the as-built data from the bridge construction site. Optimal scan positions, i.e. planning for scanning, will be carefully considered for capturing as much detail as possible. Completed or partially completed objects present in the 4D information model will be recognized in the scans. The timeline of completion of a bridge component is defined by the start and end dates indicated in the schedule.

The 3D bridge design, schedule information and the as-built point cloud data are the inputs into the framework. The 3D as-designed model is first converted into a triangulated mesh (STereoLithography (STL)) format. Once converted, the object recognition algorithm virtually scans the 3D IM and matches as-planned data point coordinates with as-built data point coordinates, and based on a pre-defined threshold value, it identifies model objects that are present in as-built data. The results are then reflected in the project schedule for each activity. It is important to note here that the results are based on the number of objects recognized, which can easily be converted into Earned Value (EV) for each activity.

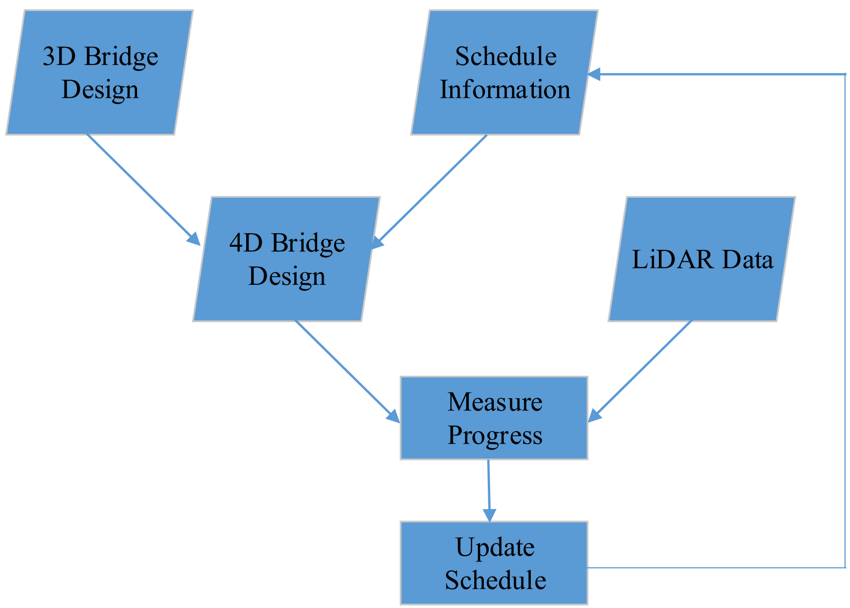

Figure 1 Bridge Construction Project Progress tracking using LiDAR and 4D Information Models

The progress made, in terms of completed number of components and the percentage of components that are completed, will be calculated and the planned schedule will be updated. The updated schedule will represent the actual on-going progress and reflect the discrepancies between the planned and actual schedules. Based on the actual schedule, the expected start and end dates of the subsequent bridge components will be updated, providing an accurate and objective construction progress report. Scanning will be performed at regular intervals, depending on the project, and the schedule will be updated in a similar manner until the entire project is completed.

CONCLUSIONS AND FUTURE WORK

This paper presented a review of the current state-of-the-art techniques and technologies for measuring progress tracking in vertical and horizontal projects. It was found that there are no studies which have directly used LiDAR technology and Information Models for progress tracking for horizontal construction projects. Based on the evidence from previous research (Turkan *et al.*, 2012 and 2013), it is expected that LiDAR and 4D information models could effectively be used for tracking transportation projects, i.e. project resources and commodities, and update project performance information in a timely manner. Thus, the paper presented a framework showing how progress tracking of a bridge project can be performed using LiDAR and Information Models.

Future research efforts will be directed towards applying the framework for two bridge projects owned by ODOT. Since it is not a common practice among DOTs to develop 3D information models for bridge projects, the model required as input for the framework will be manually developed by the authors using commercially available off-the-shelf software. The framework will be validated using the developed 3D model, the project schedule information and the acquired as-built data using TLS. It is expected that one of the challenges will be the recognition of elements that are still in progress in non-segmental bridges. For instance, cast-in-place concrete box girders may require several days to complete and the progress made during each day may need documentation. The portion of the box girder completed will have to be identified based on the comparison with the 4D information model, where the box girder may be designed as a single unit. The percentage of completion of a box girder must be identified. Similar challenges may be encountered when detecting the construction progress of slip-formed pylons.

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Improved Stakeholder Communication and Visualizations: Real-Time Interaction and Cost Estimation within Immersive Virtual Environments

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Abstract

One of the main desired qualities of an efficient project management in the construction industry is the ability to visualize a construction project in 2D drawings and execute them accurately and efficiently on-site. However, there are several types of delays that significantly influence project durations, often resulting from misunderstanding and miscommunications among parties (owners, contractors, and other stakeholders). One of the more common delays is change orders that are usually attributed as one of the major reasons behind delays in construction. Making changes after a building enters the construction phase can be very expensive, conflicting, and time-consuming. Such delays may arise due to the lack of communication and coordination among the owner and the contractors regarding the change orders. In most instances, it is highly conflicting to form a mutual agreement when there is a predicted price difference to accept a change order. To minimize the impact of change orders on the design and total cost, an approach that allows communication and interaction with 3D models through advanced visualization tools (i.e., virtual and augmented reality environments) can be effective. To further identify the influence of immersive virtual environments (IVEs) on project management, a systematic approach is proposed through which stakeholders can: (1) visualize and interact with 3D models in one-to-one scaled realistic virtual environments (fully immersive); and (2) visualize the dollar amount changes as the results of change orders. The results of the presented case study show that clients can exercise the ability to make changes virtually well before actual construction begins.

Keywords: Cost estimation; Building information modeling; Immersive virtual reality; Change orders; Design.

INTRODUCTION

The Architecture, Engineering, and Construction (AEC) industry heavily relies on digital modeling, simulation, and visualization to improve communications among stakeholders, identify clashes, and examine alternative solutions (e.g., value engineering).

These tools have significantly assisted project teams to complete projects on time, within budget, and at a higher quality. They also have shown to be strong tools to communicate different change orders and alternative solutions among stakeholders, resulting in increased satisfactions among the involved parties. The core element of these simulations and visualization techniques and tools is Building Information Modeling (BIM) which has widely been adopted by the AEC industry over the past few years. One of the main applications of BIM is to better understand the prospective creation or changes before physical implementation of different segments of projects. Implementation of BIM workflow that can integrate model-based data into an array of platforms, quantity takeoffs, and cost estimations is getting more granular, changing the decision making the process for each project and how they are conducted.

Although BIM has revolutionized the AEC industry, getting ramped up to 5D (3D + cost and time) takes time as BIM capabilities are expanding. Additionally, BIM does not represent the entire scope of the project. The main reason is that the best imagination cannot be made using just a 3D model. In order to create more clarity regarding the models and reduce the uncertainties associated with project details among stakeholders, advanced visualization tools such as virtual reality (VR) tools have shown to be very effective. Such tools have the potential to improve the current approaches in design by involving end-user (owner or project manager) feedback, without requiring to know how to read and understand 2D drawings or CAD models. These tools allow stakeholders to fully be immersed in 1-1 scaled virtual environments and examine different aspects and specifications of the designed models. As the complexity of designs is increasing among all infrastructure projects, VR tools have shown promising benefits to ensure and improve communication among stakeholders, which perhaps is the major shortcoming in understanding and approval of change orders.

Although, it is possible to develop VR models within VR packages (e.g., Unity 3D), AEC practitioners have a desire to directly transfer geometrical building data from CAD to VR (e.g., directly through Revit). The reason for this is to reduce repetition, data redundancy, and loss of information. Additionally, existing VR techniques lack the ability to show the cost impacts of different change orders in real-time. In order to address these challenges, there is a need to develop and implement a model-based cost estimating approach within Immersive Virtual Environments (IVE). Not only such approach would eliminate the use of VR packages for creating interactive virtual environments, but also allow the stakeholders to gain an understanding of cost impacts associated with each order. The proposed method in this paper aims towards addressing these changes and specifically answer the research question: "how various design alternatives can be evaluated within IVEs in order for stakeholders gain a proper understanding of performance and cost impacts of each alternative design?"

The paper presents the research through a literature review and gap analysis on the use of VR and IVEs for integrating design changes as well as the associated cost impacts. The paper presents the proposed method, the IVE system for data acquisition, and a case study on how the proposed approach can have the cost-saving impact of AEC projects. Finally, the paper is concluded by a discussion and presentation of the planned future work.

RELATED WORKS

Preparation of a reliable and realistic preliminary estimate to aid the decision makers to commit funds for a specific project is a complicated assignment. Traditional methods and operations produce unsatisfactory aid due to the lack of accuracy of project details, especially in the pre-design stage of a project (Jiang 2011). Within the past decade, the AEC industry has adopted BIM to visually communicate and exchange information among project stakeholders. Although BIM provides 3D models along with the geometric and semantic information about the building and its components, prior researches illustrate that BIM does not fully provide the cost of the various architectural design features that the decision makers might need to provide design feedback for (Kozhevnikov et al. 2008; Shiratuddin et al. 2004). In order to provide the cost of various alternative designs, a process of integrating the object attributes from the 3D model with the cost information from a database of the estimator has shown to be accurate and effective (Sattineni and Bradford 2011). Model-based cost estimating offers reducing time, eliminating errors, and improving productivity on the cost estimating process. It also offers users with accurate and consistent design-related data and information, accommodates the functions needed to model the building, and provides a virtual view of the building model. Moreover, BIM modeling provides estimators exact quantities and estimate construction costs in a less time with more accuracy (Bazjanac 2006). Hence, there is a significant amount of improvement in communication and interoperability of information among different participants involved in an AEC project (Drettakis et al. 2007; Heydarian et al. 2015). However, there is a need for involving stakeholders during the architectural design process, which has been identified as one of the major issues in current design approaches (Bullinger et al. 2010). User Centered Design (UCD) has shown to be an effective approach to improve the final product based on end-users' needs in many domains, including software design and the automotive industry. However, due to the lack of time and resources, as well as the growing number of parties involved in design and construction phases of AEC projects, end-user involvement is usually minimized and in many cases eliminated (Bullinger et al. 2010; Heydarian et al. 2015; Oijevaar et al. 2009). In order to effectively allow stakeholders to fully understand the design, IVEs are used for engaging them in the design process of projects by combining the strengths of pre-construction mock-ups that provide a sense of presence to decision makers and BIM models that provide the opportunity to evaluate alternative design options in a timely and cost efficient manner (Eastman et al. 2011; Goucher and Thurairajah 2012). Furthermore, by creating a better sense of realism through its 1-to-1 scale, building engineers and designers can incorporate IVEs in their work processes as a tool to understand the impact of design features on cost, and receive constructive feedback during the design phase.

The other technology that has progressed greatly in the construction industry in recent years is visualization technology and 3D graphics. VR is a computer generated simulation of a 3D image or environment that can be interacted with in a seemingly real or physical way by a person using special electronic equipment such as a helmet with a screen or sensor fitted gloves (Whyte 2003). VR applications allow the estimators to visualize design and construction information in 3D, photo-realistic, and interactive images. Hence, it allows the owners to visualize the building and to interface with it. The VR confers the estimators' ability to select the components that should be included in the estimates (interaction) and walk inside the building and have a better understanding of project elements (navigation) (Farnsworth et al. 2015; Hilfert and König 2016).

This study tries to make a process of construction estimating simpler and more instinctive as well as allows the estimator to observe the exact location of the project elements and the relationship between those elements while being in the virtual building. Moreover, the estimator can visually estimate the project by selecting the different elements and apply various materials to the components. While choosing the different components and materials, the quantity takeoff and the estimated price will be updated. As a consequence, it helps decrease the time for manual data entry by extract and transfer the data from a virtual model. Information can extract from the model while estimators navigate through the model.

METHODOLOGY

The proposed method is an integration of BIM models and cost databases in an IVE. The first phase consists of integrating BIM model with an external relational cost database in an attempt to automate the preparation of real-time costs for change orders. In the second phase, a dynamic link between BIM and VR game engine is created. The VR environment allows for easy exchange of data and information during the conceptual estimation process. The graphical overview of the proposed methodology is shown in Figure 1.

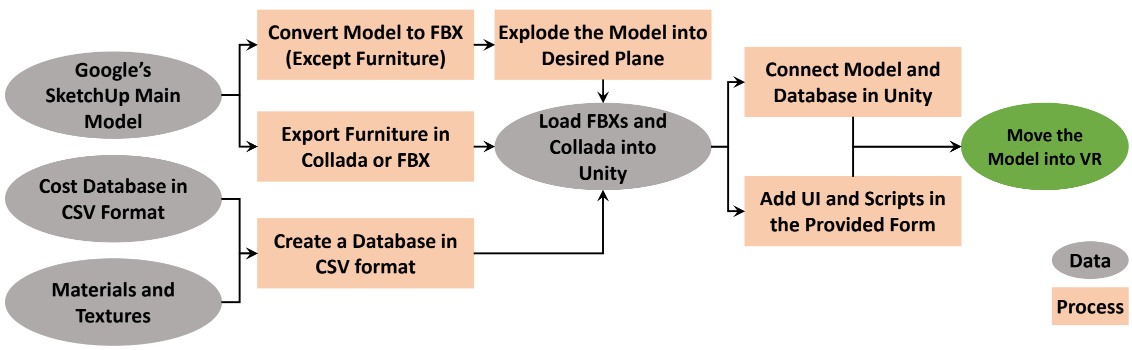

Figure 1. Overview of the proposed method

Importing 3D Models into Game Engine

As the first step, the 3D SketchUp models are imported into Unity 3D. It is important to note that Sketch up was chosen in this paper due to the fact that 3D models are lighter (processing and computationally) and easier to transfer to other programs; the similar procedure can be done through other 3D modeling programs such as Revit. However, those programs are more computationally costly. To import the models into Unity, the 3D model is divided into two base sections, furniture, and building components such as walls, floors, beams and columns. The furniture is imported into Unity 3D as COLLADA and/or FBX formats. However, the building components are at first imported to AutoCAD (or 3ds Max) in order to be able to convert the Autodesk material library to standard material. Through this approach two main purposes are met: (1) an export from AutoCAD can assure better division in elements (we just need to detach elements or attach them so we can use them in Unity; and (2) AutoCAD does not make any glitches or lose any materials and it also names elements in an organized format, which is helpful in Unity 3D. The AutoCAD model is then imported as an FBX format into Unity 3D and the building components and furniture are attached together. In Unity, 3D colliders are then generated for the model. The importing procedure is extremely important because it is important not to lose any material or specification information and every single detail can cause a terrible result in cost estimation.

Material and Texture Conversion

Once the importing procedure is completed, there is a need for implementing a functionality where the user can interact with the model and change the materials and textures. To achieve this, the textures and materials are imported to Unity by the referenced name in the main database. There are a number of different cost estimating databases that can be chosen (i.e. RS Means). To increase the speed and simplicity of interactions for the user, the cost estimation information from those databases are exported as a CSV file. Within the first two steps of the proposed approach, the model elements, materials, and cost related information are imported into Unity 3D.

Model Integration

In the next step, a number of scripts are introduced for (1) detecting what element/material is selected; (2) calculating the exact surface area of the selected element/material, and (3) updating the price and visualizing the new material in real-time. These scripts are made to ensure the model can dynamically update the visualization and provide cost estimation without any errors. After adding the scripts to the model in Unity, the selected objects can be divided automatically and detected based on the imported name of the selected element's name (the click function provided by Unity is adopted). Lastly, the game engine sends the element to the surface function where it makes it possible to calculate the exact surface area of that element of interest.

One of the main contributions of the presented work is calculating the surface area of the selected elements in real-time. To achieve this, it is important to know that Unity uses a four point mesh system. Therefore, there is a position of a local set of vertices along with its normal. Through this, the local position of all vertices in the model can be identified. Since surface properties hide within the local positions, there is no need for any kind of global positioning. The surface area of the elements can be calculated by breaking down the elements into triangles, which their surface area can be calculated by $0.5absin(\alpha)$. By adding up the areas of the identified triangles, the exact surface area of the selected element can be calculated. Figure 2 shows an example of how the area of a shape can be calculated by knowing the local positions of every point and the three vertices of each triangle.

$$0.5 * \left|(\vec{1} - \vec{0}) \times (\vec{2} - \vec{0})\right| = S_{012} = S_I$$

$$0.5 * \left|(\vec{2} - \vec{3}) \times (\vec{1} - \vec{3})\right| = S_{123} = S_{II}$$

$$S_{total} = \sum S_i = S_I + S_{II}$$

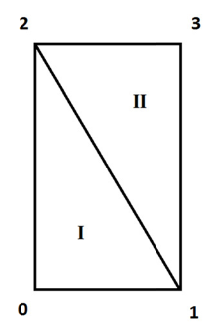

Figure 2. An example for calculating the surface area using the proposed method

It is important to note that Unity doesn't provide any measurement unit for area calculation. Therefore, the model should be imported with the exact units. By having the exact and accurate area of the selected element, selected material, and cost-related information, the prices of new elements can be calculated and visualized in real-time.

Pushing the Model into VR Environment

In this researched study Samsung Gear VR was used to transfer the proposed model into an IVE. Figure 3 shows the graphical overview of the proposed method for such transfer.

As shown, the imported model and cost database are connected to Samsung Gear in Unity, using the device ID. Using that ID, an OSIG file format is exported from Unity into Samsung Gear.

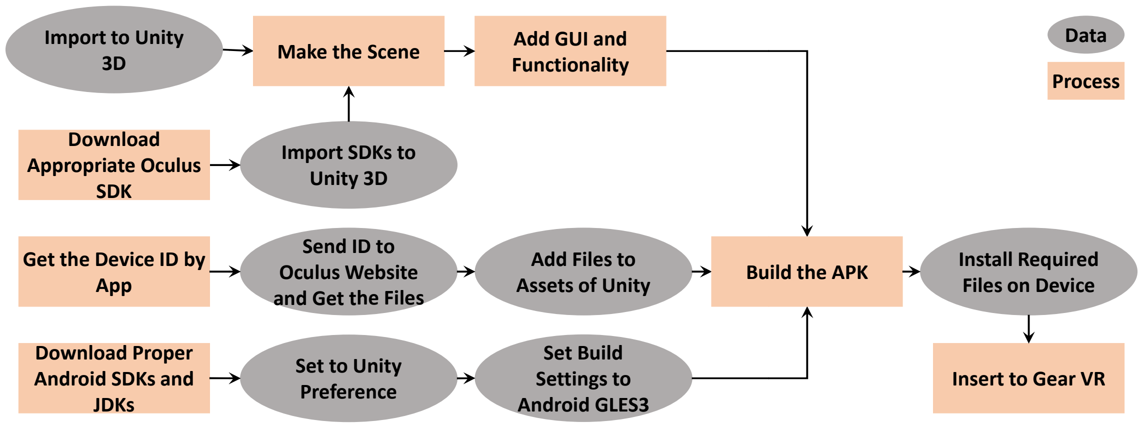

Figure 3. Graphical overview for transferring the proposed model into VR environment

EXPERIMENTAL RESULTS AND DISCUSSION

This paper presents a new model-based method to measure costs by changing materials to give user better understanding about alternative designs and cost associated with various change orders. The proposed method requires a modeling application (i.e., SketcheUp) and a game engine (i.e., Unity 3D) and also a VR head mounted display (i.e., Oculus Rift or Samsung Gear). To evaluate the performance of the proposed method, a case study is presented in this section. The proposed methodology is applied toward evaluating various alternative materials of a wall along with the associated costs in real-time. Figure 4 shows the developed VR model. As it is shown, building elements (i.e., walls) can be selected and then the user is provided with different options to select a specific type of material for that element. Once a specific material is selected for the identified element, the user will also be provided with the increase/decrease amounts in the cost of the alternative design.

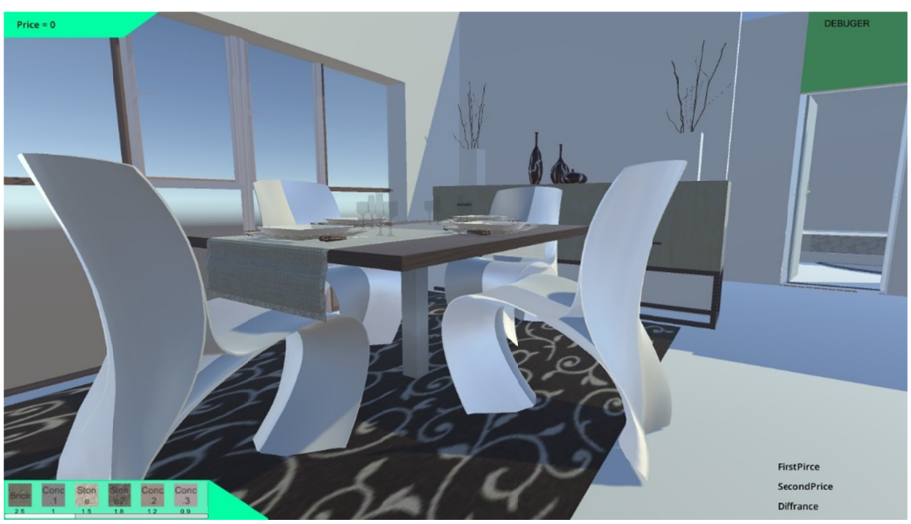

Figure 4. Developed VR model for selecting building elements and materials