ASSESSING THE POTENTIAL OF DEVELOPING A TOOL FOR RESIDENTIAL FACILITY MANAGEMENT USING BUILDING INFORMATION MODELING SOFTWARE

A Thesis

by

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Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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December 2012

Major Subject: Architecture

ABSTRACT

Building Information Modeling (BIM) has changed the ways buildings are designed and constructed. Along with design and construction, operation and maintenance of the built facility is also gaining importance in the Architecture-Engineering-Construction industry. Facility management (FM) is widely adopted by industrial, healthcare and other types of commercial facilities for better maintenance and management of assets. BIM is being adopted in the field of Facility management and has become one of the most important tools for better application of operation and maintenance.

Facility management is performed by professionals with training and experience in the related fields of building operation, maintenance, upgrade and repair. BIM is a professional tool which requires intense training and knowledge. This tool cannot be used and is hard to understand for non-professionals and people who do not have training to use it. Management of residences is as important as management of commercial, industrial and healthcare facilities for the life and smooth running of such facilities. Residential facilities are properties with one or more residential units or buildings. These buildings could be low rise, high rise or individual units.

This thesis will help in analyzing the scope of using BIM and Application Programming Interface (API) for management of maintenance in residences by the owner who are not professionally trained. The research analyzes a single, basic function of a BIM tool to

determine the potential for such a tool to help non-expert, first time user to be able to understand their residential facilities maintenance requirements. It is an attempt to propose a system which provides alerts to the owners regarding required maintenance and which shows the location of the work in a 3D model.

The system was designed and tested in Microsoft Windows 7 operating system by using Autodesk® Revit building information software to make the 3D model, a Revit API plug-in to craft the alerts and show the location of work and Open Database Connectivity (ODBC) to export the model to a web browser. The system worked through Revit program, but the concept of applying the system to work through web browser failed.

DEDICATION

I dedicate this thesis to my parents, mentor and my professors.

ACKNOWLEDGEMENTS

First of all, I would like to thank my committee chair, Dr. Stephen Caffey for always motivating and guiding me during the entire period of my research work. I am also thankful to my committee members Dr. Wei Yan and Dr. Sarel Lavy for always being there to relieve my doubts and also for giving their precious time whenever I needed.

I am indebted to Sandeep Kota, Rajanesh Kakumani and Darshana Kanani for going out of their way to help me in my research work. And I am thankful to all my friends at Texas A&M University.

I am grateful to GOD for always being there with me and giving me the strength to work harder after every problem that I faced. And most of all I would like to thank my family members who always stood by me and inspired me in every little step I took.

And last but not the least; I would like to thank Texas A&M University for giving me this opportunity.

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1. INTRODUCTION

The concept of Facility management (FM) is expanding and has become an important part of the construction and maintenance industries worldwide as globalization's impact on business and on the growth of related professionals and organizations increases. Today Facility management as a profession is much more accepted and recognized than in 1999 (David G. Cotts, Kathy O. Roper, and Richard P. Payant, 2010). Facility management, defined as a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process, and technology, allows stakeholders to secure an important part of the design, construction and maintenance process due to various advantages like cost savings, increasing the life and quality of a facilities and simplifying methods of maintaining facilities (David G. Cotts, Kathy O. Roper, and Richard P. Payant, 2010). Commercial, public, industrial and healthcare facilities have so far been the focus of Facility management as they have high energy use and deal with mixed functions. Facility management is also required in residential structures.

Though it is not as well established as in industrial, public, commercial and healthcare facilities, Facility management as a practice has important applications in the residential sector. There is no universally accepted definition for Facility management in the residential sector, as this term is relatively new to the construction industry itself.

Housing and property management are the terms used in management of residential sector. Facility management consists of planning, acquisition, operations and maintenance and disposition stages (David G. Cotts, Kathy O. Roper, and Richard P. Payant, 2010).

Residential buildings, like any other building, need to be maintained and managed. For the purposes of this thesis, residential architecture is defined as "Properties developed only for residential purposes irrespective of the type of housing i.e., single family, multi family, apartments and condos." There is no data available on how professionals and laypeople in the residential sector perform Facility management. Use of computer-based management and maintenance technique is common in Facility management, but there is only limited use in the residential sector. There is no data available which would demonstrate whether the influence of computerized maintenance management systems (CMMS), BIM, or any related technology has spread to residential Facility management.

A major set of activities during the operation of a facility relate to maintenance and repair. Currently most of maintenance work is reactive and excessive expenses often occur when reactive maintenance and repairs are performed (Mobley 2008; Franklin 2008; Sullivan et al. 2002). This practice is not always efficient, since reactive maintenance can cost three to four times more than the same repair activity if it were to be performed as planned maintenance (Mobley 2008; Sullivan et al. 2002). Therefore there is a need within residential FM for supporting more planned maintenance work. Reducing the number of reactive maintenance activities requires effective planning strategies to identify proactive maintenance activities. Visualizing maintenance activities within a BIM context helps in identifying spatial trends for each type of repair activity and spatial relationships between different types of activities (Akcamete, A., Akinci, B., and Garrett, H. J. Jr. 2010).

One important trend that has implications for residential Facility management is the fact that BIM is changing the way buildings are designed and constructed. The Autodesk Whitepaper, 2008 focuses on ways that facility managers and FM applications can take advantage of the consistent, coordinated building information that comes from a BIM design process. There are various possible solutions which can be provided and worked on to simplify management of residential facilities. BIM has been used in the design phase as well as for construction management and coordination. There are various methods developed to make construction processes easier, faster and more economical by using a computer- based BIM tool with various plug-ins, such as integrating Application Programming Interface (API), Structured Query Language (SQL), Microsoft Access database management software, wireless sensor networks (WSN), and web-based interaction. Integrating BIM into a serious gaming platform is one of the methods researched to educate safety training in construction industry and also for architectural visualization. Games capture user attention and prompt a desire to win. In serious games, winning requires learning how to achieve points. Games reward correct actions in virtual situations with points, extra life, or other positive feedback measures. This motivates game players to learn if the games are designed to require and facilitate learning. Design education and building operation both benefits from the educational potential of games (Nidhi Jain, 2010; Wei Yan, Charles Culp, and Robert Graf, 2011). BIM has also started to draw interest from the FM industry and better solutions are being developed to use BIM for managing facilities. Integrating a BIM tool with API holds the potential to improve and simplify Facility management of residences by owners who are not professionally trained or licensed and who have little or no knowledge of management and maintenance. A BIM tool for FM would allow residents and owners to visually identify the FM task and its location and schedule the necessary action to address the issue.

This thesis focuses on integrating BIM with API and RDB Link to propose solutions which would improve residential Facility management by modeling a user-friendly BIM-based maintenance tool for owners with no background in architecture, engineering and/or construction (AEC). The research proposes an interactive BIM-based solution using Revit Plug-ins which would be designed for managing and providing timely alerts to users for scheduled, proactive and (when necessary) reactive maintenance work. Globally, use of smart phones and various applications for home and office security has amplified. With increase in use of smart phones and applications by owners, such a tool would be viable across all housing type. Thus this research would contribute in providing a method to manage and maintain residential facilities by integrating RDB Link and API with BIM tool.

2. MOTIVATION

CMMS has also proven to be an important tool in automating maintenance and management work but at the same time it is expensive and needs professional training to use. With growing importance of Facility management in the residential sector it becomes important to provide solution based on CMMS technology which is simpler and has utilizes visualization for better management. This research translates some of the most basic concepts of CMMS into a tool intended for use by occupants and owners with no training in AEC industries. Introducing a simple management solution using the BIM tool integrated with an API and RDB LINK application demonstrates the potential for development and influence in the use of BIM in Facility management in the residential sector.

This tool would not only help improve management of facilities by using BIM-based API to send timely alerts to the owners but also provides a visualization component to help the user locate the position and highlight the component which requires maintenance.

3. OBJECTIVES

Main purpose of this thesis is to investigate the potential of Building Information Modeling in developing a system for management of maintenance work in residences. In this research project BIM tool will be used in combination with web application and API to produce a system which provides maintenance alerts to the owner or occupant of a residence using a 3D model produced in Revit and displayed on a Smartphone or computer screen. The prototype of this app is designed for preventive and predictive maintenance but not reactive maintenance. The purpose of developing this system is that the users who do not have professional training in handling BIM or FM is able to identify issues and participate in maintenance of their facilities.

4. LITERATURE REVIEW

4.1 Facility management

The basic definition of Facility management given by International Facility management Association (IFMA) is: “Facility management is a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, place, process and technology.”

For the purposes of this thesis Facility management (FM) will be defined as a profession that encompasses multiple disciplines to ensure functionality of the built environment by integrating people, places, processes and technologies (David G. Cotts, Kathy O. Roper, and Richard P. Payant, 2010). Demand for Facility management has increased to a considerable amount in the construction industry as the researchers, investors and designers realize its importance. Facility management not only helps in easing the maintenance of physical structures but also improves durability and tends to help save money over a period of time. Past and current research on Facility management focuses primarily on improving business, making operation and maintenance easy, creating long-term savings, etc. However there is no known published research which directly deals with the current research topic.

Research on the residential sector in eastern and central Europe investigates the need for improvement in Facility management for the residential sector and has provided strategies through which to do so. Otherwise, there is limited published research on Facility management in the residential sector, in some cases termed "housing" or "property" management. With Facility management becoming a more widely used term in most of the construction industry, its presence in and relevance to the residential sector has also increased. Although Facility management for the residential sector may not be used at the same level as in commercial or industrial facilities, analyses have proven its importance to improving the lifespan of residences and enormous cost savings and control by limiting unnecessary waste. These analyses show the systematic procedures followed in implementation of Facility management and scope of improvement and introduction to advanced technologies (Roode Liias, 1998).

According to recent studies the use of BIM in the operations phase, in addition to other commercially available technologies has enabled FM professionals to focus on transferring information from the design and construction phases to the operations phase. Some of the commercial systems provide automated transfer of such information from BIM to CMMS and/or CAFM through .dwf file format (Hyo-Kyung An, Lee, Seul-Ki, and Jung-Ho Yu, 2012). But the focus in such instances is limited to automated transfer of space and asset data with an emphasis on gathering information of manufacturer and maintenance schedule. Currently available Facilities management systems do not benefit from the 3D visualization capabilities that BIM can provide (A Akcamete, B Akinci, J H Garrett, Jr, 2010).

4.2 Maintenance

Building maintenance is defined as “work undertaken in order to keep, restore or improve every part of a building, its services and surrounds, to a currently accepted standard, and to sustain the utility and value of the building” (Seeley, 1987). The systematic format provided in David G. Cotts, Kathy O. Roper, and Richard P. Payant, 2010 on operation and maintenance (O&M) stage of Facility management, proves the importance of FM in the O&M stage of any project. The O&M stage deals with the entire life span of a building. It also states that applying Facility management in this stage would help increase the life of the facility, provide systematic maintenance of utilities and operating systems and intern cause a lot of savings. David G. Cotts, Edmond P. Rondeau, 2004 state that proper implementation of Facility management in the O&M stage would help the facility better control revenue and would prove to be a sound investment for the owner. Although Facility management focuses on improvement and management of these facilities for business and maintenance efficiency, Kwang Jun Lee, 2006 shows that residential property developers and stakeholders are also exploring Facility management and implementation of advanced technology for improving maintenance.

4.3 Software

BIM has proven to be successful in the design and construction phases by confirming benefits such as cost estimating accurately within 3%, reducing time taken to generate cost estimates by 80%, eliminating unbudgeted changes by 40% and reducing total project completion time by 7% (Azhar, Hein, and Sketo, 2008., p. 3). Building Information Modeling has also begun to capture widespread attention in the AEC industry. BIM represents the development and use of computer-generated n-dimensional (n-D) models to simulate the planning, design, construction and operation of a facility (Azhar, Hein and Sketo, 2008).

BIM helps architects, engineers and constructors to visualize what is to be built in a simulated environment and to identify potential design, construction or operational problems. One of the emerging methods of managing facilities is the use of BIM technologies in various ways. Many large scale projects use BIM tools during the design and construction phases and continue using it for Facility management. Progress of BIM in construction industry has been an observable fact in various, attributed in large part to the use of diverse methods and plug-ins. Malatras et al. (2008) found that BIM serves as a central point for all building related information to facilitate the successful use of web enabled WSN (wireless sensor networks) for Facility management.

There are benefits of using web-based approaches to transfer architectural information to construction site by a process of converting BIM objects to XML files (Ibrahim et al., 2004). For example, a case study of the Hilton Aquarium project in Atlanta illustrates the cost and time saved by developing and using BIM (Azhar et al., 2008). A growing number of comparable case studies have shown the benefits of using BIM technology for building models. In the construction industry, the current trend is toward applying BIM in order to efficiently integrate and manage engineering information.

Building models and BIM technology are set to become the standard method and technology for architectural construction, engineering and maintenance information representation in the foreseeable future (Eastman et al., 2008; Chuang et al., 2011). Beyond being a drawing and documentation tool, BIM offers a platform for enhanced interdisciplinary collaboration, the capability to manage change, and the ability to extend information support throughout the building lifecycle. The FM Exemplar Project has established that BIM is an appropriate and beneficial technology enabling storage and retrieval of integrated building, maintenance and management data for the Sydney Opera House (Sabol, 2008).

BIM integrated with gaming has proved to be a simple means through which to provide safety training in the construction industry (Nidhi Jain, 2010). BIM integrated with gaming has also proved to be useful for design and visualization by integrating object-oriented programming (OOP) in game and parametric modeling in BIM (Wei Yan, Charles Culp, and Robert Graf, 2008). The information and data available from these sources would help in providing models from which to derive a residential Facility management solution using a BIM tool integrated with API AND RDB LINK to simplify management of residential facilities by owners and tenants.

According to Boznos (1998) “The primary uses of CMMS appear to be as a storehouse for equipment information, as well as a planned maintenance and a work maintenance planning tool”. CMMS packages are able to provide management with reports and statistics, detailing performance in key areas and highlighting problematic issues (Ashraf W. Labib, 2004). CMMS can manage all requirements within the area of maintenance management for buildings with commercial and industrial functions. Additionally, computerized networks can transmit that information immediately anywhere in the world based on real-time need. This level of technology has been accompanied by the creation, at times integral to the CMMS, of a vast array of specialist systems to manage reliability- and condition-based information. The current state of CMMS technology is at a very advanced level, in many cases far more so than users are able to apply it. This tool has very strong and provable results, yet there are a great number of projects involving CMMS systems that end in failure and in cost and time overruns (Daryl Mather, 2003).

5. METHODOLOGY

Simulation and Modeling Research (SMR) is the methodology used in this research. The project consists of modeling a room and creating a time simulation for a system which manages the maintenance of the modeled facility. The system in its current state functions for Preventive Maintenance, and Predictive Maintenance, but not for reactive maintenance. Preventive maintenance is maintenance performed before fault occurs irrespective of it occurring. Predictive maintenance is maintenance performed only when it is certain that a fault will occur. Reactive maintenance is maintenance performed only after the fault causes failure.

The procedure begins with using Autodesk® Revit as a BIM tool to model a room which consists or four walls, a floor, a ceiling, a door and two windows. This room is the experimental model to test the tool. The room is 40’ x 20’ with 8 windows, 1 door and a partition wall dividing the space into two rooms. This type of model could be a part of a building or a discrete structure.

1. Simulation of system working as preventive and predictive maintenance tool.

For the purpose of this research, only three components are assigned with a time parameter, which in this portion of the analysis represents the time of maintenance. Walls are assigned a time parameter of 10 years and the doors and windows are assigned a time parameter of 5 years. To test the result, 5 years is equal to 5 seconds and 10 years is equal to 10 seconds. An API plug-in to Revit is used to create pop-up messages which appear on computer screen when the system reaches time of maintenance. The entire system is designed in Microsoft Windows 7 computer operating system and Microsoft Internet Explorer web browser is used to link the Revit model via the internet. Along with this, the Revit model is also linked to a webpage where the 3D model is displayed. This pop-up message offers the user the ability to see the element that requires attention and repair. Once the problem is attended, the user can click “ok” button to reset the clock and the alert pops-up again when the timer reaches its limit. This process of alerts popping up and clock resetting is repeated.

Although this prototype system is not capable to work as reactive maintenance tool, an idea is proposed and described. At its current state, the system is not tested to work as a reactive maintenance tool. For the system to work as a Reactive Maintenance tool, the model is designed to be capable of live updating itself.

2. Describing the working of the system as Reactive Maintenance tool.

For the system to work as reactive maintenance tool, it is considered that the building is a smart building which is synced with the system. Smart Buildings LLC (a US-based engineering and design firm) offers this definition: “A smart building is the integration of building, technology, and energy systems. These systems may include building automation, life safety, telecommunications, user systems and Facility management systems. Smart buildings recognize and reflect the technological advancements and convergence of building systems, the common elements of the systems and the additional functionality that integrated systems provide. Smart buildings provide actionable information about a building or space within a building to allow the building owner or occupant to manage the building or space." (http://www.greenbang.com/from-inspired-to-awful-8-definitions-of-smart-buildings_18078.html). Same model and electrical component are used to narrate the working of system as reactive maintenance tool. Considering the model and system are updated live, in case the ceiling light stops working before either of the two parameters have reached its limit, then the system produces a pop-up message. In this case the alert has an emergency message and does not allow postponing the task. The message is only removed once the responsible party completes the task and updates the component. .

Thus the preventive and predictive maintenance work is managed by the pop-up messages and web-based 3D model and for reactive maintenance; the system and model should to be able to live update itself. This system uses complex BIM tool, web and API plug-ins to provide management of maintenance work. This system could be used by owners with no professional training, as it provides alerts and guides the user to the location of task.

6. PROTOTYPE DESIGN

Traditional building design was largely reliant upon two-dimensional (2-D) drawings like plans, sections, elevations, etc. Building information modeling (BIM) extends this beyond 3-D augmenting the tree primary spatial dimensions, i.e. width, height, and length, with time that is scheduling and sequencing as the fourth dimension and cost that is estimate as the fifth. Design of this tool emphasizes on 3-D, 4-D and 5-D by providing timely alerts for maintenance which helps reducing expensive repair or replacement cost due to expired maintenance and provides visual connection of the maintenance element with location.

Presently, there are many commercial packages which provide large-scale and complex functionality for managing very large facilities. The use of these programs for Facility management applications requires professional training. These packages include a number of specialized functionalities which exceed the needs and technical capabilities of most common users (i.e. owners of the facility) to maintain residential facilities.

The main motivation behind developing this prototype is to demonstrate the potential of BIM-based tools in residential Facility management by testing an application designed to provide a timely alert to the common user so that he can monitor some basic functions of maintaining the facility. Also, the prototype which is developed does not require any additional training for the using to maintain the facilities. The target groups of facilities for which this prototype can be adopted are small commercial, single-use office facilities and residential facilities.

The prototype which is presently created is a web based prototype. The facility can be viewed through a web page and also the alerts which inform the user as to what has to be maintained. The main advantage of adopting web-based prototype is that user can have direct view of the building model through a web page rather than using the visualization tool. This would require the users to be equipped with desktops and laptops in order to view the alerts and the model.

Figure 1 show the web interface of the prototype. The Revit model is exported using ODBC and RDB Link. A template available from course website URL http://faculty.arch.tamu.edu/wyan/ARCH653/lectures/lecture15/1.html was used to display the model in internet explorer web browser.

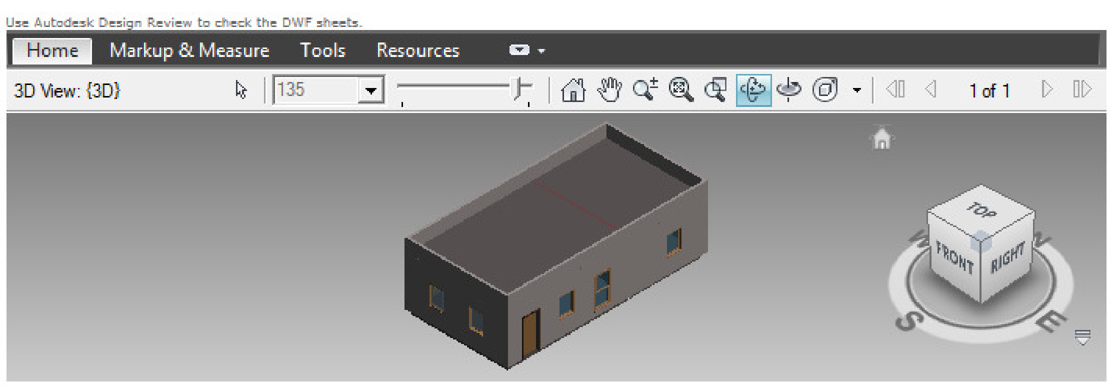

Figure 1: Web interface of the prototype

The prototype is developed using Revit Application Program Interface (API) and C# (pronounced as “see sharp” or “C sharp”) programming language. The external programs which run in Revit are called Add-in programs.

The prototype has three main stages. Figure 2 shows the flowchart of the functioning of the prototype.

1. Initialization of the project

2. Alerts

3. Viewing of the building components which are to be maintained

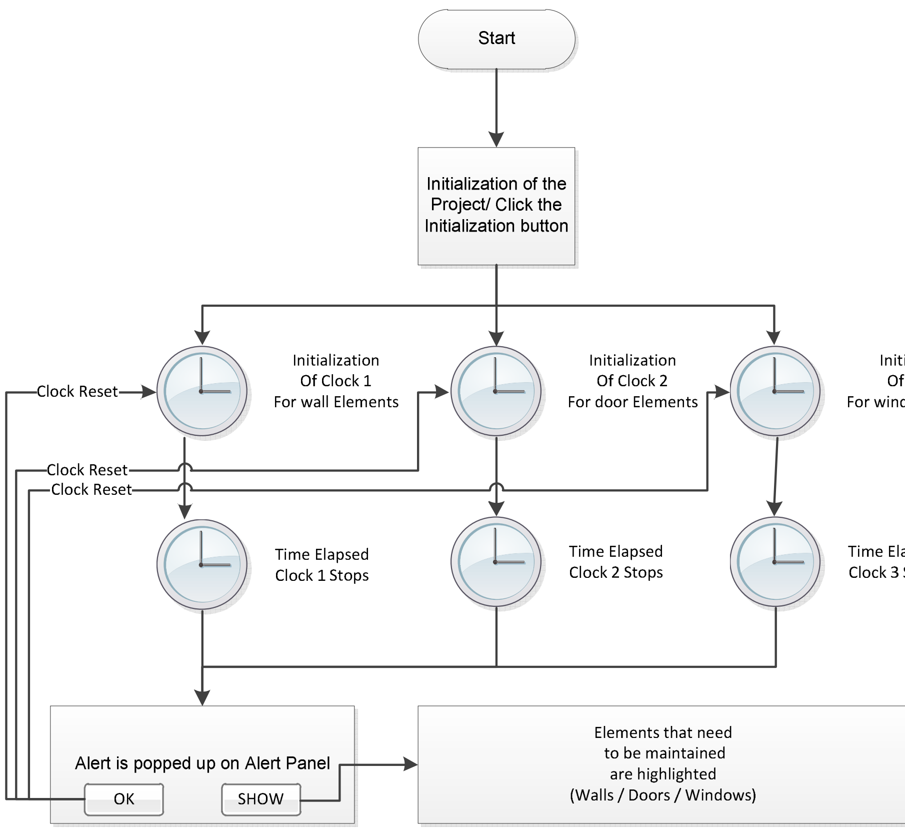

Figure 2: Flowchart showing the functioning of the Prototype

6.1 Initialization of the project

In the first step the Revit Add-in program (i.e. Prototype) is loaded using Add-In toolbar in the Revit program user interface. Figure 3 Shows the Add-in manager and the Add-in program loaded.

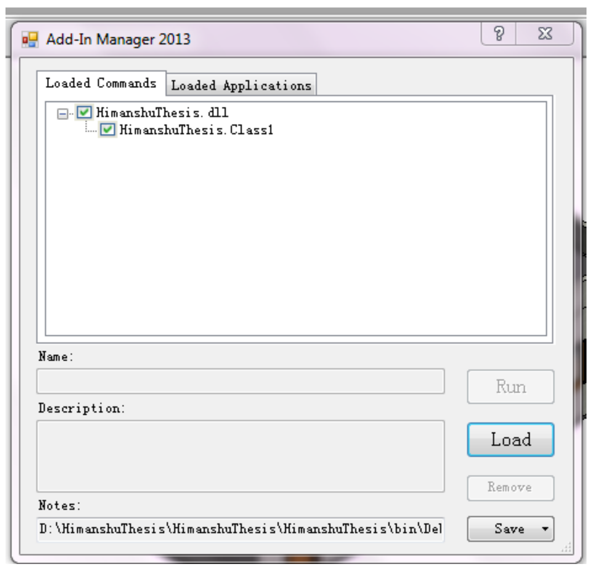

Figure 3: Revit user interface showing Revit Add-In manager to run the prototype

Once the Add-in program is run, a window form named “Alert Panel” will appear with button to initialization project (Figure 4). Figure 5 shows the Add-in program code which triggers the Alert Panel form. Once the button is clicked the project is initialized. After initialization the program keep track of timings for alerts connected to maintaining different elements of the facility.

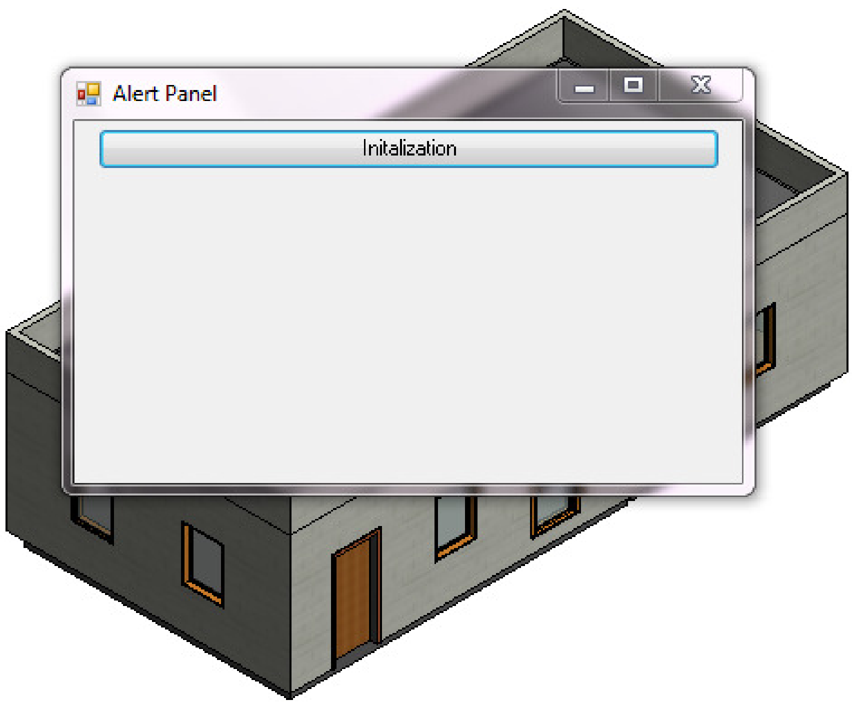

Figure 4: Windows form showing the project initialization button

```
// THE CODE TO SHOW THE INITIALIZATION FORM
Form1 form1 = new Form1(); // FORM 1 IS INITIALIZED
form1.Show();
```

Figure 5: Code which invokes the initialization form

For the present prototype three alerts have been designed: one for walls, a second for doors and a third for windows. A timer for each element type is assigned. All the three timers are initiated at the same time as project initialization. The time interval for each element is different and alerts show up when each element reaches the assigned time. Figure 6 shows the code which shows the initialization of the timers for the three components.

```
private void button1_Click(object sender, EventArgs e) // this starts the clocks initialization
{
    button1.Visible = false;
    timer1.Start(); // clock 1 is for walls and it is initialized
    timer2.Start(); // clock 2 is for doors and it is initialized
    timer3.Start(); // clock 3 is for windows and it is initialized
}
```

Figure 6: Code showing the initialization of the clocks assigned to each element

6.2 Alerts

Once the time period for each element has expired, the clock which is assigned to a particular element stops automatically and a Graphical User Interface (GUI) appears in the alert panel along with two buttons (Figure 7).

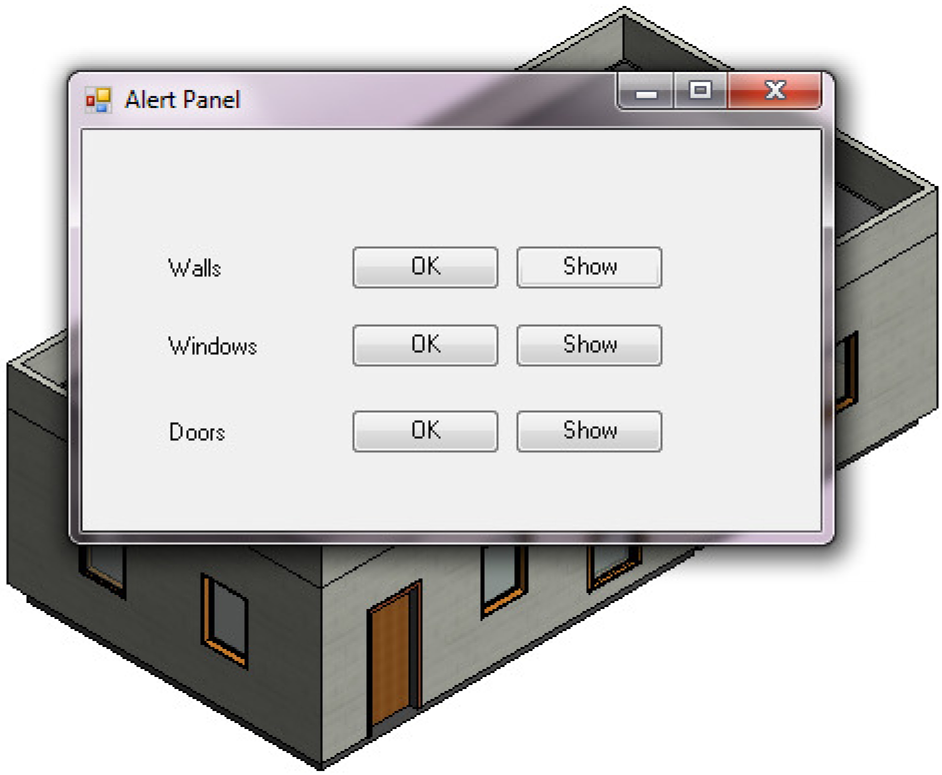

Figure 7: Alert Panel showing alert of different elements

Figure 8 show the code for the clock assigned to wall elements. Timer 1 is the clock assigned to wall elements. Once the time interval is over the clock automatically stops and wall label with "OK" and "Show" buttons are displayed on the alert panel.

```
private void timer1_Tick(object sender, EventArgs e) // timer for the walls (e.g. 5 years)
{
    timer1.Stop(); // clock 1 for walls is stoped after 50 days

   // The following code will show the alert for walls

    |
    label1.Visible = true; // code to show the wall lable
    wallbutton.Visible = true; // code to show wall OK button
    wallshow.Visible = true;   // code to show wall SHOW button

}
```

Figure 8: Code showing the clock for the walls

6.3 Viewing of the building components which are to be maintained

The Show button is for viewing which of the building components of a particular element needs maintenance. Once the “Show’ button is clicked by the user, the elements are highlighted in the model. Figure 9 show the highlight walls in the facility that need maintains.

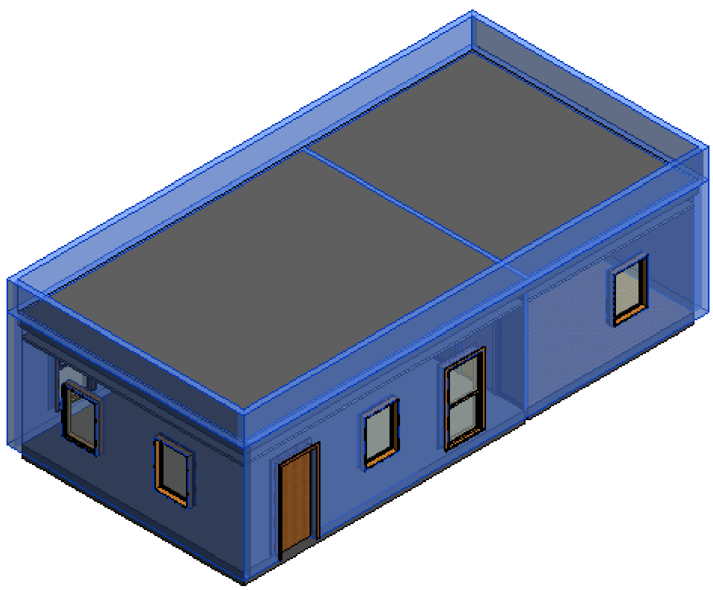

Figure 9: Highlighted walls that need maintenance

Figure 10 shows code for highlighting the wall elements that need to be maintained.

```
public void button2_Click(object sender, EventArgs e) // show button for walls
{
    FilteredElementCollector collector = new FilteredElementCollector(Class1.document);
    ICollection<Element> collection = collector.OfClass(typeof(Wall)).ToElements();
    foreach (Element w in collection)
    {
        walls.Insert(w);
    }

    HimanshuThesis.Class1.m_document.Selection.Elements = walls;

}
```

Figure 10: Code for highlighting the wall elements which need to be maintained

Once the wall maintenance issue has been addressed, the user must click the OK button. With the clicking of the OK button the timer for that particular element type will be reset and the clock cycle is again initiated. This process repeats for each elements type and once the maintenance time for that particular element (e.g. walls) is reached an alert is again displayed on the alert panel. Figure 11 shows the code for restarting the wall clock.

```
public void wallbutton_Click(object sender, EventArgs e) // ok button for walls
{
    timer1.Start();
    label1.Visible = false;
    wallbutton.Visible = false;
    wallshow.Visible = false;
    walls.Clear();

}
```

Figure 11: The code for restarting the clock for wall elements

This prototype demonstrates a part of a concept application that can be developed for maintenance of residences by owners with no professional knowledge and training. The system works continuously only when the Revit program and the Add-in manager stay open. The application and model are integrated with system time. API Add-in for Revit used for this application works continuously to perform alerts. The alert for each element is shown in the alert panel when the clock reaches the assigned maintenance time. 'Show' button highlights the particular element in the model and 'OK' button restarts the clock for next maintenance cycle. RDB Link Add-in for Revit is able to get the model on the web browser, but fails to show alerts, buttons and highlights.

The idea of this application was to develop a system which can be easily accessed through the web and does not involve use of professional software. The application fails to attain that goal and needs further development or different approach of designing the application for it to be used as a web based maintenance alert tool.

7. ANALYSIS

The tool is designed to provide alerts and useful information to the users which help them in performing regular maintenance of their property. The wall element in this model is given a maintenance time of 10 years considering the paint applied on the wall comes with 10 year warranty and has requirement that the wall be painted every 10 years. The alert is designed to pop-up in advance and not on the exact date of maintenance requirement. This provides the owner the ability to plan their future activity and probably schedule future plans accordingly. He could also make arrangements to attend the maintenance work in advance. Similar to paints on walls, all other elements are linked to this tool and alerts for each of them are provided.

Further development to this alert by giving priority to attend to the alert depending on its level of importance and urgency helps the user attending the maintenance work without postponing. Paint on wall could be an alert of less importance as compared to servicing of an electronically operated door as not painting wall on the exact date of maintenance would not cause a major problem but not servicing an electronically operated door could cause sudden failure in its working which could either trap you in or out of the property. Being able to make use of technology and getting connected to the maintenance alerts of the property and being able to issue maintenance even during your absence is important.

Due to limited knowledge and restricted capabilities, the tool could not be completely developed but the concept of the users being able to receive alerts on smart phones, tablets in the form of text and emails proves useful and important.

Capability of this tool of being able to highlight the elements provides the user a visual connection with the property and better understanding of location. Current model being simple highlights the elements in a normal 3-D view. In complicated models and properties, the highlights can be seen with different cameras at different locations for option to choose better view. In case of maintenance of interior elements or elements which are hidden by other elements, the 'show' could hide curtain elements and also provide sectional 3-D showing the elements.

This tool currently only provides alerts and not solutions. But these alerts can be provided with information stating the reason for the alert to pop-up which helps the user understand what he has to do or whom he can contact. This is how the tool would be useful for the property owners.

The tool can be evaluated for validation by proposing the following test. To perform this validation process, the tool has to work without the use of Revit so that users who do not use professional software are able to perform and evaluate the test. The comparison is between users managing hand documents and drawings required for maintenance and the tool providing information and alerts to the user for managing the maintenance. This makes it important for the tool to be validated without the participants using Revit. As the tool at its current stage cannot work without Revit, validation is not performed; but once tool works on web or without actual use of Revit, following procedure would help validate to use of this tool. Two groups of home owners with no knowledge in the field on maintenance and maintenance related computer software can be chosen for this test. Each group consists of 10 home owners, each with different type of houses/apartments. Both groups should have at-least one owner with similar type of house as in other group. 1st group is shown a video demonstration of this tool and provided with a model with certain maintenance issues. The video provides step by step tutorial on how the participants can deal with the maintenance issue that would come up during the test. Each participant is provided with a model similar to their own housing type. The participants simply need to attend to the task and for the survey, list each task with date and time of maintenance and attach a print screen of element location. The 2nd group will be provided with a 2-D hand drawings and folder of documents related to similar maintenance work as in the 1st group. The participants in this group need to list each task with date and time of maintenance and mark their location on the 2-D drawing.

Once this test is performed, tests are swapped and each group needs to perform other group's task. Accuracy of the information provided by the participants in the survey would be compared. A questionnaire directed towards the use of each tool would determine if the tool helps the user with no professional background maintain their property without getting much in detail with drawings, elements, and paper work related to warranty and maintenance schedule. This test and survey would help validate the usability of this tool in managing the maintenance of facilities by owners with no professional knowledge or training.

With limited development of with tool in its current stage due to restricted knowledge on coding, web-designing and information technology (IT) related subjects, software developers could include this concept in development of software in future. Currently this tool is reliant on Revit, which gives Autodesk, and other software companies that use Autodesk products, to develop Add-ins or applications that can make this tool independent and run in background. For users that like to learn how to attend to maintenance problems on their own without profession help, this tool with the help of web-based search engines could provide links to tutorial videos. Companies like Google could get involved in developing this tool further and could have their search engine attached to the maintenance alerts. This would help the growth of this tool. Also major IT Company being involved in the development on this tool would lead; major home improvement companies advertise and provide information useful to users.

For this tool to be used by owners, architects and facility manager need to design the Revit model in as much detail as possible with true information of each element. Once this model is made, the timers for each element need to be set according to the material specifications. The tool runs with information either stored in the user's personal database or an external database which would be maintained by architects.

This tool promises to have scope for owners with no professional knowledge and technology dependant. This tool works only on clicks of button and no major expertise required. This tool is not only useful for the owners, but for software developers to get advanced and IT companies and web-world to get connected with construction and management industry.

8. LIMITATIONS AND FUTURE SCOPE

The BIM-based residential FM prototype serves the purpose of providing alerts for regular maintenance and highlights the elements which require attention. The tool stores all the warranties, scheduled tasks for each element in the facility and as a result the user does not have to keep records of warrantees and keep a track on sheets of scheduled maintenance work. As the tool alerts the user about the scheduled work, the user does not have to worry about forgetting task or missing maintenance deadline.

Although this system is helpful and useful, it has certain limitations which prevent it from putting it to public use in its current condition.

Following are the limitation which prevents public use of the application:

1. This application uses system time for alerts but the alert panel form and Revit program must be kept open and cannot be closed. The panel can be minimized but not be closed as it would stop the system.
2. Although the model can be seen in web browser, the application cannot be linked as the browser only allows the user to view the model. Getting alerts through the web browser is out of scope for the prototype in its current state of development.
3. As the model is not an actual smart building which is linked with the system, reactive maintenance cannot be shown to work in current model.

4. This application in its current stage only provides alerts and shows particular elements. It does not indicate the priority as to whether the alert is an urgent case. This application also does not provide solutions in its current stage.

Overcoming these limitations and developing this system further would help determine the future scope of this application. Developing this system to address the above mentioned limitations and further future development, would help in preventive, predictive and reactive maintenance. Some future potentialities for further development of this application which could help non-professionals to maintain and manage residential and small facilities include:

1. The application can be developed in a way that it runs in the background even when computer is off.

2. When used for smart buildings, this application can be used to show alerts on reactive maintenance.
3. Information on materials of particular elements and related professionals to attend the work can be found just by adding few buttons. When the alert is popped-up, along with the user being able to see highlighted work, a description of work and information about related professional services could be added.
4. Contacts of nearby maintenance and service professionals and suppliers with customer ratings can be added in the alert for the user's convenience. This would

give users multiple options and enable them to order and oversee the required work provided by the selected licensed contractor and/or order the materials necessary to perform the work.

5. Existing structures that were not built as smart buildings can be retrofitted with sensors that use the BIM-based residential FM platforms.

9. SUMMARY

Analyzing the design of the BIM-based residential Facility management prototype system for providing alerts and identifying the location of required work shows that the application works for the assigned task, but with limitations in the current stages of development and analysis. The purpose of designing this application is to provide a system for non-professional users and so that there is no requirement of any professional training for managing the maintenance of the property.

The system does work for its purpose but is not practically workable in its current state as it has limitations of not being able to shut down the application or the computer, not being able to run in background and not being able to see the highlighted maintenance work on web browser.

Developing this application further and overcoming current limitations would prove to be extremely beneficial and should be a productive tool for users with non-professional background. BIM-based residential Facility management tools that will improve profitability, quality of life and building lifespan through technology-based participation of owners and occupants in the predictive, proactive and reactive maintenance of their homes. In the era where people shop online and get alerts on their friends' and family's whereabouts, this tool would be a step towards receiving updates on the health and condition of the residential property intended to generate income.

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