Mode and Effect Analysis (FMEA), Automation, Building Information Modelling (BIM)

1 INTRODUCTION

Safety in construction sector has always been a major concern, be it developed nations such as USA, UK, Germany or developing nations such as India. According to a report from International Labour Organization (ILO), accident rates in construction is almost three-four times more in developed or industrialized nations while it is up to six times in developing nations (International Labour Organization 2015). Indian construction sector employs 51 million and stands second in line to provide employment in India after agricultural sector (Invest India 2022). In contrast to its enormous size, it is far behind in keeping pace with the modern training methods, safety standards, technological advancements and innovations (Marefat et al. 2019). It is estimated that out of 48,000 occupational accidents per year at least 24.20% of them are construction related and results in on an average 38 deaths everyday (Patel and Jha 2016). Construction related fatalities remain unreported because of the unorganized nature of this sector (Hämäläinen et al. 2006; Patel and Jha 2015). These fatalities come with other losses too such as man-hours loss, compensation cost, work delays, etc. In a study conducted by Mahalingam et al. (2007), researchers found that many Indian construction workers and contractors do not have adequate safety awareness. Lack of awareness also impedes the ability of identify hazards which is a major cause of accidents at the site. Since only 4% of construction workers get formal training, safety training is essential to increase awareness about hazards as part of safety planning.

Safety planning is often considered a secondary task and is not given as much importance as planning of activities or cost in project management (Mihić 2020; Zhang et al. 2015). Lack of proper safety training module, poor safety management and traditional training approach leads to accidents at sites and reduced productivity which ultimately increases indirect cost (Bansal 2011; Farghaly et al. 2021; Lin et al. 2017). Since strong safety procedures and records contribute to a positive, hazard-free, and productive work environment, pre-planning for safety is the most crucial stage in managing safety. Hinze and Wiegand (1992) studied that only one-third of the designers considered safety of construction workers during planning and designing. Karakhan et al. (2018) emphasized on the involvement of architects, designers and engineers during design stage for safety planning and supported the fact that intervention during design stage has maximum benefits in terms of safety. It is evident that the ability to influence safety reduces as the project progresses. Project Initiation, concept design, and detailed design phases are ideal for safety planning. Designers can impact construction safety during these initial phases by making better decisions. Contractors would have to make fewer site decisions as a result of this (Kamardeen 2010).

The major contribution of this study is to identify major hazards associated with each construction activity as part of safety planning. To achieve that, risk analysis was done to rank hazards, which is a major component of the safety schedule. The method of processing data and generating the safety schedule was automated using BIM tools. Since safety training is one of the most effective hazard control method, a prototype was developed which records workers' details and tells the required safety trainings based on the job role. In a nutshell, this study uses a holistic approach to mitigating hazards using engineering and administrative risk control methods.

2 LITERATURE REVIEW

The dynamic and complex nature of construction industry has made it one of the most hazardous sector in which almost all activities have some level of hazards associated with them (International Labour Organization 2015; K.A 2018). Thus identifying and categorizing hazards is of utmost importance so that appropriate mitigation steps can be taken. Mihić (2020) categorized hazards into three main groups viz. Self-induced hazards (when workers endanger themselves), Peer-induced hazards (when workers endanger others), and Global hazards (hazards present on entire construction site). Hazards can also be divided based on factors such as Frequency, Severity and Risk. For example, near-miss hazards/accidents are those when a hazard occurs but does not cause serious impact while accident is caused when a hazard results in serious impact on health and safety of workers. Many researchers and organizations tried to identify and rank hazards according to their potential to cause harm as shown in Table 1 (Hallowell and Gambatese 2007; Kanchana et al. 2015; OSHA 2021; Zhang et al. 2013, 2015).

According to OSHA fatality incidents report from January 2015 to May 2021, falls (37.1%), struck-by (20.45%), caught (20.9%), compressed (8.38%) and electrocution (1.9%) are the top five hazards on a construction site as shown in Table 2 (OSHA 2021). Selecting the most appropriate method of study is a high priority on the survey as there is lack of safety data available in the construction industry of India (Hämäläinen et al. 2006; Patel and Jha 2015). Once hazards are identified, next step is to assess the severity and frequency of the risks involved. Subsequently, risk evaluation and analysis are carried out using various available risk assessment methods. Various national and international codes have defined framework for risk assessment such as IS 15656:2006 (Hazard identification and risk analysis - Code of practice), IS 18001:2007 (Occupational Health and Safety Management Systems), ISO 31000:2009 (Risk management) etc. Safety risk assessment requires data to be assessed, whether quantitative or qualitative or semi-qualitative. Since there is a lack of accurate data on fatalities and accidents in the construction sector, especially in developing countries such as India, many researchers have used qualitative or semi-qualitative tools for risk assessment (Jha et al. 2022; Liu and Tsai 2012). Failure Mode and Effect Analysis (FMEA) is considered be to most commonly used method for risk assessment. Current study also utilizes the FMEA for risk assessment and ranking of hazards.

Table 1: Hazards in construction during execution stage

Hazards (during execution stage)	[1]	[2]	[3]	[4]	[5]	[6]	[7]
Fall from height	✓	✓	✓	✓	✓	✓	✓
Struck-by	✓	✓	✓		✓	✓	✓
Slips and trips	✓	✓		✓		✓	✓
Caught-in or compressed	✓	✓	✓		✓	✓	
Electrocution		✓	✓	✓	✓	✓	
Transportation accidents	✓	✓	✓	✓		✓	✓
Exposure to harmful substances	✓	✓		✓			
Repetitive motion	✓					✓	
Overexertion/manual handling	✓					✓	✓
Cut by machinery/object		✓					
Exposure to high or low temperatures		✓					
Explosion or demolition			✓	✓	✓		✓
Fire		✓		✓			✓
Others	✓			✓			✓

Note: [1] (Hallowell and Gambatese 2009); [2] (Liu and Tsai 2012); [3] (Kanchana et al. 2015); [4] (Purohit et al. 2018); [5] (Marefat et al. 2019); [6] (OSHA 2021); [7] (Li et al. 2019)

Table 2: Top 5 hazards as per OSHA fatalities record (January 2015 to May 2021)

S. No.	Hazards	Total Fatalities	Total %
1	Fall	24167	37.10
2	Struck-by	13319	20.45
3	Electrocution	1247	1.90
4	Caught	13652	20.90
5	Compressed	5459	8.38

Although too behind in the queue for harnessing digital tools, construction industry is trying to keep pace with the growing technological trend (Lin et al. 2017). Zhou et al. (2013) developed a technique to detect hazards and suggest corrections with the help of 'Rule-Based' tool in BIM by comparing 4D model with actual site conditions. As an output, hazardous elements were highlighted in red so that that safety precautions can be taken beforehand. Zhang et al. (2013) proposed model on fall protection using Rule-based algorithm in BIM to analyze and predict safety hazards and found that separating safety planning from core project planning causes miscoordination and inefficiency in safety process. Rodrigues et al. (2021) developed a Revit plugin which consumes project planning data to automate detection of risks from fall hazards. Choe and Leite (2017) integrated safety data from project schedule and BIM model to calculate Risky work period. Model simulation shows risky activities, days, and zones. Work zone risk was identified and shown with Green for low, Blue for medium, and Red for high risky work zones.

3 OBJECTIVES

Based on the analysis of current research gaps, industry needs, and scope of this study, the following objectives were set for this study -

a) To carry out safety risk assessment for identification and ranking of major hazards associated with project activities.
b) To generate a project-specific automated Safety Schedule as a proactive tool to foresee hazards and train construction workers accordingly.

4 RESEARCH METHODOLOGY

Research methodology has been divided into four phases viz. Risk Assessment, Safety Database was created to identify, extract activity details and finally integrate into Dynamo v.2.10 as shown in Figure 1. The scope of this study covers only execution stage of a G+4 Administrative building as case study. Risk management methodology was employed for identification and ranking of risks, divided into three parts viz. risk analysis, risk assessment and risk control as shown in Figure 2.

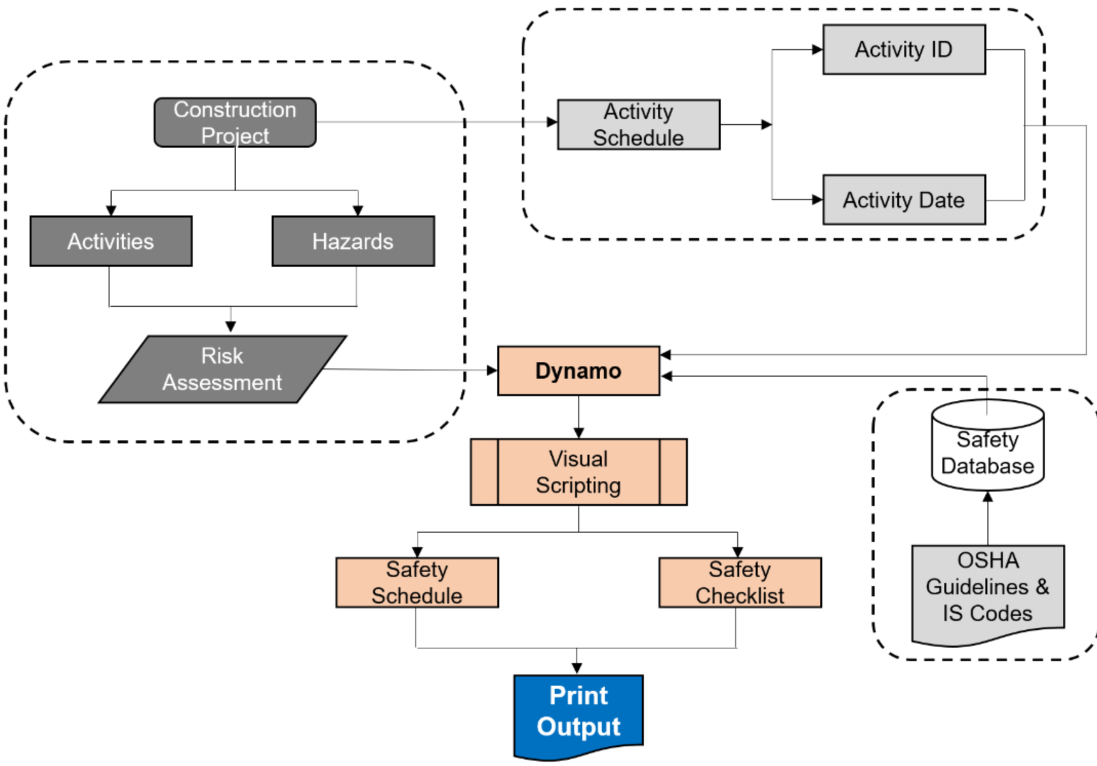

Figure 1: Research Methodology for Risk Management

4.1 Risk Analysis and Assessment

For this study, construction activities at execution stage of a RCC building were taken into consideration and were categorized into nine generic and repetitive activities viz. excavation or earthwork, shuttering or de-shuttering, scaffolding or staging, concreting or casting, curing, masonry or brickwork, reinforcement tying and placing, plastering and MEP works. Furthermore, 10 major hazards were identified from literature and OSHA records which are present in a typical RCC building. For risk analysis, activities and hazards were grouped into two subsets, 'B' and 'C' respectively, of superset 'A' which represents Risk Analysis Framework as shown in Figure 3. It can be expressed as $A \supset \{ B , C \}$.

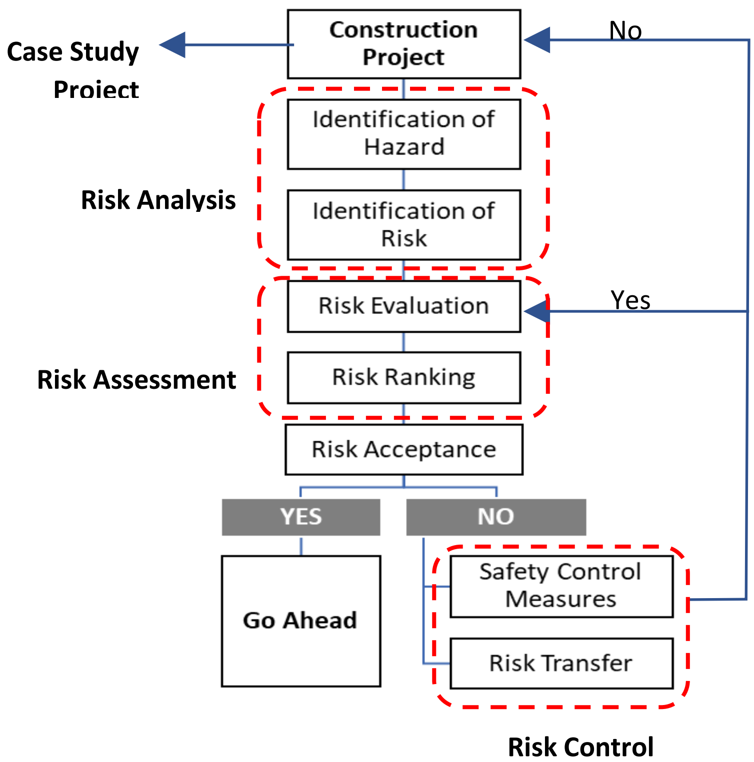

Figure 2: Research Methodology for hazard identification and risk management

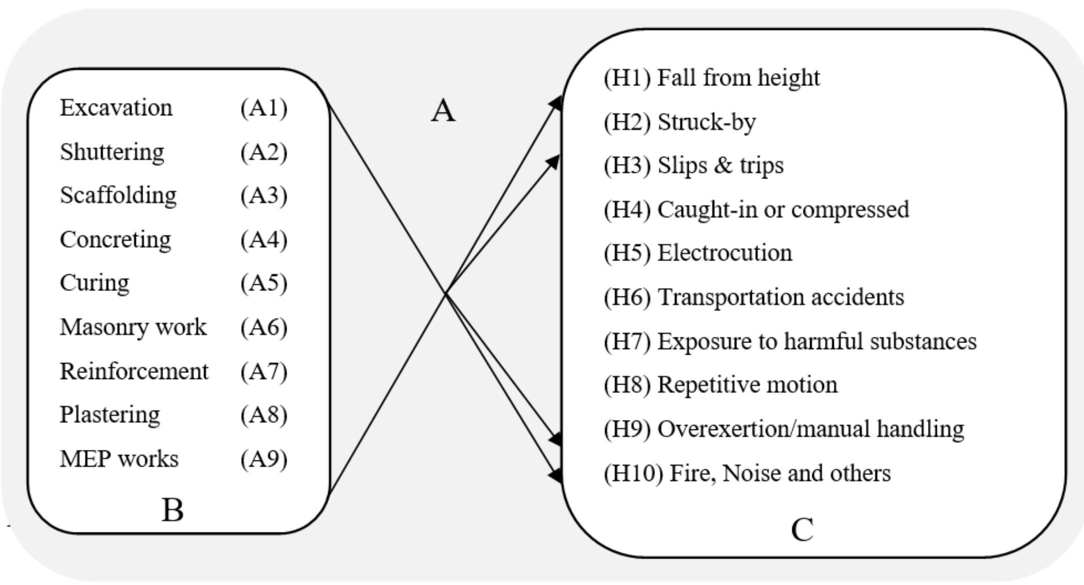

Figure 3: Risk Analysis Framework

A matrix-type questionnaire was prepared for the expert survey as part of the semi-quantitative analysis by FMEA method. Industry experts were selected and approached to participate in the survey through a risk assessment sheet. Some points of the expert survey process were adopted from Delphi method. Usually, 12 respondents is considered sufficient for achieving consensus in Delphi exercise; however, big sample sizes can yield diminishing returns (Vogel et al. 2019). Experts were selected based on following criteria: a minimum of 3 years of experience, an academic degree not below Diploma, designation not below Assistant Engineer and experience of similar project execution. Mode of the survey was in-person and remote/online discussion. All experts were given brief of the current study and the same was provided for those participating online. Survey was divided into two parts- first respondent's identification information, second, the core activity-based questions with required rating on scale of 1-5 for 3 parameters viz. Severity (S), Occurrence (O) and Detection (D) for each hazard in correspondence to each generic activity. Responses from 15 experts were received 40% experts had more than 20 Years of experience with average experience of 28 years, 27% experts had 3-5 years of experience, 20% experts had 6-10 years of experience while 13% experts had 11-15 years of experience. Total average experience of experts from all categories was 15.3 years. Risk assessment data was then used to calculate Risk Priority Number (RPN) for ranking of hazards. RPN of each hazard was summed-up and the total RPN value was obtained corresponding to each activity. Since RPN of each hazard corresponding to each activity differs for each expert, Relative Importance Index (RII) method was used to get an overall weighted value for each hazard for each activity.

Equation 1 and 2 state the formula for calculation RPN and RII respectively-

RPN = Severity (S) x Occurrence (O) x Detection (D) (Eq. 1)

Relative Importance Index (RII) = $\frac{\sum W}{H \times n}$

Where, W = Weight appointed to the factors by respondents/expert

H = Highest weight of the scale

n = Total number of respondents

In other words, RII = (RPN1 + RPN2 + RPN3 ……. + RPNn) / (5*n) (Eq. 2)

4.2 Risk Evaluation and Ranking

Rank of the hazards can be determined according to the respective weighted RPN value. Once the manual ranking of hazards was done, hazard categorization into 'High', 'Medium', and 'Low' was done based on the weighted RPN value. Hazards with 3 lowest RPN value were categorized as Low-Risk (highlighted in green), hazards with 4 highest RPN value were classified as High-Risk (highlighted in red) while rest of the intermediate hazards were classified as Medium-Risk Hazards (highlighted in grey) as shown in Table 3. Ranking and categorizing hazards is an important step in implementing Risk Control.

A project schedule was prepared in Excel which contained activity description, start date and end date, duration, etc. Each activity was given an Activity ID according to the code given to each generic activity in 'B' subset as shown in Figure 3. This was further connected with the risk assessment results obtained from risk ranking as shown in Table 4. If-Else condition was used in Excel to automate the process of linking of project activity with the risk assessment data based on the Activity ID. Example of the code is as follows:

```
=IF(B2="A1", $I$9, IF(B2="A2", $I$10, IF(B2="A3", $I$11, IF(B2="A4", $I$12, IF(B2="A5", $I$13, IF(B2="A6", $I$14, IF(B2="A7", $I$15, IF(B2="A8", $I$16, $I$17))))))))
```

This sample code matches the Activity ID with the risk assessment data and appends the applicable high-risk hazards corresponding to that activity in the project schedule file, ready to be imported into Dynamo.

4.3 Safety Database

A safety database was prepared by referring 11 Indian Standard Codes, National Building Code (NBC) 2016, OSHA Guidelines, Health & Safety Executive (HSE) guidelines, and other relevant safety standards given by Government of India. The information was extracted from these documents to get the potential failure modes, failure causes and process control data. This information was used to generate the hazard specific risk control annexure with safety schedule in Revit using Dynamo.

Table 3: Risk evaluation and categorization of potential hazards

Risk Ranking	A1	A2	A3	A4	A5	A6	A7	A8	A9	**Total**
H1	2.62	5.44	5.51	3.67	1.27	5.42	6.36	2.27	4.22	**43.27**
H2	4.45	6.64	5.67	4.07	4.27	5.07	4.82	4.16	4.53	**48.67**
H3	3.36	3.80	4.25	3.42	3.31	4.31	4.49	3.47	3.96	**41.55**
H4	2.78	3.36	3.05	2.84	1.07	3.29	3.45	2.80	3.25	**31.25**
H5	5.65	3.35	3.04	4.13	4.15	3.09	5.13	2.07	6.00	**33.81**
H6	3.96	2.31	4.05	5.33	1.38	4.00	5.93	1.89	4.18	**27.81**
H7	3.07	1.36	1.04	4.18	1.31	3.04	0.80	2.47	3.73	**19.12**
H8	3.05	3.53	2.85	3.15	1.25	2.55	2.64	3.33	3.73	**22.75**
H9	1.76	4.36	3.18	3.58	1.51	4.02	4.22	2.98	4.40	**32.40**
H10	2.75	3.07	3.40	3.91	0.85	1.56	3.18	1.64	5.40	**22.48**

4.4 Dynamo Integration

Dynamo, a plug-in of Revit, is a visual scripting tool used to compose custom algorithm for processing data. Dynamo uses Nodes, which represents objects and functions, wired together to form a set of instructions for processing data and generates the output. For current study, in-built Dynamo v.2.10 of Autodesk Revit 2022 was used to integrate and process the data using a visual script. Process is designed to automate the process of integrating project schedule, safety and risk assessment data to generate a safety schedule as shown in Figure 4.

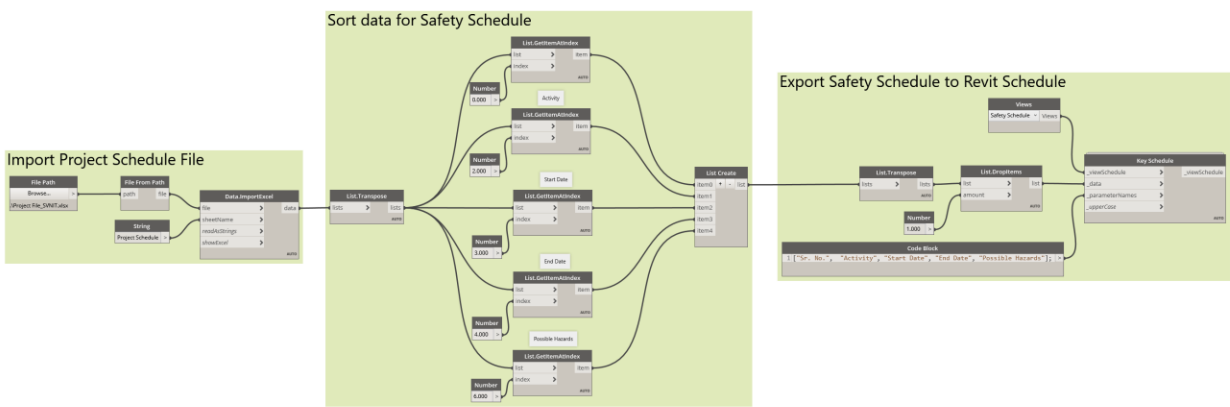

Figure 4: Workflow of project and safety data integration into Dynamo

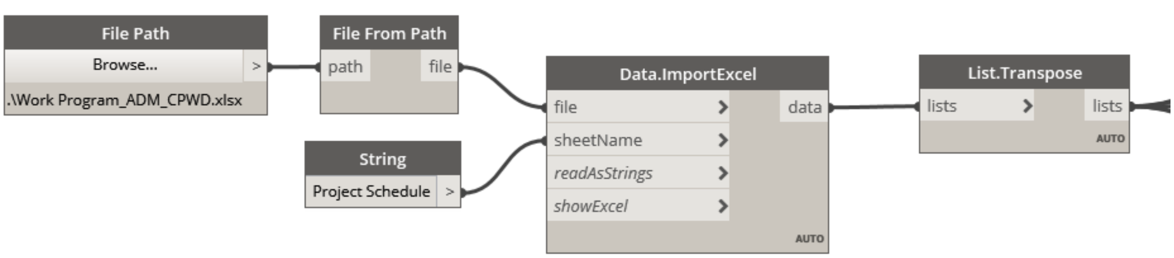

Figure 5: Visual scripting in Dynamo for importing raw Excel data file

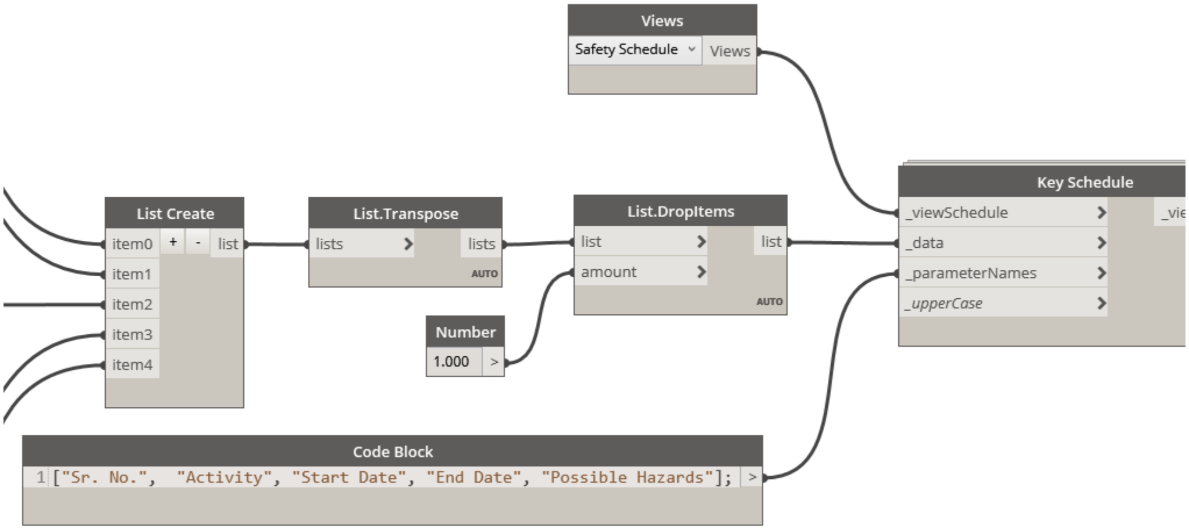

Figure 6: Visual scripting in Dynamo for exporting processed data to Revit Schedule

5 RESULTS AND DISCUSSIONS

Hazard identification and risk assessment process was carried out using FMEA method. 15 experts participated in the risk assessment survey with total average experience of 15.3 years. Furthermore, Risk associated with each activity was determined and ranked using RPN value. Dynamo v.2.10 was used for to process and generate safety schedule and exported in Revit as shown in Figure 7. Schedules can further be exported into sheet and printed.

Safety Schedule

<Safety Schedule>

A	B	C	D	E
Sr. No.	Activity	Start Date	End Date	Possible Hazards
1.0	Excavation for footings	3/11/202	3/31/2022	H2 - Fall From Height H3 - Slips and Trips H5 - Electrocution H6 - Transportation accidents
2.0	PCC	4/5/2022	4/11/2022	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar
3.0	Raft shuttering, reinforcement and casting	4/9/2022	4/10/2022	H1 - Hit by object H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents
4.0	Column Shuttering and Casting upto Plinth beam botto	4/11/202	4/14/2022	H1 - Hit by object H2 - Fall From Height H3 - Slips and TripsH9 - Overexertion & manual handling
5.0	Backfilling upto Plinth Beam bottom including compacti	4/21/202	5/20/2022	H2 - Fall From Height H3 - Slips and Trips H5 - Electrocution H6 - Transportation accidents
6.0	Plinth beam steel placing	5/2/2022	5/20/2022	H1 - Hit by object H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents
7.0	Plinth beam shuttering	5/2/2022	5/20/2022	H1 - Hit by object H2 - Fall From Height H3 - Slips and TripsH9 - Overexertion & manual handling
8.0	Plinth beam casting	5/10/202	5/24/2022	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar
9.0	Backfilling upto Plinth beam top	5/20/202	5/27/2022	H2 - Fall From Height H3 - Slips and Trips H5 - Electrocution H6 - Transportation accidents
10.0	Columns from Plinth beam to F. F. L. top (Reinforceme	5/27/202	6/5/2022 1	H1 - Hit by object H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents
11.0	Columns from Plinth beam to F. F. L. top (Shuttering)	5/30/202	6/8/2022 1	H1 - Hit by object H2 - Fall From Height H3 - Slips and TripsH9 - Overexertion & manual handling
12.0	Columns from Plinth beam to F. F. L. top (Casting)	6/9/2022	6/10/2022	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar
13.0	Masonry work From Plinth beam top to F.F.L. top	6/5/2022	6/15/2022	H1 - Hit by object H2 - Fall From Height H3 - Slips and Trips H9 - Overexertion & manual handling
14.0	Backfilling upto F.F.L. top	6/11/202	6/20/2022	H2 - Fall From Height H3 - Slips and Trips H5 - Electrocution H6 - Transportation accidents
15.0	Grad Slab (Shuttering)	6/16/202	7/5/2022 1	H1 - Hit by object H2 - Fall From Height H3 - Slips and TripsH9 - Overexertion & manual handling
16.0	Grad Slab (Reinforcement)	6/16/202	7/5/2022 1	H1 - Hit by object H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents
17.0	Grad Slab (Casting)	6/16/202	7/5/2022 1	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar
18.0	Columns from Ground Floor to 1st floor (Scaffolding)	7/1/2022	7/10/2022	H1 - Hit by object H2 - Fall From Height H3 - Slips and Trips H6 - Transportation accidents
19.0	Columns from Ground Floor to 1st floor (Reinforceme	7/11/202	7/29/2022	H1 - Hit by object H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents
20.0	Columns from Ground Floor to 1st floor (Shuttering)	7/1/2022	7/29/2022	H1 - Hit by object H2 - Fall From Height H3 - Slips and TripsH9 - Overexertion & manual handling
21.0	Columns from Ground Floor to 1st floor (Casting)	7/1/2022	7/29/2022	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar
22.0	Curing	-	-	H2 - Fall From Height H5 - Electrocution H6 - Transportation accidents H7 - Exposure to harmful substar

Figure 7: Safety Schedule exported in Revit schedules

Total RII values of risks for each hazard in current study revealed that H2-Fall from height (48.67), H1-Hit by Object (43.27), H3-Slips & Trips (41.55) and H5-Electrocution (33.81) were the top-3 riskiest hazards. On the other hand, H7-Exposure to harmful substances (19.12), H10-Fire, noise & others (22.48), and H8-Repititive Motion (22.75) were the least-3 riskiest hazards. It was also observed that hazards H2 (Fall from height) are present in all activities and thus are the riskiest of all hazards. Hence, a safety schedule and knowing potential causes of failure can be an important technique to mitigate such hazards. The integration and automation process are quite seamless with minimal interoperability issues. The results can be used further in preparing the worker's safety training module. Also, the current workflow can further be automated by automatically allocating Activity IDs based on generic keywords for activities, which was done manually in this study. This study utilizes project data of an RCC building and implements the FMEA method with inputs from different experts who might differ as per their experience. Integrating BIM model to identify hazardous elements and location automatically can also be explored to prevent fall hazard.

6 CONCLUSIONS

Present study uses a project-specific BIM-based approach to generate a safety schedule and control measures, which is a novel idea in the domain of construction safety. Fall from height, hit by object and slips & trips were found to be the top three major hazards. The current study also pierces the bottlenecks in the use of digital tools in construction H&S. Utilizing digital tools to automate workflow in construction safety planning could improve efficiency in the workflow. The risk assessment data used in this study can also be used to develop safety training modules and prepare safety budget. This study attempts to arrest safety concerns using engineering and administrative tools proactively.

This study aims to help safety managers and other supervisors foresee possible hazards associated with any ongoing activity. Proactive safety measures can be taken beforehand to ensure safety and to keep a check on productivity and competence, which is also a future scope of this ongoing study. Proactive measures are the key to protecting any workplace from unforeseen hazards, and this study anticipates to fulfil the same.

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