FEASIBILITY ANALYSIS OF POST DISASTER RECONSTRUCTION ALTERNATIVES USING AUTOMATED BIM-BASED CONSTRUCTION COST ESTIMATION TOOL

Sharareh Kermanshachi[1,2]; and Behzad Rouhanizadeh[1]

[1] University of Texas at Arlington, USA

[2] Sharareh.kermanshachi@uta.edu

Abstract: Reconstruction of damaged or totally devastated constructions is an immediate action needed after occurrence of a disaster. Among various reconstruction alternatives, the one which is technically and economically justifiable is what the decision-makers inquire. To determine the economic viability of an alternative, the accuracy and quickness of the used techniques are very decisive. Since in a post-disaster situation acting quickly is the priority, the traditional manual cost estimation methods are not feasible. Based on the previous studies, there is a need for a tool to quickly and automatically calculate the construction cost of the proposed alternatives. This paper proposes an automatic cost estimation methodology and develops a Building Information Modeling (BIM) based decision-making tool to automatically obtain the construction cost of the different construction alternatives for post-disaster reconstruction. To develop this Application Programming Interface (API), C Sharp (C#) programming language was used and then it was added to Revit environment. In addition, the code was programmed to extract the needed data from RSMeans database. The difference between this code and other existing ones could be due to the high level cost estimations as it uses the quantity of elements rather than computing based on materials and/or detailed design. This tool can be used for decision-making for large number of projects within a very short time. This tool saves time required for evaluation of the feasibility and practicability of different construction options and is a useful decision support tool for decision-makers. Furthermore, by means of this tool, human-based errors will highly reduce and a more efficient and accurate cost estimation will be performed. By modeling the project geometry, the above-mentioned tool determines the number of each element, selects the unit cost for each element, computes the total cost for each element and calculates the final construction cost of the whole project. To verify the developed tool, a residential building case study was selected, and the cost of various design alternatives were estimated. To visually illustrate the application of the developed tool, this process is graphically explained and presented in detail. The main application of this BIM-based tool is when an area is drastically touched by a severe disaster and the constructed facilities are entirely demolished. Under this circumstance, quick rehabilitation of the affected areas is the priority action of corresponding decision makers. Therefore, implementing this prompt tool could assist policy-makers and authorities with immediate decisions and the tool acts as a decision support tool by providing more accurate economic insight to them.

1   INTRODUCTION

Disasters of any kind frequently occur all over the world leading to community-wide devastation. As countries develop constantly, the number of constructions increases causing the disasters to result in

more considerable economic losses. After a disaster happening, the policy-makers commonly desire to rehabilitate the affected areas in a short time, even better than before (Comfort, 2005). In this respect, the interest of researchers has increased in expediting post-disaster reconstructions in order to minimize the economic losses. To have an efficient management approach, the quick and accurate estimation of economic damages is necessary when facing a disaster. This approach assists to create confidence in correct evaluation of drastic situation.

Recently, the application of BIM has been universally raised in construction industry. BIM enables providing vital information of the elements of 3D visualization of a building for users. In this regard, cost estimation using BIM tool could bring advantages to the users due to the following reasons: 1) BIM based cost estimation allows the user to have access to the exact dimensions of the project. This capability not only eases the process but also reduces the wasted time. 2) BIM-based cost estimation allows the user to access the project material type. This feature, not only calculates the amount of required material fast but also it allows to reduce the material waste and shortages due to the human miscalculations. 3) BIM-based cost estimation allows the users to have access to the real time material and quantity update in case of the BIM model update. This capability allows the user to compare different building designs versus their total project cost. 4) BIM-based cost estimation helps decision-makers to provide fast initial construction cost estimation and have enough time to evaluate which project is economically the most efficient. Therefore, the overall goal of the present study is to develop a BIM-based cost estimation tool to facilitate swift evaluation of the feasibility of different reconstruction alternatives after disasters taking place. This tool addressed the following objectives to achieve the aim: (1) development of a code for counting/measuring the elements used in a construction project, and report these quantities to the user, (2) development of a code to accurately calculate the final project cost. Implementation of the developed tool will aid policy-makers to make a decision expeditiously, and consequently expedites the process of reconstruction of affected areas by natural disasters by reserving the accuracy.

2 LITERATURE REVIEW

Rapid-onset disasters such as hurricanes, earthquakes, and floods cause tremendous losses to human life and social property (Delaney and Shrader, 2000, Gall et al. 2011, Field et al. 2012, NCA 2014). Many studies have been conducted in examining natural disaster costs on social and economic systems (Barthel and Neumayer 2012, Simmons et al. 2013). In addition, several researchers made an effort to quantify the cost losses by different cost estimation techniques (Munich Re 2014, Swiss Re 2014). In this regard, the major challenges that estimators of post-disaster reconstructions face to decision making is unavailability of reliable data of affected areas (Samphaongoen, 2010). Moreover, as the affected communities are suffer due to loss of their shelters, the decision-makers need to evaluate various alternatives in a very short period of the time. However, this limitation could significantly impact the reliability of the estimated costs for potential reconstruction options and lead to either of over or under estimation of the selected alternative. Although allocation of more resources would overcome the cost overrun challenges associated with such complex environments (Safapour et al, 2017 and Safapour et al., 2018), yet, the negative reinforcing effect of inaccurate cost estimation on the actual project performance could not be neglected (Kermanshachi, 2016). In other words, inaccurate estimation of project cost could be one of the factors causing more cost overrun (Habibi et al., 2018).

Automating the process of construction cost estimation based on objective data is desirable not only for improving the efficiency, but also for removing the subjective questionable human factors as much as possible. However, the problem of cost estimation for post-disaster reconstruction is not amenable to traditional problem-solving approaches. The costs of construction materials, equipment, and labor depend on numerous factors, with no explicit mathematical model or rule for price prediction. Recently, neural networks have been used for learning and prediction problems with no explicit model such as securities price prediction (Hutchinson et al. 1994), system identification (Narendra and Parthasarathy 1990), engineering design (Hung and Adeli 1991), and image recognition (Adeli and Hung 1995). In this regard, many studies have developed tools to estimate and calculate project cost at the early stages

of its development and implemented to various types of residential and transportation projects (Kermanshachi et al, 2016a and 2016b).

Building Information Modelling (BIM) as an emerging process and technology has attracted many initiatives across the globe recently. BIM is a digital representation of the geometric and non-geometric data of a facility (National Institute of Building Sciences, 2007, Monteiro and Martins 2013). BIM is considered to benefit the architecture, engineering and construction (AEC) industry in terms of improving production efficiency in the design and construction processes through shared information and collaborative working amongst project participants (Ramaji et al, 2018). BIM also delivers buildings with better performance by taking into account various attributes including whole life cost and environmental issues as design develops (Eastman et. al, 2008, Yun and Kim 2013).

BIM was first proposed during the late eighties to early nineties (Eastman, 1992). Its impact on the AEC industry is immense (Stanford University Centre for Integrated Facility Engineering, 2007) although the adoption has been considerably slower than expected (Bernstein and Pittman, 2004). Recent surveys reveal that the industry adoption rate varies geographically (Golaszewska and Salamak, 2017). The Smart Market Report (2009) suggests that there is a strong growth of adoption rate from 28% in 2007 to 48% in 2009 in the US AEC community. A similar survey by building SMART Australasia also reveals high adoption rates amongst various stakeholders in Australia but the result was considered to be heavily biased and the actual adoption rates were recommended to be a lot lower by the experts (Allen Consulting Group, 2010). In a different survey by the National Building Specification (Hamil, 2010) looking at construction professionals in the UK, predominantly architects from small and medium-sized enterprises (SMEs), revealed that only 13% of the respondents are currently using BIM. Major potential barriers for adoption have been identified in the literature which includes the lack of standards; presence of skill gaps; hesitation to embrace technological changes within organizations; presence of externalities; ambiguity in data ownership and legal risks; and high investment cost (Azhar et al., 2008). Although it is evident that the adoption rate is increasing, many argue that only large-scale projects implement BIM and the use by SMEs remains limited (Arayici et. al, 2010). The situation is alarming as the majority of the AEC industry is made up of SMEs. For instance, 97% of the construction industry in the Europe have less than 20 employees and 93% have less than 10 (Schultmann and Sunke, 2007).

3   RESEARCH METHODOLOGY

To achieve the objectives of the present study, the following three-step methodology has been implemented. Figure 1 illustrated the research methodology process.
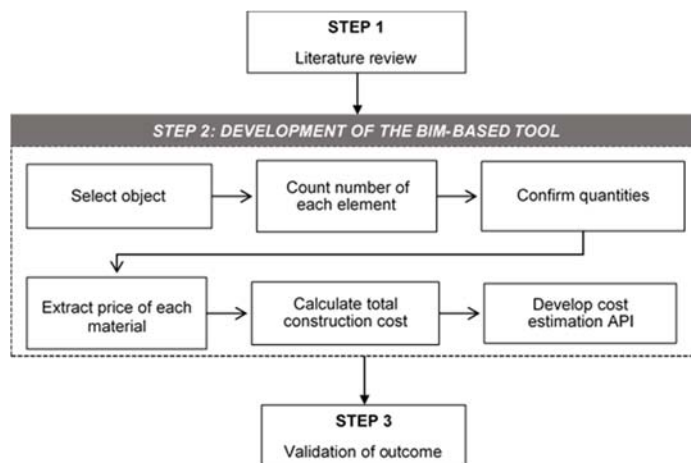

Figure 1. Research Methodology Process.

This study initially reviewed the existing literature to define the objectives of the present study. In this step, the BIM-based tool was developed. This tool consisted of several codes to achieve the aim of the

present study. First, the code was developed to allow user to select object/objects that are considered for cost estimation. The rectangle shape selection has been utilized in order to ease the selection process of numerous elements. The code was then developed to counts/measures the principal elements which have been used in the project. In this regard, code counts the number of windows, doors, columns and also measures how many square feet of wall, floor and roof have been used for the mentioned project. In order to inform the user how much material has been used in the project, the researchers generated the code to make a form. It also allows the user to press OK button and confirm the quantities, and in case there is a mistake, the user does not need to continue with the process. Then, developing the code to open a new Excel spreadsheet which not only shows the quantity of the project materials but also it demonstrates each element's price, was performed. In the next column, code multiplies each element by its cost and brings up the elements cost. In the last cell, code adds all the elements costs and comes up with the final project cost. Next, the code was developed that the final total construction cost estimate is shown as a message in the Revit environment. The purpose is to ease the process for the user and eliminate the need of the Excel sheet. Then, the code was developed to eliminate the need of loading the code for every single use. In this step, the authors have created a "Cost Estimation" button in order to ease the process of using the code. In the last step, the outcome obtained in the previous step was verified.

4   AUTOMATED BIM-BASED COST ESTIMATION CODE DEVELOPMENT

In the context of construction, cost estimation is regarded as an endeavor for determining the quantities of the elements of the project, and then calculating the corresponding cost of the whole work on the basis of the performed quantity takeoff. This section describes how the user could utilize the developed API for construction cost estimation and what product should be expected implementing the developed API tool. Figure 2(a) shows a schematic of a simple one-story building without the roofing. To start the quantification, first the objects should be selected. While using the tool, by selecting the elements, the number of utilized elements in the whole project will be counted/measured by the tool automatically. Figure 2(b) shows that when the user selects the objects, the code counts/measures the quantity of the utilized elements in the schematic. It is worth mentioning that based on the type of the selected object, the unit of measurement varies. For example, for area of the walls, the unit is sq. ft. whereas the number of the windows simply will be counted. Figure 3 shows a scratch of the C Sharp code generated for developing the above-mentioned tool.
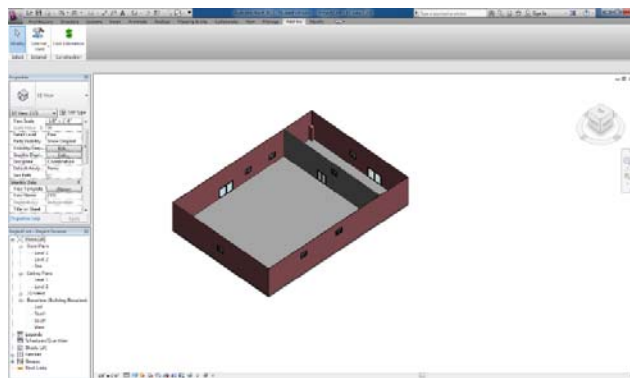
(a)
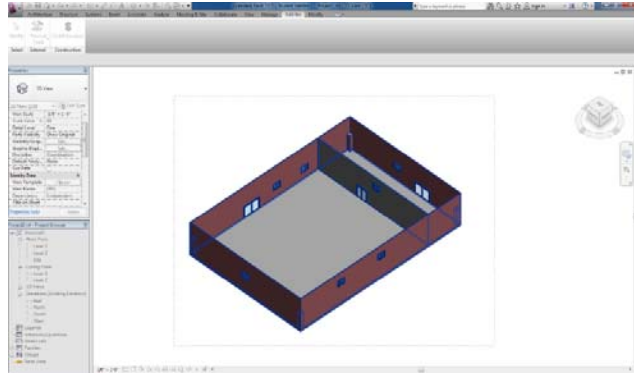
(b)

Figure 2. (a) Selection Process for BIM-based Construction Cost Estimation; (b) Highlighted Selected Objects for BIM-based Construction Cost Estimation.

```
1  using System;
2  usingSystem.Collections.Generic;
3  usingSystem.Text;
4  usingSystem.Windows.Forms;
5
6  // Revit libraries
7  usingAutodesk.Revit;
8  usingAutodesk.Revit.DB;
9  usingAutodesk.Revit.UI;
10 usingAutodesk.Revit.DB.Structure;
11 usingAutodesk.Revit.DB.Architecture;
12 usingAutodesk.Revit.Attributes;
13 usingAutodesk.Revit.UI.Selection;
14
15 //Excel Libraries
16 using Excel = Microsoft.Office.Interop.Excel;
17 usingSystem.Reflection;
18
19 namespace ClassLibrary5
20 {
21     [TransactionAttribute(TransactionMode.Manual)]
22     [RegenerationAttribute(RegenerationOption.Manual)]
23 publicclassCreateExcel : IExternalCommand
24     {
25 publicResult Execute(ExternalCommandDatacommandData, refstring message, ElementSet elements)
26         {
27 #region 1. Initialize, get the project
28
```

Figure 3. Part of the Generated C Sharp Code for Tool Development.

When the process of selecting the elements is performed, a form indicating the summary of the counted/measured elements will be shown on the screen. Figure 4 demonstrates the form which the user will see after the item selection process. This form, which is called Cost Estimation Form, shows the quantities of different items of the project. As demonstrated, the number of doors, windows, columns, as well as the area of the walls, floors, and the roof, which is zero here, are quantified by the tool and then shown on the form.
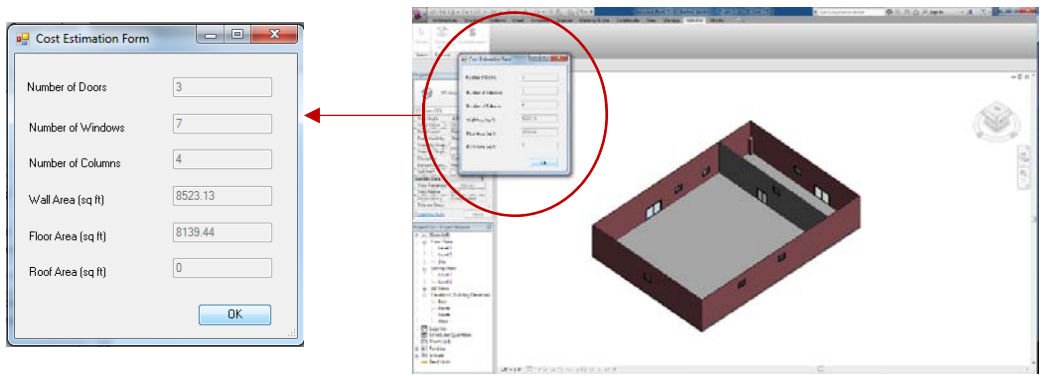
Figure 4. Cost Estimation Form for the Element Quantities.

The unit prices of each item have been stored in a spreadsheet in advance. By having the quantities, the tool calculates and saves the total cost for each element as well as the total project cost in an Excel worksheet. Figure 5(a) shows the new Excel spreadsheet which is opened for each construction cost estimation. Obviously, the unit price of each item is adjustable based on the new market prices.

Figure 5(b) illustrates the final message that will be shown in the Revit environment which showing the total project cost. This message is shown to enable the user to access the final estimated cost without opening the Excel spreadsheet.
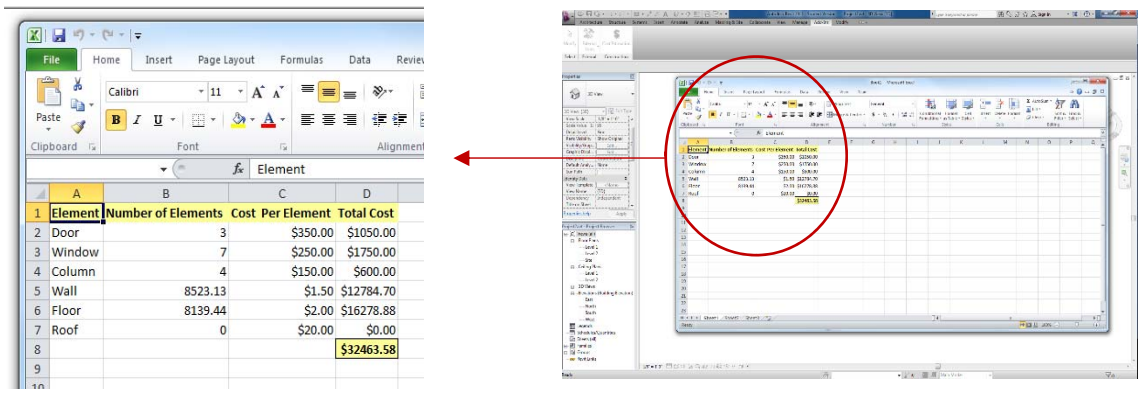
(a)
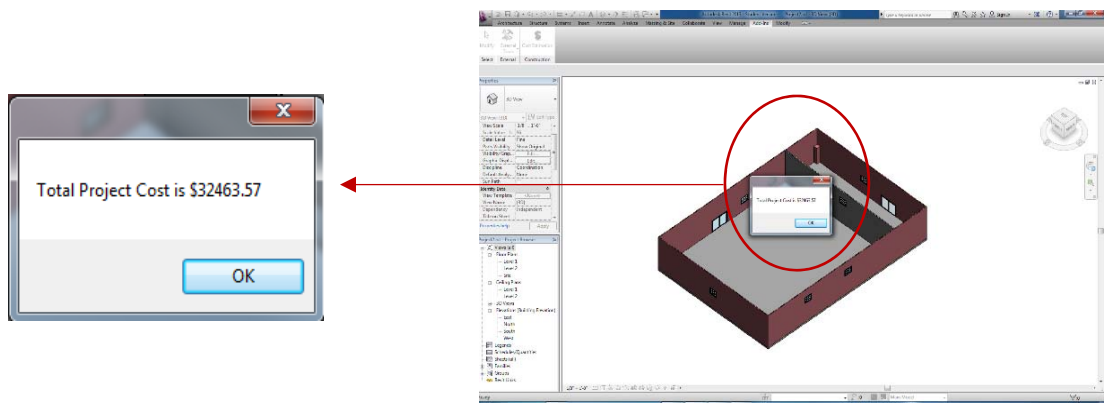
(b)

Figure 5. (a) Excel Spreadsheet for Cost Estimation; (b) Revit's Final Message for the Total Construction Cost Estimation.

In Figure 6 the created Cost Estimation button added to the ribbon of BIM is shown. By means of this button which is added to BIM as an add-on, the user can directly make use of this tool by clicking on that without running the generated code directly from a compiler. This feature was added to BIM to make the tool more user friendly.
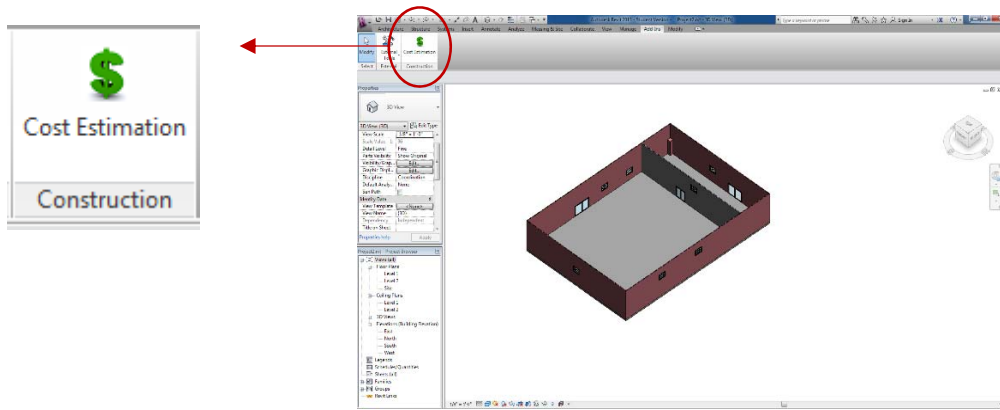

Figure 6. Development of Cost Estimation Button in Revit Environment.

5   IMPLEMENTATION AND DISCUSSION-CASE STUDY ANALYSIS

The implemented API tool, like any other computer-based model, needs to be verified to ascertain the credibility of the model. While the project referenced in the previous section did not have roofing and the roof's area was assumed as zero, in this section the accuracy of the code was tested by adding the roofing on top of the previous project. Figure 7 shows the schematic of the project for the mentioned purpose.
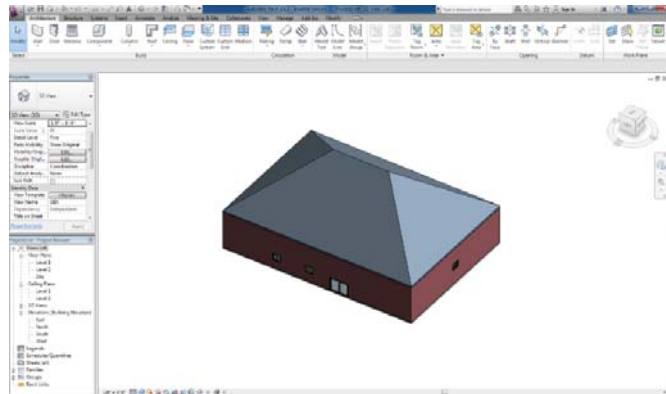

Figure 7. Schematic of the Defined Construction for the Verification of the API Code.

By implementing the tool for the aforementioned project, takeoff was performed automatically and the results shown on Cost Estimation Form. Figure 8(a) shows the form on which the project quantities were demonstrated. As revealed in this figure, the area of the roof has been calculated as well as other elements' quantities. Comparing the acquired quantities with the ones obtained by Revit, the values are correctly extracted by the tool. Table 1 shows the calculated quantities by the API tool and Revit.

Table 1. Comparison of the obtained quantities by API tool and Revit.

Measuring tool	Number of doors	Number of windows	Number of columns	Wall area (sq-ft)	Floor area (sq-ft)	Roof area (sq-ft)
API tool	3	7	4	8523.13	8139.44	10174.31
Revit	3	7	4	8523.13	8139.44	10174.31

Then, each element's cost was calculated by the tool using the unit prices prepared in the Excel database provided beforehand. Figure 8(b) shows the model's cost estimation output interface form which displays the calculated total cost of the project. Comparing the obtained cost for the project with the roofing with the one calculated for the project without it, shows that adding the roofing has significantly increased the construction cost. Table 2(a) demonstrates the calculated costs for each item as well as the total cost of the project. The main difference between this model's procedure for cost estimation and the one of Revit is that this model is developed to be applied to support post-disaster immediate decision-making in a simpler and quicker manner comparing with Revit.

Table 2. Total Project Cost calculation for

Element	Quantity	Unit cost ($)	Total cost ($)
Door	3	350.00	1050.00
Window	7	250.00	1750.00
Column	4	150.00	600.00
Wall (sq-ft)	8523.13	1.50	12784.70
Floor (sq-ft)	8139.44	2.00	16278.88
Roof (sq-ft)	10174.3	20.00	203486.20
	Total cost		235949.78

Element	Quantity	Unit cost ($)	Total cost ($)
Door	3	400.00	1200.00
Window	7	300.00	2100.00
Column	4	150.00	600.00
Wall (sq-ft)	8523.13	1.50	12784.70
Floor (sq-ft)	8139.44	2.00	16278.88
Roof (sq-ft)	10174.3	15.00	152614.65
	Total cost		185578.23

Alternative 1 (Left); and Total Project Cost calculation for Alternative 2 (Right)

To verify the cost estimation process, the unit price of a door, a window and one sq. ft. of the roof were changed and then the tool was reapplied. As it is shown in Figure 8(c), the total project cost has changed accordingly. The calculated results after unit price changes are shown in Table 2(b). The total cost in the first case was $ 235,949.78 and in the second case changed to $ 185,578.23. Manual calculations show that the amount of change in the total price of each item as well as the total price of the entire project were computed by the API tool. Therefore, it can be concluded that the tool correctly reflected the changes made on item unit prices.
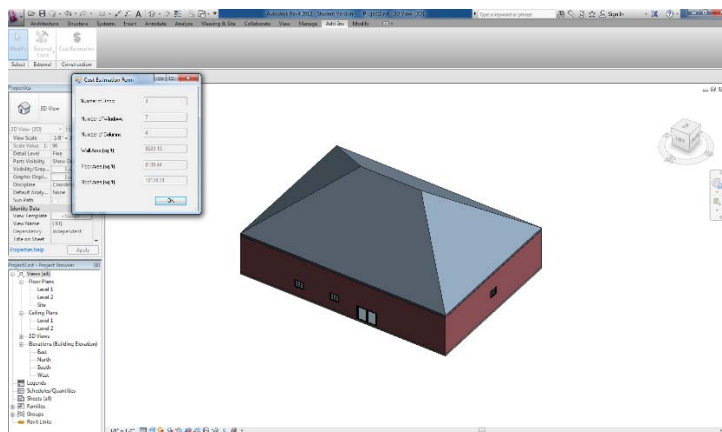
(a)
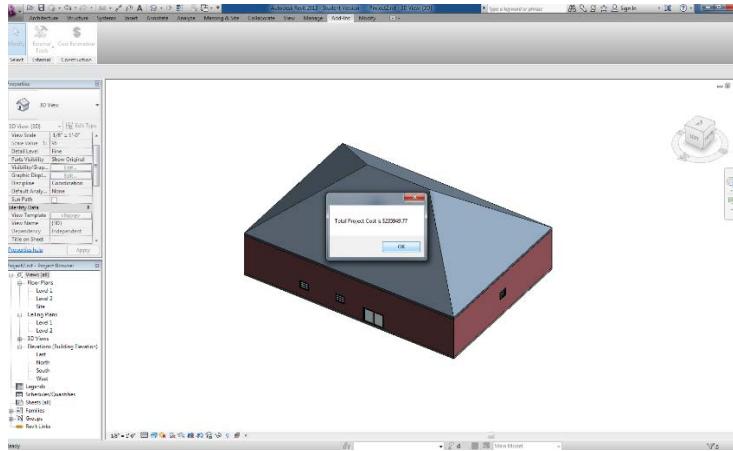
(b)
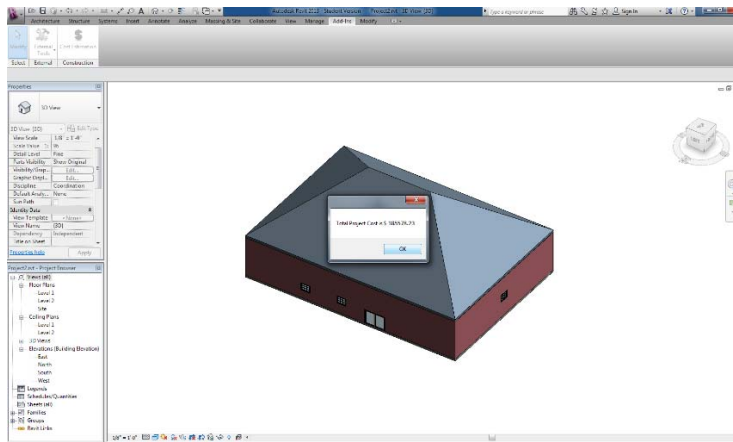
(c)

Figure 8. (a) Test of the code for the roof area; (b) Total cost for the new project (roof is added); (c) Total cost for the new project (number of doors, windows and columns are changed).

6   CONCLUSION

An API tool was developed to evaluate various alternatives for post-disaster reconstruction. Timely and accurate feedback of actual total cost of reconstruction options for post-disaster decision-makers was the main aim of this paper. The developed tool in this study makes an intuitive means to rapidly and precisely estimate the reconstruction cost of alternative construction suggestions in post-disaster situations. A simplified construction was selected to assess feasibility of this tool. The results revealed that, implementing the BIM-based cost estimation tool can assist the decision-makers to efficiently and effectively calculate the total cost of each project and select the most adequate proposed option for reconstruction purpose in the shortest possible time. As a matter of fact, this tool saves money by enabling the user comparing the ultimate project cost of all proposed alternatives by different suppliers. Moreover, using this application leads to eliminating the human-based errors associated with performing the takeoff and cost estimation.

This study's focus was on the construction's which were entirely devastated, but in many cases the constructions are partially damaged. In such cases, the decision-makers need to know associated costs

for damages. Thus, it is recommended to advance this code to estimate the reconstruction cost of facilities which are partially damaged. Moreover, this application could be enhanced by allowing the user to provide his/her input for cost of each material. By this method, daily variation in the cost of some materials does not impede the cost estimation process. This code could also be enhanced if it could be connected to online databases for material costs.

References

Adeli, H., and Hung, S. L. (1995). Machine learning-neural networks, genetic algorithms, and fuzzy systems. *John Wiley & Sons, Inc.*, New York, N.Y.

Allen Consulting Group. (2010). Productivity in the buildings network: assessing the impacts of building information models, *Report to the Built Environment Innovation and Industry Council*.

Arayici, Y., Coates, P., Koskela, L., Kagioglou, M., Usher, C. and O'Reilly, K. (2010). Technology adoption in the BIM implementation for lean architectural practice, *Automation in Construction*.

Azhar, S., Hein, M. and Sketo, B. (2008). Building information modeling (BIM): benefits, risks and challenges, *Proceedings of the 44th ASC Annual Conference*, Auburn, Alabama, 627–634.

Barthel, F., Neumayer, E. (2012). The economics of natural disasters: a survey. IDB working paper series IDB-WP-124, 55.

Bernstein, P.G. and Pittman, J.H. (2004). Barriers to the Adoption of Building Information Modeling in the Building Industry, *Autodesk Building Solutions*, San Rafael, CA.

Comfort, L. (2005). Risk, security, and disaster management. Ann. Rev. Polit. Sci., 8, 335-356.

Delaney, P, Shrader, E. (2000). Gender and post-disaster reconstruction: the case of hurricane Mitch in Honduras and Nicaragua. Draft Report. World Bank, 58.

Eastman, C. (1992). Modeling of buildings: evolution and concepts, *Automation in Construction*, **1**(2) 99–109.

Eastman, C., Teicholz, P., Sacks, R., and Liston, K. (2008). BIM handbook: A guide to building information modeling for owners, managers, designers, engineers and contractors, Wiley, New York.

Field, C. B., Barros, V., Stocker, T. F. (2012). Managing the risks of extreme events and disasters to advance climate change adaption. Cambridge University Press, Cambridge.

Golaszewska, M., Salamak, M. (2017). Challenges in takeoffs and cost estimating in the BIM technology, based on the example of a road bridge model. *Technical Transactions*, 4, 71-79.

Gall, M., Borden, K.A., Emrich CT, Cutter SL. (2011). The unsustainable trend of natural hazard losses in the United States. *Sustainability*, 3, 2157-2181.

Habibi, M., Kermanshachi, S., and Safapour, E. (2018). "Engineering, Procurement and Construction Cost and Schedule Performance Leading Indicators: State-of-the-Art Review," Proceedings of ASCE Construction Research Congress, New Orleans, Louisiana, April 2-4, 2018.

Hamil, S. (2010). What BIM is and How It is Being Used, CIBSE BIM: who benefits? *Conference presentation*.

Hutchinson, J. M., Lo, A., and Poggio, T. (1994). A nonparametric approach to pricing and hedging derivative securities via learning networks. *MIT A.I. Memo No. 147*, Cambridge, Mass.

Hung, S. L., and Adeli, H. (1991). A model of perception learning with a hidden layer for engineering design. *Neuro computing,* **3**(1), 3-14.

Kermanshachi, Sharareh (2016). Decision Making and Uncertainty Analysis in Success of Construction Projects. Doctoral dissertation, Texas A & M University. http : / /hdl .handle .net /1969 .1 /158020.

Kermanshachi, S., Beaty, C. and Anderson, S.D., (2016). Improving Early Phase Cost Estimation and Risk Assessment: A Department of Transportation Case Study. In Transportation Research Board 95th Annual Meeting, No. 16-2202.

Kermanshachi, S., Yue Z., Anderson D., Schexnayder C., and Molenaar K. (2016), "Cost Estimating Tool for Early Estimates for Rural and Small Urban Transit Facilities." In Transportation Research Board 95th Annual Meeting, No. 16-1657.

Monteiro, A., Martins, P. (2013). A survey on modeling guidelines for quantity takeoff-oriented BIM-based design. Autom. Constr., 35, 238-253.

McGraw Hill Construction. (2009). Interoperability in the Construction Industry. Smart Market Report, *the Business Value of BIM.*

Munich Re. (2014). Severe weather in North America, perils, risks, insurance. Munich Re Group, p 274.

Narendra, K. S., and Parthasarathy, K. (1990). Identification and control of dynamical system using neural networks. *IEEE Trans. on Neural Networks,* 1, 4-27.

National Institute of Building Sciences. (2007). United States National Building Information Modeling Standard *Version 1 - Part 1: Overview, Principles, and Methodologies, Final Report*, December 2007.

NCA. (2014). Billion-dollar weather and climate disasters.

Ramaji, I., Richardson, N., Mostavi, E., and Kermanshachi, S. (2018), "Investigation of Leveraging BIM Information Exchange Standards for Conducting LOD-Based Cost Estimating," Proceedings of Construction Research Congress, New Orleans, Louisiana, April 2-4, 2018.

Safapour, E., Kermanshachi, S., Habibi, M., and Shane, J., (2018), "Resource-Based Exploratory Analysis of Project Complexity Impact on Phase-Based Cost Performance Behavior," Proceedings of Construction Research Congress, New Orleans, Louisiana, April 2-4, 2018.

Safapour, E., Kermanshachi, S., Shane, J. and Anderson, S. (2017), "Exploring and Assessing the Utilization of Best Practices for Achieving Excellence in Construction Projects," proceedings of the 6th CSCE International Construction Specialty Conference, Vancouver, Canada May 31-June 3.

Samphaongoen, P. (2010). A Visual Approach to Construction Cost Estimating. Master's Theses. Paper 28.

Schultmann, F. and Sunke, N. (2007). Study on the Future Opportunities and Challenges of EU-China Trade and Investment Relations, *Study 9: Construction, European Commission Trade.*

Simmons, K., Sutter, D., Pielke, R. (2013). Normalized Tornado damage in the United States, 1950-2010. *Environ Hazards*, 12, 132-147.

Stanford University Centre for Integrated Facility Engineering. (2007). Specific Report Needed. *Center for Integrated Engineering*, CIFE Technical Reports.

Swiss Re. (2014). Sigma-natural catastrophes and man-made disasters in 2014. Zurich, Switzerland.

Yun, S., Kim, S. (2013). Basic Research on BIM-Based Quantity Take-off Guidelines. *Architectural Research.* **15**(2), 103-109.