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Utilizing Building Information Modeling to Create Site Safety and Construction Project Coordination Efficiency

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ABSTRACT: The use of Building Information Modeling (BIM) has significantly improved building planning and enhanced site safety. Civil engineers rely on the software to generate work plans, develop three-dimensional architectural drawings and coordinate work professionally. The aim of the current work is to develop BIM as a technology that can ensure site safety, support proper planning and bring cost-efficient project completion. The results indicate that Revit and Level 3 BIM, both open-source systems, offer up-to-date digital ecosystems for multiple project management.

I. INTRODUCTION

Safety, coordination and timely completion are the three essentials of construction. Among these, safety has been automated the least. In the United States, around 48 percent of all safety-related casualties happen from slipping off building heights. The causes of unsafe outcomes are usually reversible because they emanate from low-key managerial planning (Nadhim, Hon, Xia, Stewart, & Fang, 2016). For instance, the crew does not check the site properly before it begins work, but then there is a hitch. The second cause is when safety barriers are not set up in a timely manner. This is especially important because improper scaffolding leads to the majority of construction casualties (Collins, Zhang, Kim, & Teizer, 2014). Thus, the overall problem of safety relates to low-level planning and project coordination. Across all industries, the construction industry ranks first in terms of site-related fatal accidents. Around 48 percent of workplace deaths in the world in 2016 emanated from falls at construction sites (Nadhim, Hon, Xia, Stewart, & Fang, 2016). This represented 36.9 percent of workplace fatal casualties in the US and 31 percent in Britain in the year 2013 (Nadhim, Hon, Xia, Stewart, & Fang, 2016). In totality, all such deaths represented a 49 percent margin of a multi-industry comparison in the same year in the United States (Natonal Safety Council, 2015). The rate was high from the early to mid-2000s. It then leveled down in the following years before it climbed slightly in 2012 (Natonal Safety Council, 2015). The graph below represents the statistics as shown in Figure 1.

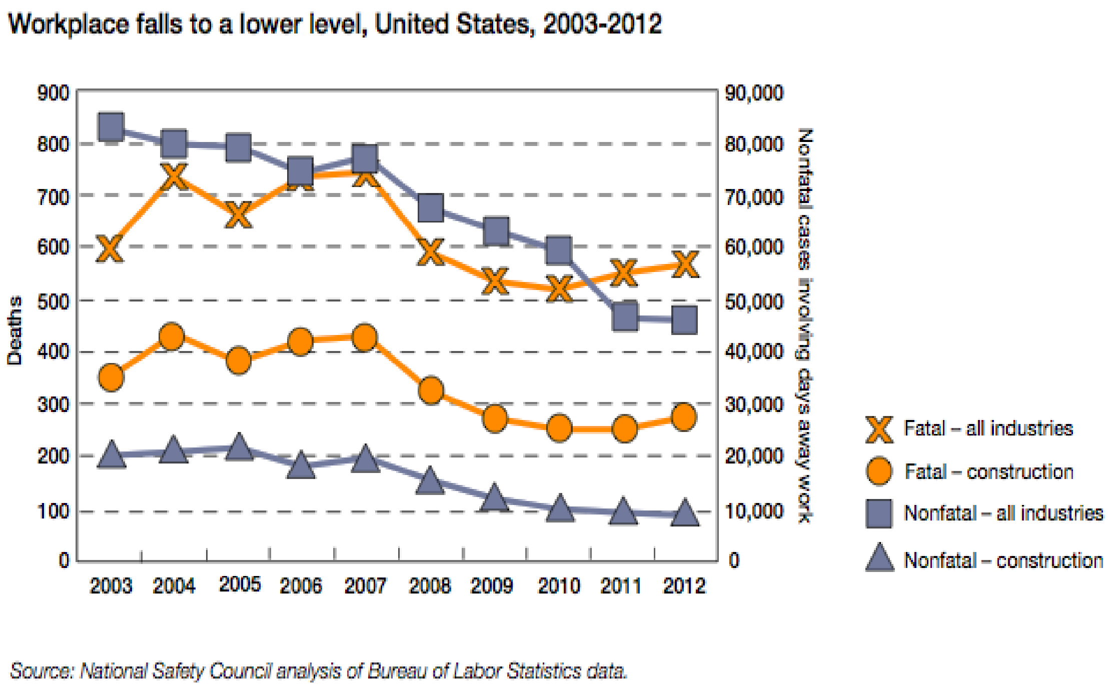

Figure 1: The rate of falls from heights to lower ledges was the highest in the construction industry up to 2012.
[Source *(Natonal Safety Council, 2015)***]**

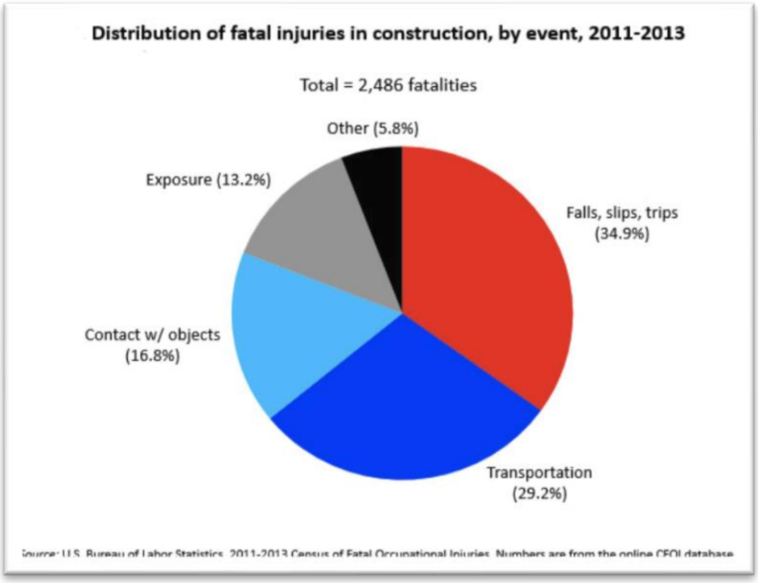

Figure 2: Falls in construction related to other sectors like agriculture shows that falling from heights has had the biggest casualty percentage at 49% between 2007 and 2016 *(Health And Safety Authority, 2018)*

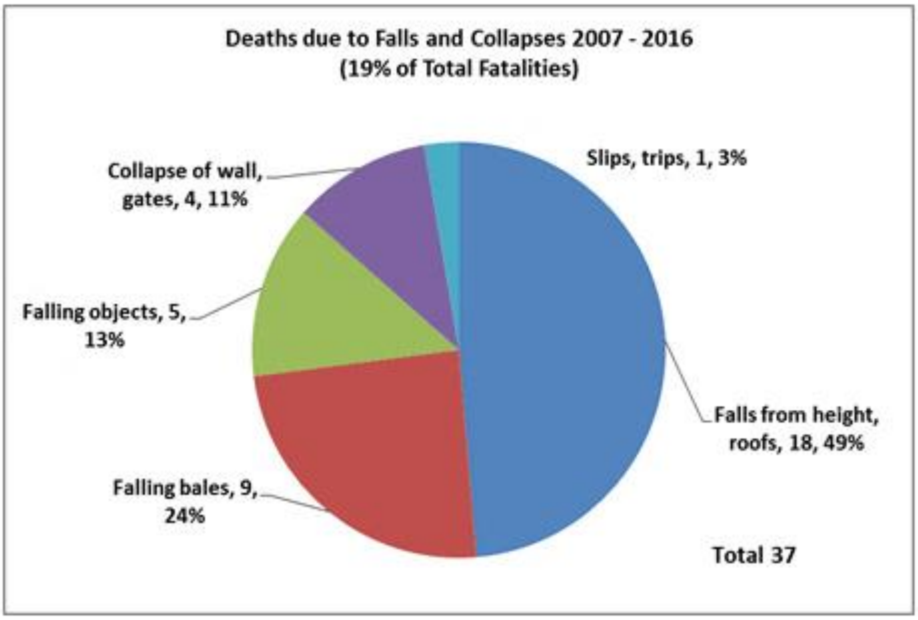

Figure 3: Distribution of fatal construction injuries between 2011-13 [Source: US Bureau of Labor Statistics, 2013].

In light of the above, safety is one of the unresolved problems in construction. The sector accounts for more serious minor injuries than all other industries, primarily due to falls (Cecen & Sertyesilisik, 2013). For this reason, the timely erection of barriers is necessary. A solution comes from the use of computerized construction models for large-scale buildings; BIM mock models offer visualizations on the exact area to install barricades.

<u>Observations from the above chart Figures 2 & 3 are:</u>

1. The rate of injuries from slips accounted for three percent of site injuries in the highlighted period (Health And Safety Authority, 2018). These may emanate from easily preventable actions such as spilling grease and other viscous liquids that may also cause chemical-related burns (Behm & McAleenan, 2015). They can also occur from wet, curing floors, poor concentration and lack of protective shoes (Shreevastav, 2008).

2. The safety cases from wall collapses represented 11 percent of all casualties between 2007 and 2016 (Health And Safety Authority, 2018). One of the problems is the weakness of retaining walls to hold building loads due to low-quality concrete and improper work (Binici, Temiz, Kayadelen, & Kaplan, 2010). BIM can analyze structural and building load metrics and produce timely files for review to prevent wall collapses (Razak, Endut, Samah, & Ridzuan, 2017).
3. The casualties from falling objects represented 13 percent of all incidents in 2007 to 2016 (Health And Safety Authority, 2018). This was due to the presence of flying, loose materials such as gravel, steel tools, and nails that lead to minor injuries.
4. The largest cause of casualties at construction sites in the above period was from roof falls, which was over 49 percent of all cases (Health And Safety Authority, 2018). This is a common scenario due to the prevalence of high-rise structures that necessitate unconventional work set up. Without proper scaffolding, it becomes easy for the crew to fall off ledges (Nadhim, Hon, Xia, Stewart, & Fang, 2016).
5. Falling from heights: despite employing 7 percent of the US workforce, construction work is attributed with the risk of fatal falls from heights (Siddiqui, 2014). Workers may accidentally land onto the concrete below or even in open pits, both common causes of death. The main reasons for such falls is poor site management, lack of proper ladder placement and even poor visibility, especially in winter (Nadhim, Hon, Xia, Stewart, & Fang, 2016).
6. Trench collapse: annually, four hundred workers die when working in trenches whereas ten times that number suffer injuries. The main cause is the caving in of soil and gravel due to mechanical movement above. Other risks of trench disintegration include coming into contact with chemicals, sewers and the risk of electrocution by naked underground cables (AFSCME, 2011).
7. Scaffolding collapse: because of their very nature of being temporary, scaffolds are apt to be hurriedly installed. Unstable structures disintegrate when a worker is using them and involve other risks like falls and striking by flying objects. Thus, there is a need for an experienced scaffolder to ensure the scaffold's safety (Ismail & Ghani, 2012).

Figure 4: Safety Induction is Mandatory

Building Information Modeling: BIM's inception was in 1970s, but its initial practical deployment was not until 2002 (Rokooei, 2015). It became a system that depicts the tangible and functional details of a building. These details are then scalable as the building phase progresses and can thus serve as a continuous reference point on the project's future (Rokooei, 2015). BIM is called a four-dimensional model because it accounts for time.BIM's main purpose is to generate a computer version of a building design inclusive of its architectural features and development procedure. It enables the key managers such as the architects to create a visible picture of the complete project so as to foresee such issues as the cost, continuity of plan, and safety loopholes. The use of BIM has become a major contingent factor to reduce fatalities. BIM has been used in four-dimensional digitization models of scaffolds. The utility of the software in this way has appreciably lowered injury rates due to the precision of drawings that illustrate hazard points. Although any construction site needs an induction as shown in Figure 4, there are still places where fatalities and injuries can occur on site. There are at least nine problems at a construction site that can be redressed by BIM. These include:

Lack of proper planning: improper planning is one of the biggest hindrances of projects as it leads to uncontrollable expenditure buildup. Some of the reasons for this include internal disputes that hamper decision-making, erroneous cost estimates and even weak methods for capital planning. A possible consequence of improper planning is the spill-over of the project's deadline. This scenario is one that can delay the building undertaking for up to years which, in turn, tarnishes a project's image in the eyes of its stakeholders. Thus, the assessment of the real reasons for poor planning can assist to patch overdue time and excess cost consequences. BIM can come to the rescue with the use of a 3D plan of the building per unit development feature. This way, the management can plan how much each unit costs and how to cover it, one at a time, to ensure smooth completion. (Pucko, Suman, & Klansek, Building information modeling based time and cost planning in construction projects, 2014).

Lack of coordination: also known as a 'wall of communication,' poor coordination can derail a project especially when it involves human and machine incoordination. There are plenty of overlapping actions, including manual and automatic work that require projects to have high coordination (Hai, Yusof, Ismail , & Wei, 2012). Some of the precise manual challenges include overcrowded sites, half-finished blueprints, and insufficient tools for the workers. The foremen and supervisors also may have unclear duties that lead to conflicts, delays and cost buildup (Hai, Yusof, Ismail , & Wei, 2012). The use of BIM can reduce such lack of cohesion as it comes with a full set of options to enhance collaboration between the human and mechanical aspects of construction. One of these is that it coordinates the smooth interplay between machinery, power-run activities and plumbing (Yung, Wang,, Wang, & Jin, 2014). This, in turn, reduces friction among workers.

Lack of professional education: The ability to transfer classroom practice to the site is often difficult for students who only learn theory. This can lead to poor performance at the construction site. Indeed, many students emerge out of their construction class with know how in drawing but cannot easily transfer the same skills onto the site (Shaaban, 2013). They can, however, get more practice if they attend field internships that can offer a secondary view of actual civil engineering (Shi, 2014). For instance, the graduate engineer ought to know that pouring concrete at once may lead to tension as it may cause structural and esthetic challenges. With BIM integration in some universities, however, students who join the industry for the first time in a professional capacity can learn the trade through the automated lifelike models of sites (Sacks & Pikas, 2013).

Site Injuries of construction workers: As discussed above, falls from roof tops and scaffolding heights are a significant problem. With the use of software that can foresee risk areas, such unsafe occurrences can diminish significantly (Collins, Zhang, Kim, & Teizer, 2014).

Using BIM for Safety: To reduce fatalities, bring site efficiency, decrease paperwork and even recover costs, a computer model of the site is highly necessary (Polekar & Salgude, 2015). Architects can plan ahead of the practical phase of construction through computer-generated practical illustrations (Botchway, Abanyie, & Afram, 2015). They can also cross-check machine drawings to minimize misuse of the site blueprints and bring down site errors (Usmen & Vilnitis, 2015). Such a software program also enhances early phase project requirements such as tests and verification on the safety of site (Usmen & Vilnitis, 2015). The challenge is to identify a scalable software that serves in a block chain manner: that is, it records each stage of construction that the architects and building planners can regularly refer to in order to minimize erroneous practices and conflicts (Senaratne & Mayuran, 2015). There are diverse planning software programs that have developed in tandem with the increase in the construction of high-rise structures but very few have enjoyed full utilization (Botchway, Abanyie, & Afram, 2015). It is a post-CAD medium that enables civil engineers and architects to generate work plans, develop three-dimensional architectural drawings and manage project coordination more easily (Rokooei, 2015). In light of the above, this study seeks to develop a further understanding of BIM cognizant of site safety, timely work plans, coordination and cost-efficiency. The aims of the study are to present the merits of using the Building Information Management (BIM) suite of programs for the purpose of improving construction processes. Indirectly, more efficient construction will be safer. Also, BIM can be used directly to monitor safety.

The objectives of the study are:
1. To present BIM as the most appropriate building software.
2. To promote the notion of practical, professional education for civil engineers to enhance coordination in the construction site.
3. To provide a case for more utilization of software for design, analysis and management of construction through 3D BIM software such as Revit.
4. To enhance site planning, energy efficiency and timely completion of projects through 3D post-CAD software environment like BIM.
5. To use the software to provide timely barrier erection in high-rise construction so as to reduce the

incidents of injury.

BIM has several potential levels of implementation with each offering greater control over construction, and therefore greater levels of potential safety improvement. Since BIM is an intelligent 3D model-based process, it could provide users with many possibilities for a successful project, and to gain the respect of the owner. The idea is to create a process with less risks, high expectations, minimum mistakes, and good strategic planning.

Development of a Revit Safety Plug-in: A plug-in for Revit was developed that aids creation of barricades. Safety barricades will prevent falls. Tracking of barricades in BIM improves the ability to track them as a function of time so that they become a regular part of safe construction practices.

The main plug-ins in Revit include the following:

1. Journals: these are text format files made up of XML and Notepad++ extensions. Their role is to help diagnose any mistakes that derail the functioning of Revit. This is because the journals record all data that goes through the program so that the user can find a problem by consulting the old records in a legible text format (Firman, 2014).

2. Scanning add-ons: currently, the external plug-ins for scanning drawings from Revit to the BIM cloud ecosystem are available as open-source programming. These allow multiple users from diverse operating systems to use any add-on that is compatible with their systems.

3. Visualization plug-in: one of the most important needs of an architect is to have control over resolution and shadow in CAD drawings. The visualization features include widgets like 'Realistic,' which defines objects with sharp edges, or 'Ghost Surfaces,' which enhances the image's visual quality (Khemlani, 2011).

4. Paint: this is a tool that enables the creation of high-resolution colored drawings that are layered on a surface that the architect chooses. This tool is a part of the visualization plug-ins as shown in figure 5.

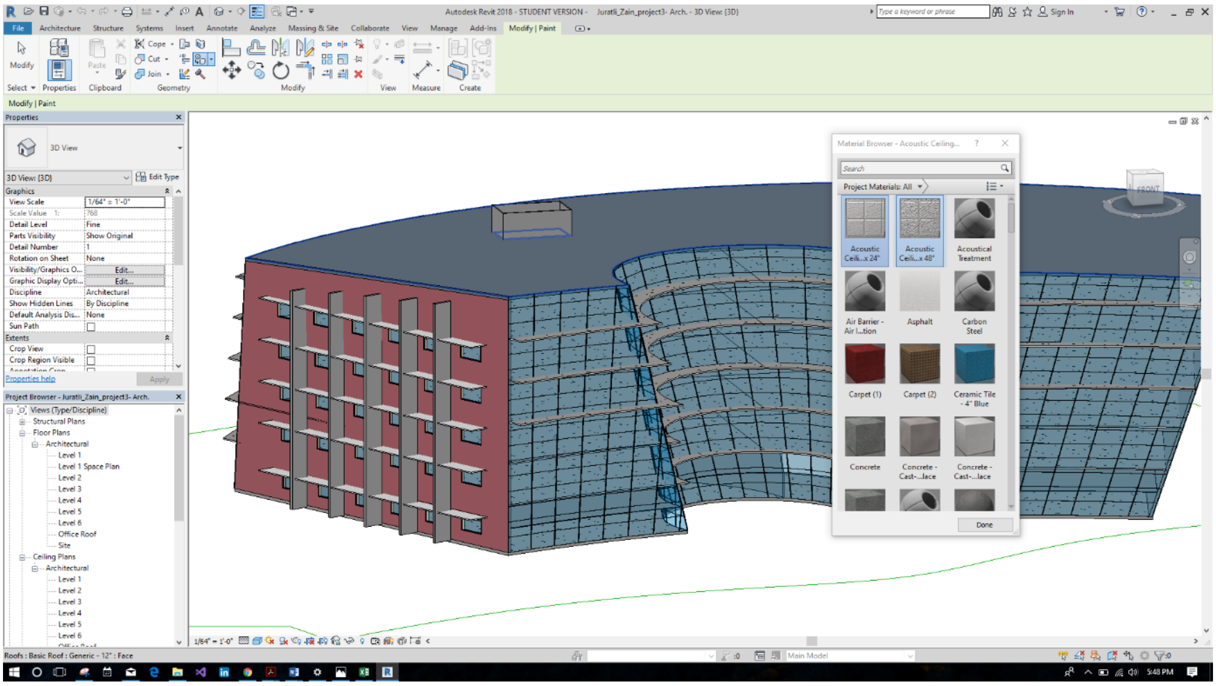

Figure 5: an image with the details of an unfinished paint tool job and a finished paint tool job.

Revit programming has a wide scope, one being that it can couple with external programs to minimize the challenges that face the use of pure BIM tools. For instance, there have been suggestions of the merger of Revit and tools that interpret user input decisions (Tammik, 2012). This way, the engineer will always find their creation updated automatically every time the combined systems detect a decisive change (Harding, Suresh, Renukappa, & Mushahat, 2014). Another scope is that Revit can attain the limits of up to 5D drawings, an impossible feat in the 2D CAD era. The idea of 5D is to offer near-complete visualization of the entire building's undertaking from the initialization to the completion stages (Jununkar, Aswar, & Mittapalli, 2017). Revit can bring the scope to near-perfect real-life models on the screen with the diverse information layers of time, budget and physical design (Jununkar, Aswar, & Mittapalli, 2017).

Overall, BIM programs like Revit have a possible limitation of low inclusivity of all stakeholders (Tammik, 2012). Because of its automated nature, mostly engineers and architects use it while developers rely on the final designs to make comments. Another limitation is the newness of the technology. Since some architectural teams are still reliant on 2D architecture, they find it hard to update their systems. This may be due to issues of incompatible software (Tammik, 2012).

Other than using different programming languages with Revit, it is possible to program new commands, add-ons or macro processes using the following stages:

1. Initialization of the code manager: if it is a new command, then one needs to go to the programming language's library such as in C# and initialize the new commands manager.
2. The other important process is to set up a new module, which is basically a set of commands bundled together. The user can name it and save it in a fresh project file that the commands manager helps to create (Kilkelly M. , 2016) as shown in Figure 6.

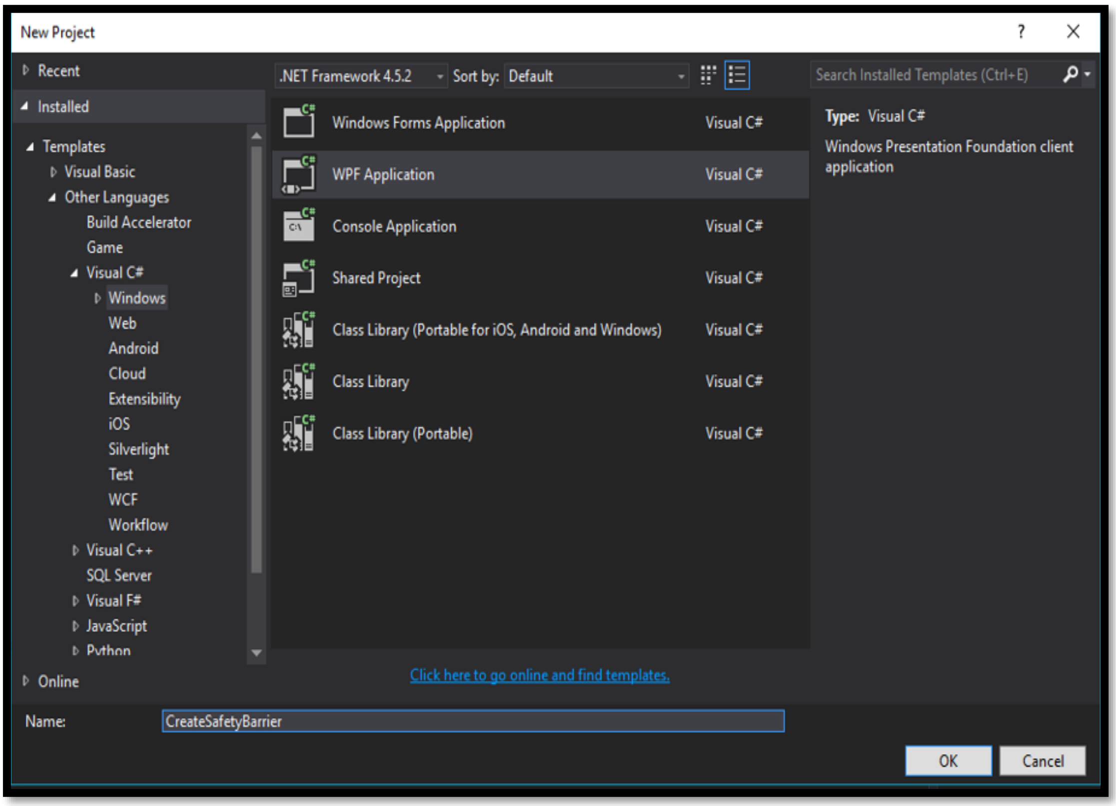

Figure 6: Set up of a new module to initiate the coding of a new command or programming function in Revit macros.

3. The other process is to save the modules into a new macro/commands file in the language that the Revit architecture uses. This could be C# or VB.Net, to name the most common (Kilkelly M. , 2016).
4. Coding or writing the newly created command is an important process. It is usually an automatic process that the programming language generates, especially in *VB.Net* (Kilkelly M. , 2016). This leads into a new text file that the user types into to give the code a human interface.
5. Building the new command in such a manner that it will be functional is the next essential step in the programming process. When the user clicks on the 'build' section in the coding interface, the program affirms the action (Kilkelly M. , 2016).
6. The new code is double-tested in the '*.Net'* framework for any erroneous entries. If there are such faults, it will show through a pop-up. If there are none, the program will be ready to run and then launch.

(Kilkelly M. , 2016)

7. Running the program and reformatting it are usually the end steps. This means that the new command will always be booting with the rest of Revit from then on. One can always launch it at will.

Final Script

```
<?xml version="1.0" encoding="utf-8"?>
<RevitAddIns>
 <AddIn Type="Command">
  <Assembly>CreateSafetyBarrier.dll</Assembly>
  <AddInId>b844a067-7c24-4f85-b570-4ac2ae3da552</AddInId>
  <FullClassName>CreateSafetyBarrier.RevitEntryPoint.ExternalCommand</FullClassName>
  <VendorId>GSN Studio</VendorId>
  <Text>Create Safety Barrier</Text>
  <VisibilityMode>AlwaysVisible</VisibilityMode>
  <Discipline>Any</Discipline>
  <LanguageType>Unknown</LanguageType>
 </AddIn>
    </RevitAddIns>
```

The following figures are the outcome of the script of this thesis which is creating a plug-in called “Create Safety Barrier” as shown in figure 8, and then you can see the implement or the outcomes in Figure 9.

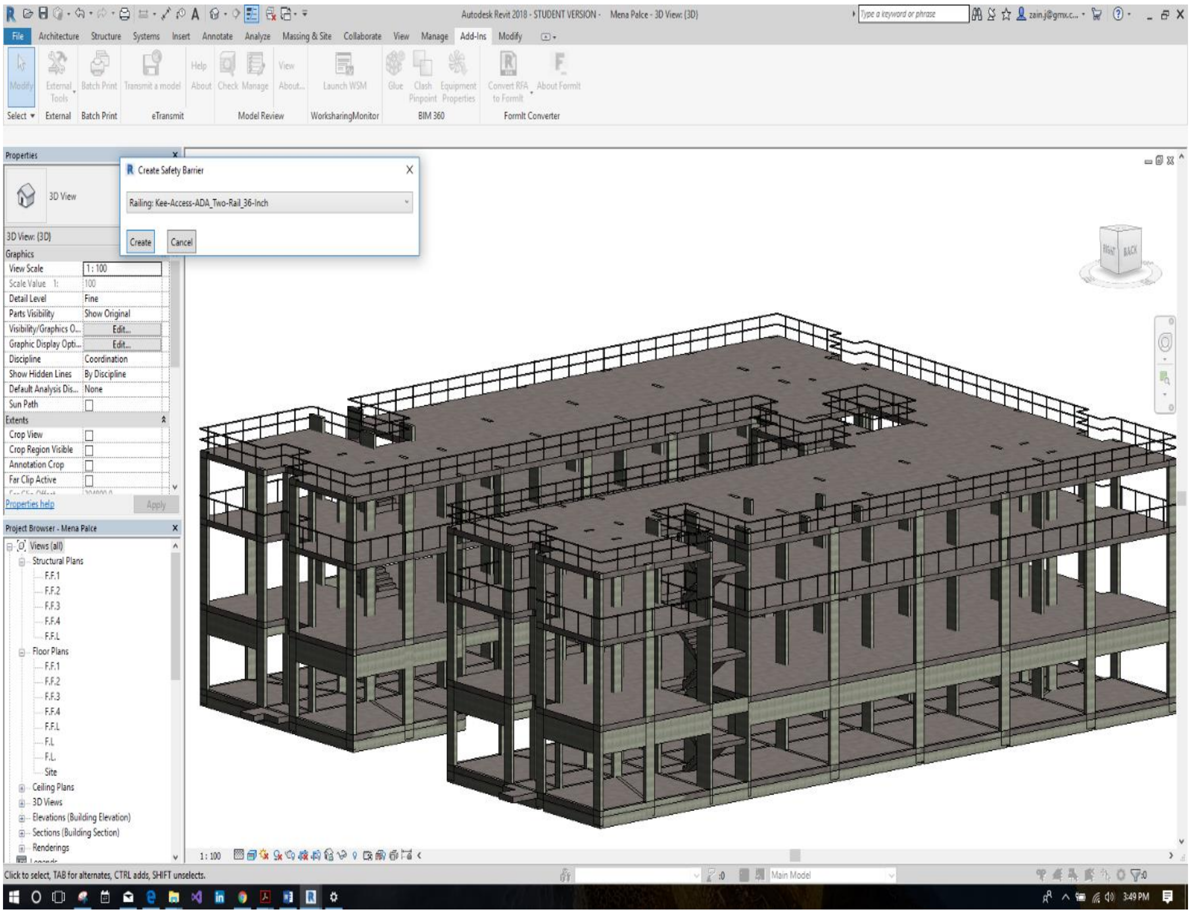

Figure 8: Final window after Add-in is created

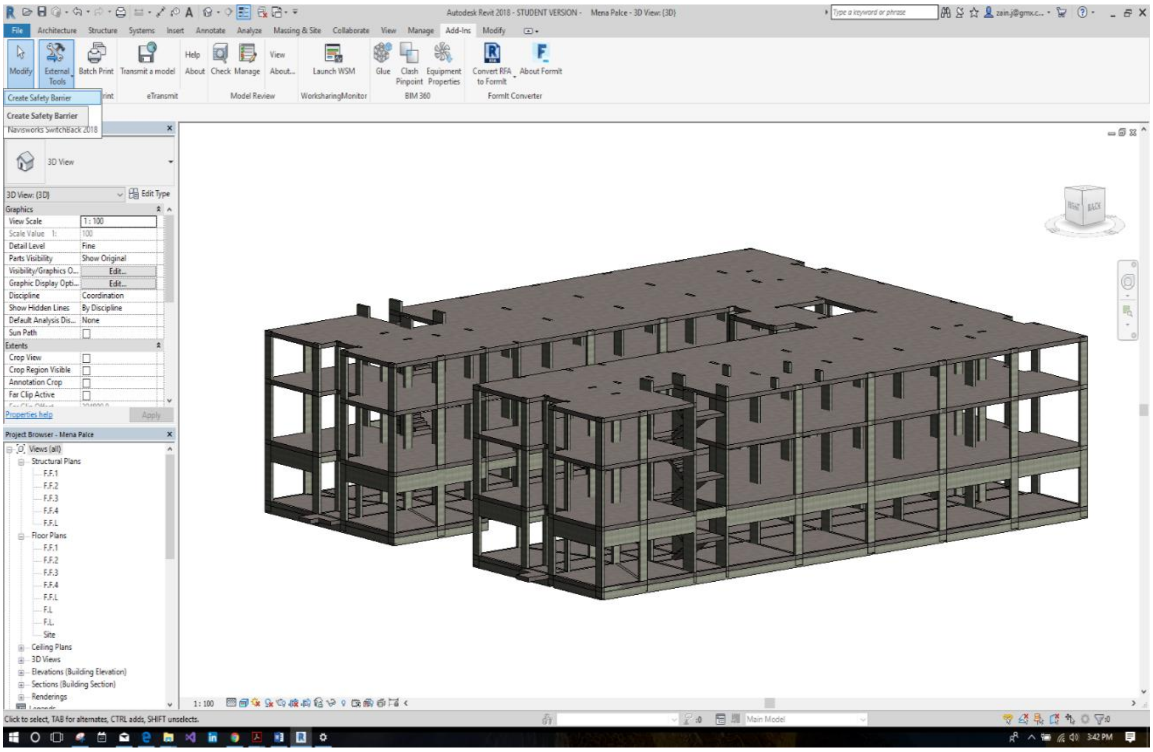

Figure 9: After choosing the safety rail as in the construction specs.

III. CONCLUSION

The high death rate from falls is avoidable through proper construction practices. Management of safety can be incorporated into BIM. Therefore, safety becomes an automatic part of the construction process monitoring. The result is that construction safety will improve which will save the lives of workers. An easy to use plug-in for Revit was created. This allows for 4D tracking of safety processes. This will result in lower fatalities on construction sites. It is also apparent that Revit and Level 3 BIM are the most suitable vendor software and technology classes for meeting energy efficiency, time-saving and coordination elements. While Revit helps to realize the programming part of a building even in 5D, Level 3 BIM creates an ecosystem of multiple-API and stakeholder collaboration for timely realization of building timelines (Ojo, Rahimian, Goulding, & Pye, 2015). In short, BIM is the one technology that can help train the crew and actualize the work plans of architects, civil engineers and developers in these post-CAD times (Rokooei, 2015).

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