Digital Twin Framework for Worker Safety using RFID Technology

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Abstract –

Construction 4.0 and Digital Twin are the emerging concepts of the digital era in the Construction Sector. The crux of these digital technologies lies in capturing the rich "real physical" data to model the "virtual" structure to enable the experiments for specific decision-making. Although protocols for the hazardous operations had been chalked out meticulously across the globe through several organizations using stern safety regulations and codal provisions, still the goal of zero-accidents at the construction site has not been achieved. One of the several reasons for accidents occurrence can be that safety is not always in the minds of the workers and require a third-party intervention. Hence, the objective of this study is to safeguard the workers working in the construction sites using digital platforms (third-party) where the safety is monitored round the clock. The scope of this study is limited to falling of materials, equipments and workers. To achieve this objective, RFID (Radio Frequency Identification System) is used to capture the site data and is modelled in BIM (Building Information Modeling) using Dynamo. Job safety analysis is performed in the BIM software and this experiment is conducted on some hypothetical construction sites-in progress and the initial results have received positive feedback.

Keywords –

Digital Twin; Construction Safety; RFID; BIM

1 Introduction

Construction 4.0 is an emerging digital era concept following the lineage of techniques captured from Industry/Manufacturing Sector to the Construction Sector. The Construction 4.0 framework [1] uses CPS (Cyber-Physical System) as a core driver. Construction 4.0 rules the digital world encompassing several information technologies such as blockchain, big data, AR/VR (Augmented Reality/Virtual Reality), drones, IoT (Internet of Things), cloud-based project collaboration, BIM (Building Information Modeling), autonomous robots, DfMA (Design for Manufacture and Assembly), PEB (Pre-Engineered Buildings), 3D printing, and the list goes on [1][2]. The crux of many of these technologies lies in capturing the "real physical" world data to generate the "virtual" model to enable the experiments for specific decision-making. Hereafter, the words "virtual" and "digital" are used interchangeably throughout the paper.

The other recent buzz word from the digital era that is popular in the construction industry is the Digital Twin. While many of the above IT techniques focus on physical to virtual models and henceforth the decision-making, the Digital Twin concept follows an iterative loop of physical to virtual and then again to physical for communicating the findings from the "virtual" model into the "real physical-construction site" [3][4] and is portrayed in Figure 1.

Researchers in the past have applied several hardware/software technologies such as IoT/Sensor, GPS (Global Positioning Systems), Tag identification systems, Drones etc. to capture/track real-time data of the mobile resources such as workers, materials, or equipment at the construction site [5][6][7][8][9]. This data can be used to perform several analyses such as scheduling, project performance monitoring, productivity analysis, etc. using a digital platform. In this study, RFID has been used to collect the data for conducting safety performance, which is a very common tag identification system in practice for several decades [10].

Any safety policy whether CDM (Construction Design and Management Regulations, 2015) [11], OSH Act (Occupational health and Safety Act, 1970) [12] or BoCW (Building and other Construction Workers Act, 1996) [13] enforce safety of all the workers working in a construction site. Researchers till date follow the OSHA's fatal four classifications such as falls, struck-by objects, caught-in/between, electrocutions, and others [14]. In this group of classification, fatality due to falls is ranked as the most hazardous. Despite several fall precautions and preventive measures that are in industry practice today, still the accidents/fatality due to falls cannot be eliminated completely. The other fall hazard included in this study is the materials/objects/debris/hand tools, etc. falling on the workers which is generally termed as overhead work.

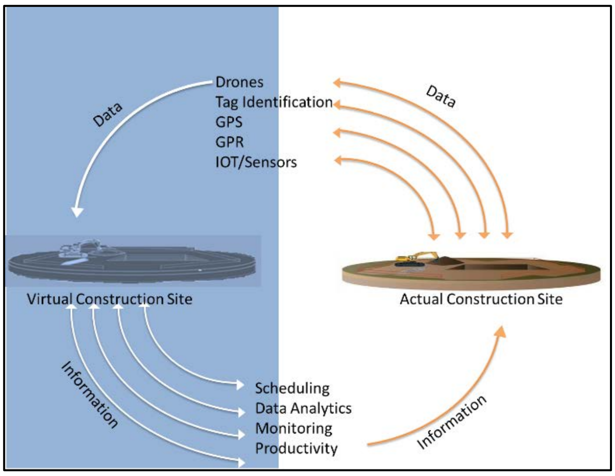

Figure 1. Concept of Digital Twin

Therefore, the objective of this study is to develop a Digital Twin framework that provides worker safety from fall hazards and overhead works during the project progress. To achieve this objective, RFID technology is used to capture the source data from the construction sites and is modeled in BIM (Revit) with the help of Dynamo. The contribution claimed in this study is the use of Dynamo Scripting to capture the data from RFID reader to the BIM software. Job safety analysis is performed in the BIM software and suitable precautions and warnings are conveyed to the site personnel on mobile application, to help sustain a zero-accident site. This experiment is carried out for various scenarios of hypothetical construction sites and the initial results are discussed in Section 4 of the paper. The scope of this study is limited to falling of materials, equipments and workers.

2 Safety Background

Construction Industry is one of the biggest industries that creates a huge employment opportunity to a large spectrum of skilled and unskilled workers [15]. As per ILO (International Labour Organization), the construction industry ranks among the top three industries having the highest accident/fatality rates with a disproportionately high number of recorded accidents globally. Patel & Jha [16] had reported that approximately 48000 workers die each year because of the occupational accidents and one in four workers die in the Indian construction sites. It is a well-known fact that accidents on sites are unavoidable and keeps recurring although the severity and marginally, the number of accidents has been reduced. Despite stern regulations and codal provisions for the hazardous operations being chalked out meticulously across the globe such as CDM, OSHA, BoCW, etc., still the vision of zero-accidents at the construction site has not been achieved. The term "zero-accident" is more of a philosophy rather than a numeric goal. The zero-accident vision is based on a belief that all accidents are preventable and therefore, must be avoided at all costs at a workplace through strategic policy implementation.

Safety measures due to worker falling from heights are classified into two categories such as fall arrest system or active protection system and fall restraint system or passive protection system. Here, fall arrest system prevents the workers from falling and examples include guard rails, barricades, etc., in addition to safety lanyard, lifeline, anchor point and a harness. On the other hand, fall restraint system protects the workers after the fall incident has occurred and examples include safety nets. Safety measures in case of overhead works include adequate toe boards in the guard rails and scaffolds, debris nets, safety nets, catch platforms, chutes, etc. Despite all these safety precautions, workers are injured in the construction sites due to falls. One of the reasons can be that safety is not always in the minds of the workers and require a third-party intervention.

There are several techniques to capture the real-time data in construction sites i.e., using RFID, vision-based, wireless networks, ultrasound, GPS (Global Positioning System), etc. [17][18][19][20]. It is a well-known fact that RFID is a very common tag identification system that is popular in construction industry practice [10]. The choice of IFC (Industry Foundation Classes) to capture the data from RFID reader into the BIM model has also been reported in some articles [21][22]. In this study, an attempt is made to investigate the Dynamo scripting for capturing the RFID data into the BIM model as it was not attempted earlier.

3 Digital Twin Framework Development using Pilot Example

As mentioned in the earlier section, the objective of the study is to implement safe worker practices in the construction site. The scope of this study is limited to falls and overhead works only. Although there are adequate passive preventive mechanisms before the construction progress happens, still accidents and/or near miss do happen in the construction site and they are unavoidable. Therefore, in this study, a Digital Twin model that has two-way interactions with the virtual model and the real physical model is setup treating it as a third-party monitoring mechanism for establishing safety. This Digital Twin framework is arranged in six simple steps as seen in Figure 2 and is elaborated below.

Step I: Select a construction site for applying the digital twin concept to monitor the safety performance.

To demonstrate this concept, a hypothetical pilot example that mimics a typical construction site-in progress is chosen. This construction site example that is modeled in the Revit software is seen in Figure 3.

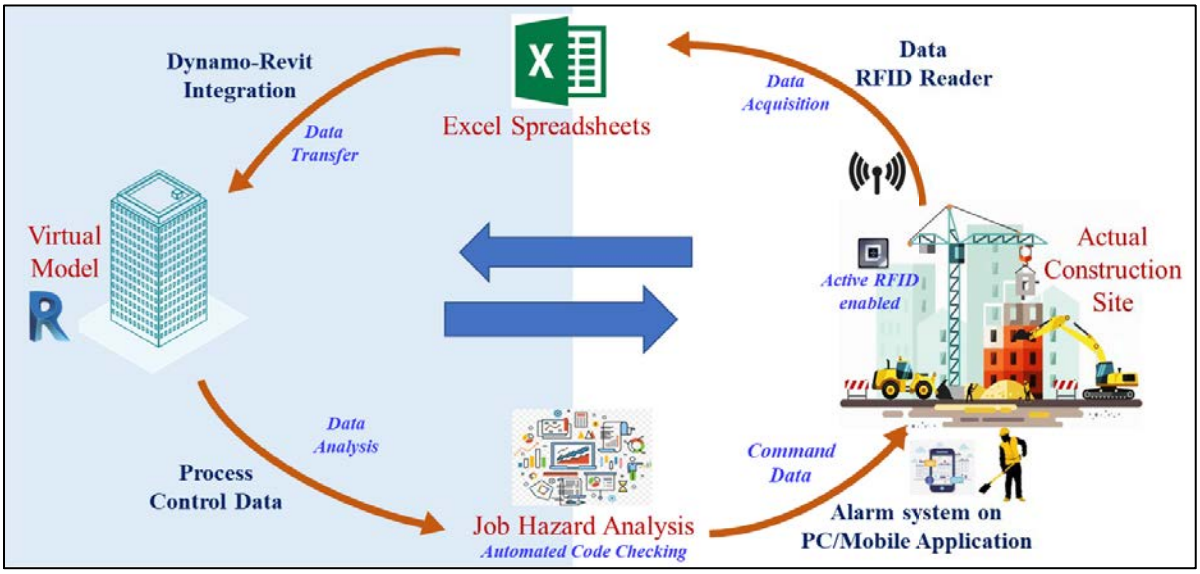

Figure 2. Framework for the Proposed Digital Twin Model

Step II: In this study, the Digital Twin concept is enabled using the RFID technology. A typical RFID system requires the tags to be attached with the resources to be tracked and the reader along with an antenna for reading the information from the tags. Accordingly, the RFID readers are placed at the earmarked locations so that they can detect the presence of the RFID tags and communicate the location to the server as seen in the Figure 2.

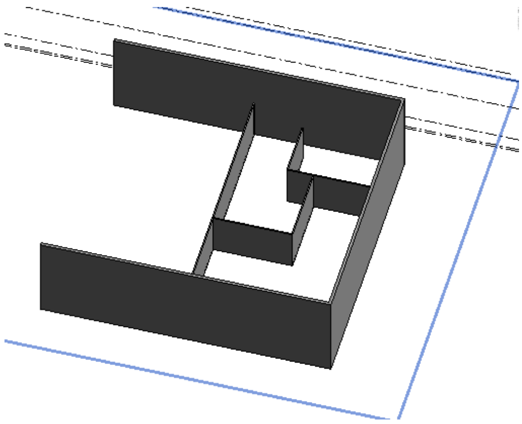

Figure 3. Hypothetical Construction Site (Pilot example)

For instance, if 2 materials and 1 worker location is to be tracked, then the RFID tags are attached to those chosen workers, materials and equipments in the site premises and the location are detected using the RFID reader along X, Y and Z coordinates. Table 1 illustrates the coordinates of the three resources and this is stored/updated in the server in the Excel spreadsheets. From this table, it is evident that although the worker is safe about Material-1, the worker can expect a fall hazard regarding Material-2.

Step III: To represent the location of resources in the actual site, this data must be imported in the virtual model. For this purpose, the coordinates from the excel sheet are transferred to the Revit model using the Dynamo scripting.

Table 1 Location Co-ordinates in Spreadsheet

Tag Description	X-co ordinate	Y-co ordinate	Z-co ordinate
Material-1	5	20	30
Material-2	5	5	30
Worker	5	5	5

The first part of the scripting is to trace the location coordinates from the Excel spreadsheet using Dynamo as seen in Figure 4.

Step IV: The next step is to differentiate the two types of resources, i.e., the workers and the materials individually without any confusion as in the screenshot in Figure 5, Figure 6, and Figure 7. Hence, in this example, sphere and polygon are chosen as the two different means of representing the materials and the workers respectively.

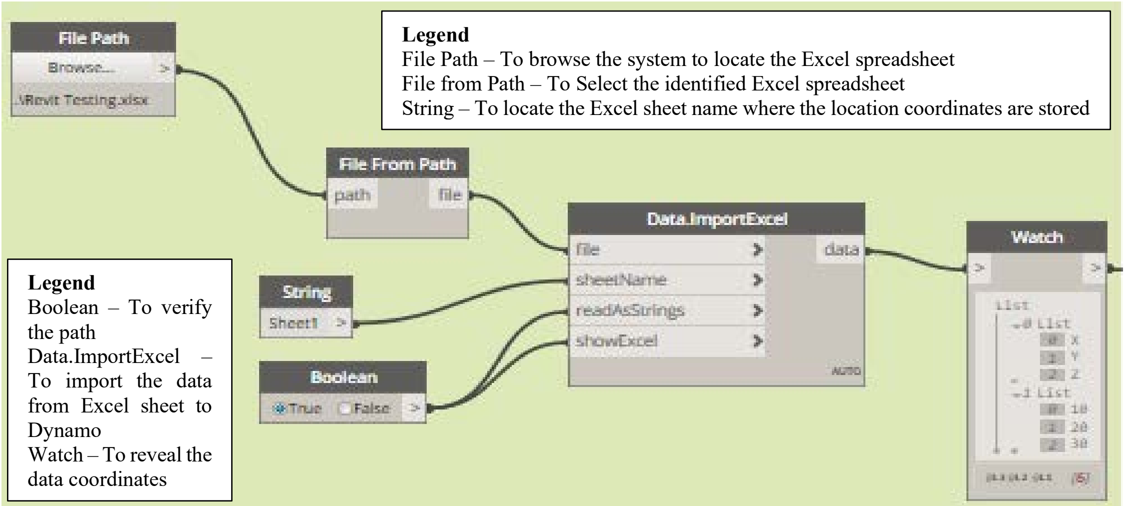

Figure 4. Dynamo Script Part 1 – Import Location Coordinates from Excel

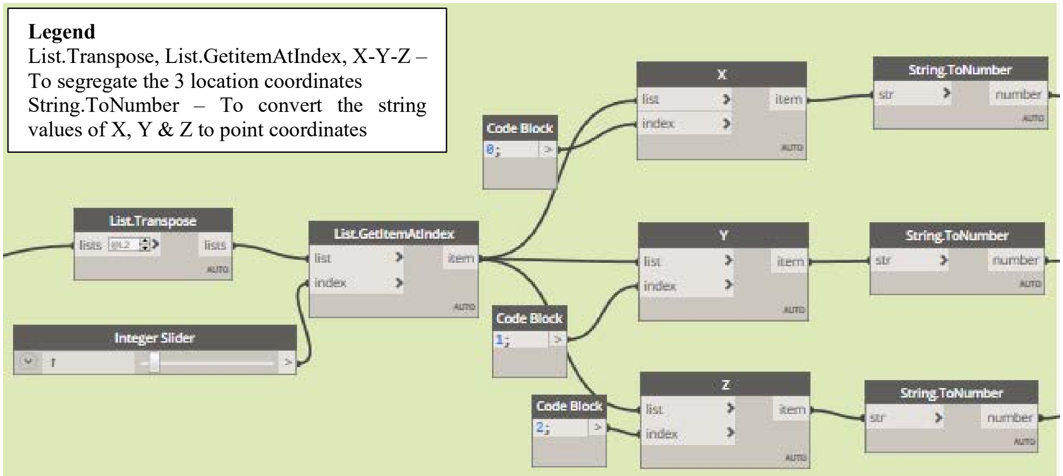

Figure 5. Dynamo Script Part 2 – Coordinates conversion in the desired format

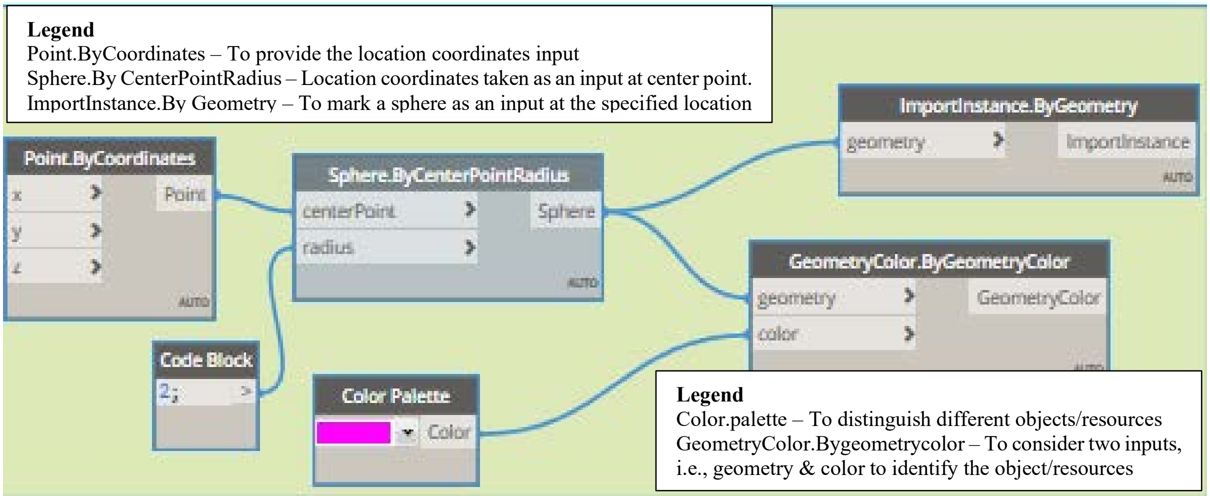

Figure 6. Dynamo Script Part 3 – Locating Materials

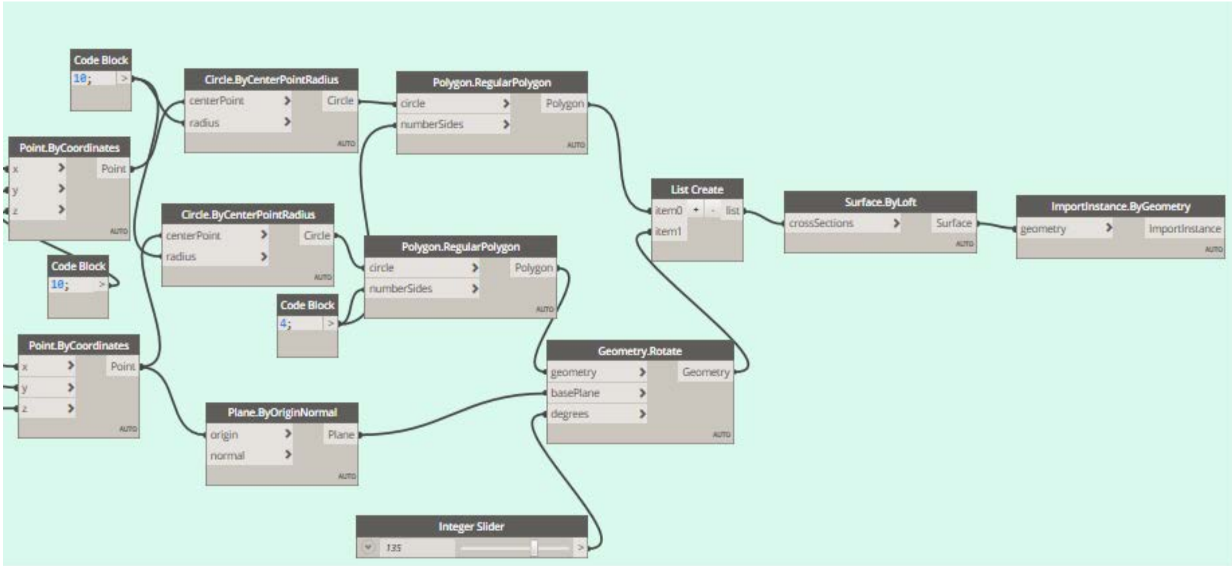

Figure 7. Dynamo Script Part 4 – Locating Worker

Step V: Reload and refresh the Revit Model so that the exact location of material and workers as captured in the construction site will be reflected in the virtual model as seen in the Figure 8 and Figure 9. This new location of workers and materials in the virtual model shall be used to analyse the hazards, if any through backend coding utilizing safety codal provisions.

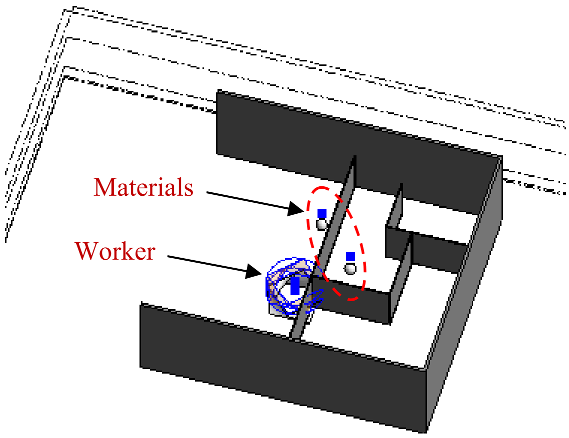

Figure 8. Regenerated Revit Model-I (Pilot example)

Step VI: After the updation of the location data, hazard proximity analysis has been carried out through backend coding (automated code checking) using python and java script (refer Figure 10). Safety guidelines regarding various site scenarios have been obtained from the codal provisions (OSH, BIS, etc.). Upon non-compliance, a warning is first generated in the virtual Revit model. Accordingly, an alarm/notification containing the appropriate safety solution will be communicated to the concerned workers/supervisors (refer Figure 10) at the construction site on their mobile application, to be safe from the falling objects/fall zone.

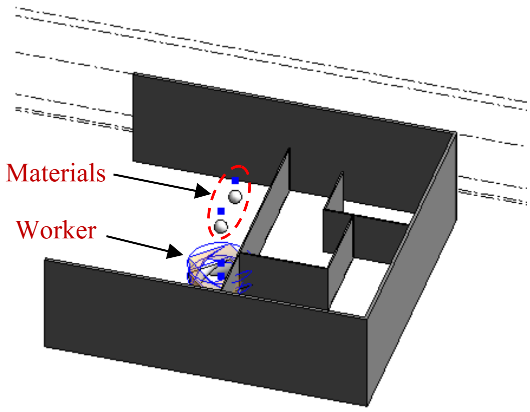

Figure 9. Regenerated Revit Model-II (Pilot example)

Pilot Example Results: Figure 8 presents the location of one worker and two materials of the construction site in the Revit model. This is a safe situation wherein the worker and the materials are far apart from one another and there is rare chance of worker incidents to occur. But there is a possibility of nil progress or idle situation which can be investigated from the site office and thereafter investigated from the crew.

Similarly, Figure 9 presents the location of one worker and two materials of the construction site in the Revit model at another instance. This isometric projection shows that one material is above the worker location and he must be warned for safety measures. The situation assumed is that the material is placed above the forklift and with the movement of the forklift, the material location and worker location are merged in the planar coordinates except in the space. Accordingly, an alarm is notified to the worker as shown in Figure 10.

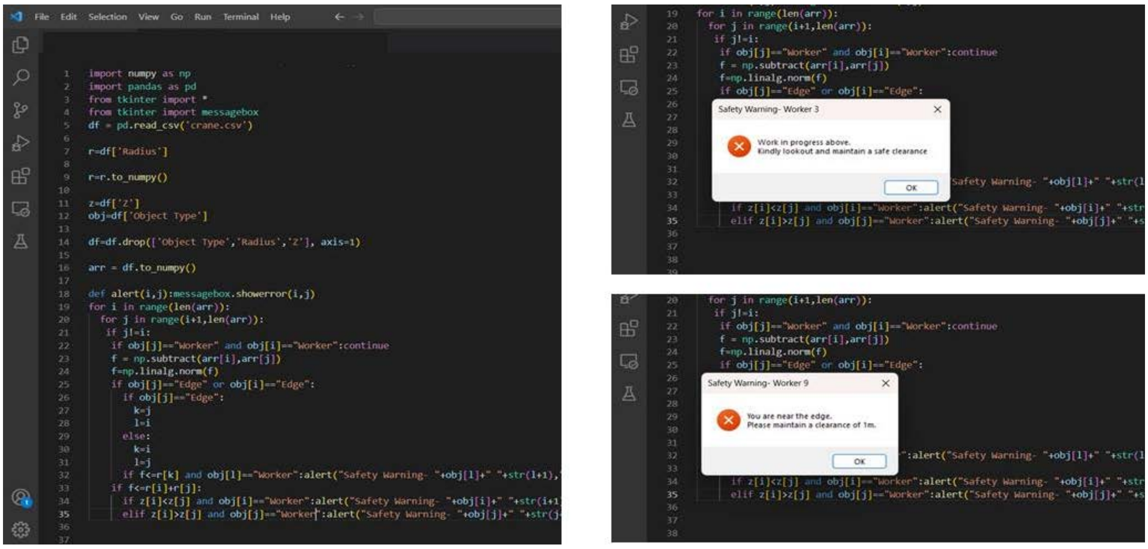

Figure 10. Coding snippet (left) and Safety warning notifications for Pilot example (right)

4 Analysis and Results - Caselets

In this section, two different scenarios about the movement of materials, equipments and worker is captured from the different types of construction sites at a specific time interval and analyzed for safety compliance. The pilot example in the previous section has been used for the development of the framework, which has been further verified by means of the two hypothetical caselets undertaken in this section.

Caselet - 1: Figure 11 illustrates the situation where a tower crane is operating at a construction site. Four different workers are working in the vicinity of the crane, thus raising a safety concern. The workers along with the crane have been provided with the RFID tags. As can be seen in the figure, there are three workers who are working under the swing radius of the crane (here 15 m). They are under the fall zone of the materials that the crane is lifting and thus need to be informed to move outside the swing radius of the crane to safety. But, the fourth worker being in the safe zone need not be notified, thus avoiding a false concern.

The scenario is modeled in Revit and the location information of the resources are obtained through the RFID sensors, which are further transferred in Revit through the dynamo plugin. Upon hazard analysis, the respective workers in the unsafe zone are notified using the mobile application as shown in Figure 12.

Caselet – 2: The next case showcases a three storey under construction building site as shown in Figure 13.

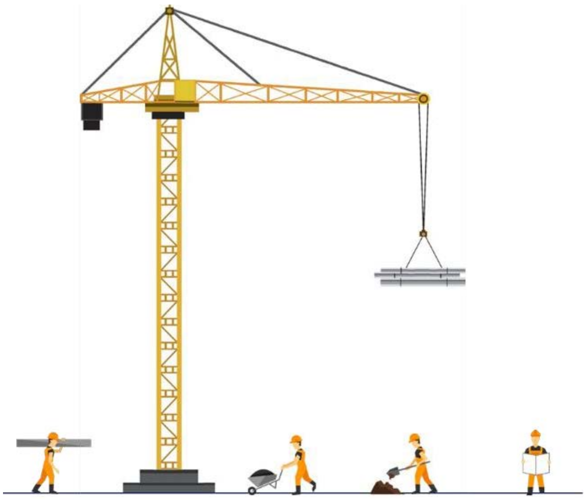
Figure 11. Construction Site Scenario (Caselet - 1)

Five workers along with three equipments namely drilling machine, chipping machine and a crowbar (all with RFID tags) working on different storey have been taken to illustrate the unsafe scenarios at site. As evident in the figure, the worker with crowbar is close to an opening on the third storey. Also, drilling work is happening on the edge of the second storey and another worker is working just beneath on the ground floor. Similarly, chipping works is in progress on the first floor and brickwork is happening just below it on the ground floor.

Similar steps of action, as already explained in the previous section are taken to model the physical site and their allied information through Dynamo-Revit integration. And then, hazard proximity analysis is performed through coding to check for safety compliance against various codal provisions. Thus, a warning is generated in the Revit model at the main site office to notify the same to the concerned person/s. Further notifications regarding any safety actions are then communicated to the concerned workers on their mobile application (refer Figure 13).

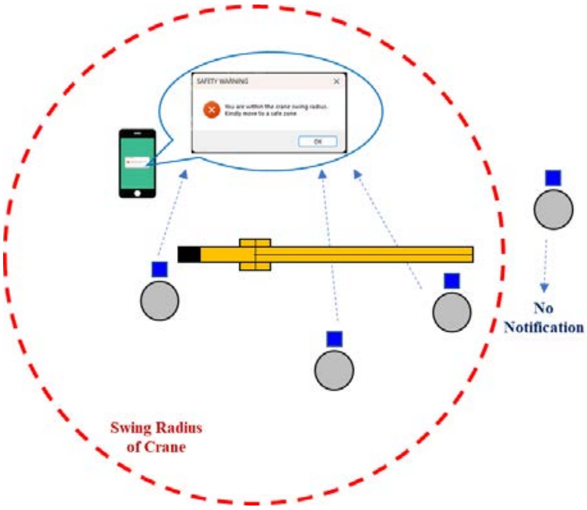

Figure 12. Safety notifications to concerned workers

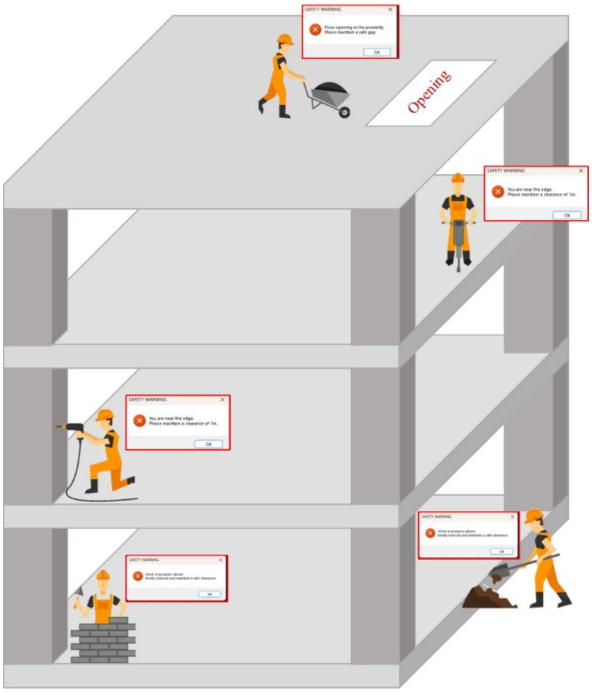

Figure 13. Building site scenario and corresponding safety notifications to workers (Caselet - 2)

5 Discussions

Live data collection from an ongoing construction project and real physical experiments was a great challenge during the pandemic. Hence, hypothetical case examples have been used to mimic typical construction sites. It is assumed that the physical experiments will generate the data that was assumed in this study and the dynamo scripting was carried out. Verification of this exercise through various hypothetical cases have been carried out in the previous section of the study. Although, the framework has proved effective for these hypothetical case studies, the validation of the framework on an actual live construction site is essential and is therefore, a plan for the future.

Also, this dynamo scripting is highly efficient for locating and monitoring few resources. Hence, in the pilot example, 2 materials and 1 worker were chosen to portray the resources. When this concept is applied in a medium or large construction site, enormous effort is required for scripting as it must be written specifically for each and every resource. Since, this is not a feasible solution, heuristic way of developing the dynamo scripting for any resource independently with minimal effort is required.

6 Summary

The framework for the Digital Twin model based on the integration of RFID-Dynamo-Revit shall provide the seamless data transfer from the actual construction site to virtual model. This combination framework is expected to read and trace the workers, equipments and materials location from the actual construction site into the virtual model for monitoring the site in terms of safety round the clock.

In this study, dynamo scripting was used for reading the resources data from RFID to model the same into the Revit software which was not attempted earlier. With the inputs given from the hypothetical construction site, the Revit model was regenerated at suitable intervals for evaluating safety performance. Hence, dynamo scripting can be applied to small construction sites for digital safety performance, keeping in mind its limitations.

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