

OpenBIM Framework for a Collaborative Historic Preservation System

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Abstract The authors have developed a novel system framework for a *historic preservation system* utilising open standards and open source tools. The framework enables the integration of open standard 3D models and GIS in a virtual environment (VE). It also allows the storage and harvesting of data via an open source web-based central repository, i.e. a BimServer. The framework is designed for *bi-directional interoperability* when utilised for monument tracking, preservation, conservation, re-excitation, etc. To date, no such system framework exists for the development and management of historic monuments using open standards *e57* for *terrestrial laser scanning (TLS)* data, the *industry foundation classes (IFC)* for 3D semantic rich models, and *CityGML* for integrating IFC and GIS in a VE. The convergence of a VE utilising CityGML and the BimServer can afford the bi-directional sharing of data. The web-based VE is accessed online from the BimServer and is intended for monitoring monument erosion, the movement and damage to monuments by human activity or nature, etc. Furthermore, the authors envision that actors such as museum curators, historians, engineers, etc., will benefit greatly from open source semantic rich 3D models. Utilising IFC for historic monuments facilitates collaboration between different industry actors to share knowledge, experience, and expertise globally through a web-based repository.

In this paper the authors apply their system framework by converting TLS data of a heritage monument at the Abu Simbel Temple in Egypt into an IFC compliant model. Semantic data is embedded into the model and then stored in a web-based database repository. The IFC model can then be interoperable with the IFC GIS VE, via the web-based system user interface, for many purposes such as georeference data for tracking and excavation purposes. This framework can be employed to develop further open source systems that maximise efficiency and minimise risk during locating and excavating disturbed monuments.

Keywords BIM, IFC, laser scanning, Open Source, CityGML, historic preservation

I INTRODUCTION

Re-establishing the location of and the preservation of heritage monuments after natural disasters and or war is a very time consuming and painstaking task. For example, imagine if the Valley of the Kings in Egypt was suddenly covered by sand, i.e. moving and altering monuments, and that traditional methods like the use of 2D drawings and topographical surveys were the only tools available to relocate and re-excavate all artefacts, buildings, monuments, etc. During the re-excavation of these objects, some may be harmed and some may never be found at all. Heritage monuments and buildings around the world suffer from erosion and other types of decay or weathering that may erase these heritage sites from existence. The research in this paper offers new opportunities for more efficient and

effective methods to address the deficits inherent where traditional practices fall short, thereby radically changing how technology can be utilised to preserve heritage monuments and buildings.

In this paper the authors focus on a single monument at the Abu Simbel Temple in Egypt. A virtual semantic rich 3D model was created from the real monument utilising 3D imaging, i.e. reality data capture, utilising open standards and tools to demonstrate the working constructs of a historic preservation system framework. Also discussed is embedding information into the model and the storage of the model in a web-based repository for multi-actor collaboration. Furthermore, the benefits and implementation of a GIS and IFC VE is explained. The authors also investigate possible model validation techniques to verify necessary data

in the model and the continued monitoring of the real monuments utilising the virtual model.

II BACKGROUND

The authors have designed an OpenBIM historic preservation system framework that allows historic preservationists to benefit from advanced technologies currently utilised by Architecture, Engineering, Construction, and Facilities Management (AEC/FM) disciplines. Historic preservation of heritage monuments and buildings is deeply rooted in the AEC/FM and has become a huge area of interest. Therefore, it makes sense that both can benefit from the same technologies.

OpenBIM refers to an *open* way of 3D information modelling and exchanging project information/data utilising open standards and schemas, e.g. the *Industry Foundation Classes (IFC)* when implementing *Building Information Modelling (BIM)*, in the AEC/FM. The system framework herein encourages remote multi-actor collaboration on a global scale. Collaboration among actors is at the heart of the BIM process and should be able to be conducted by multiple actors from anywhere in the world. The framework demonstrated in this paper utilises the open standard IFC for seamless *bi-directional* BIM model data interoperability between a BimServer database and virtual environment, i.e. a web-based centralised repository and the Common Data Environment (CDE). Also, a novel method for converting Terrestrial Laser Scanning (TLS) data into a semantic rich IFC BIM model for a preservation system is revealed.

TLS *reality data capture* is a common survey methodology widely used in the AEC/FM and it is becoming a surveying tool of choice for many historic preservationists in surveying topography, monuments, and buildings. *Scan-to-BIM* methods are utilised to convert captured reality data into semantic rich data models, which is a key component to initiate the system framework in practice. Scan-to-BIM is a common term in use for the converting of reality data capture *point clouds*, i.e. in this case terrestrial laser scan data versus unmanned aerial vehicles (UVA) or ground-penetrating radar (GPR), into 3D semantic rich IFC BIM models. The next step in the framework employs an *open source* web-based BimServer for collaboration among actors using the IFC models. The BimServer is the central repository for all data exchange/sharing and offers an infrastructure on which a CDE can live.

The framework shown later in section 4 promotes the utilisation of CityGML for the CDE due to the fact that CityGML allows the integration of GIS and IFC BIM models [1]. The BimServer and

CityGML were chosen for the system framework because they are open source which means they are free to the public and can be freely modified for specific practical applications. Utilising CityGML that enables IFC and GIS integration facilitates bi-directional interoperability which can be utilised for many different virtual-to-real and real-to-virtual scenarios. Bi-directional interoperability allows the communicating of like or different schemas, languages or files through utilisation of common semantic data during information mapping, e.g. the IFC BIM model can locally communicate, via the BimServer, with the CDE during model information validation and quality assurance methods, i.e. monitoring the real monument. It's also important to mention now the requirement of utilising one BIM model for multiple purposes omits replication and ensures possible real-time bi-directional processes. The single IFC BIM model is the model visualised in the CDE, whilst also it is the model stored on the BimServer. In theory, and system framework application, there is only one unique IFC BIM, i.e. *virtual* model, to represent each *real* object to reduce confusions commonly created by geometry and data replication in systems. Therefore, computational efficiency is optimized by reducing wasteful use of resources. These types of operational constraints encourage a leaner approach when implementing the system framework.

III RELATED RESEARCH

Current methods for surveying and documenting heritage monuments, i.e. traditional surveying to create 2D drawings for historical preservation produced by hand or in 2D CAD systems, are subjective, error prone, time consuming, and costly. In fact, it is not possible to use traditional techniques, theories, and tools for historic preservation due to the many irregular shapes of building and monument characteristics [2]. Terrestrial laser scanning (TLS) can be employed to reduce the subjectivity of traditional methods by capturing irregular shapes and providing near perfect measurement data, while also reducing the survey cost, manpower, and errors found in traditional data collection. Highly accurate 2D engineering documents can also be generated directly from the TLS data. The accurate data provides an effective medium to create 3D CAD "mesh" models from the TLS data. The mesh can then be converted into an IFC BIM model as discussed further and demonstrated later in this paper.

A BIM model is preferred over mesh model due to the fact these models can be uniquely identified from embedded Global Unique Identifiers (GUID'S), and they are semantic rich and parametric based. For example 2D construction and engineering

documents can be extracted from the 3D BIM model that can also automate schedules which distinguish between doors, windows, etc. In fact, many analyses can be conducted utilising the semantic content embedded in BIM models. Researchers have already demonstrated the creation of semantic 3D models from point clouds [3] [4]. However, the results are not exact representations of what exist in the real world therefore the objects are not deemed suitable for historic preservation due to their subjectivity and inherent inaccuracies.

The archiving of archaeological datasets is also converting from traditional methods to *open source* web-based information management data repositories for instant access to data by all actors globally [5]. Cultural heritage buildings and monuments have information about them that goes beyond physical characteristics. Prior research also proposes BIM to embed information/data into semantic rich 3D models of the building and or monuments that must be preserved. Other research conducted does not focus on semantic models but rather the focus is known as what they call HBIM and the primary interest is on the benefits of parametric modeling in conjunction with TLS point clouds for engineering drawings and scheduling [6].

Historical preservationists can benefit greatly from BIM methods and processes, e.g. GIS integrated with semantic rich 3D BIM models [7] [8]. Heritage values that need to be embedded into BIM models as critical information/data include; architectural, cultural, historical, location-based, social, environmental, etc. These types of information are critical to successful education, conservation, preservation, etc. Tracking and excavation of objects after natural disasters is also very problematic. There are very few systems for these purposes in existence. Researchers are exploring an array of options for monument tracking, that include infrared technology, digital cameras, range sensors, augmented reality, laser scanning technology, reverse modelling (similar to Scan-to-BIM), etc. [9][10][11]. Virtual excavation systems are very rare to find and most focus on the site after it has been excavated, such as the excavation system of [12] that links the excavation site with artefacts for visitor contextual awareness application within museum settings. The authors of this paper focus on utilising BIM models and a web-based platform that enables GIS methods to be employed for tracking objects, deterioration, and the re-excavation of buildings/monuments during or after natural erosion/disasters, and human destructions such as war.

IV SYSTEM FRAMEWORK

a) Developing the Framework

The philosophy supplying the theoretical basis for the system framework can be found in the nD BIM framework and ontology research and development conducted by [13]. The authors utilised the Integrated Definitions Method (IDEF) for the development of the framework. IDEF0 is implemented to show the working constructs of the framework. IDEF0 is part of the IDEF family. For further information on IDEF see <http://www.idef.com/>.

Figure 1 shows the highest level, which is the First Level or phase 0 of the framework. In this case the phase 0 model can be thought of as a theoretical model upon which future historic systems can be built. IDEF0 uses an input, output, control, and mechanism methodology to include all necessary constructs. Herein, phase 0 shows the *real* world as-is data capture upon entrance as the input construct. Once the input has entered, it then becomes integrated into the web-based centralised repository facilitated by the mechanism construct. The mechanism pertaining to this research must be an open system to ensure that the overall framework produces an open source system. The authors of this paper used the BimServer as the open source tool of choice, which is also built on the open standard IFC as the language for the system platforms infrastructure. The control is open standards e57 for TLS data and IFC for the BIM model. The output is an IFC model, created from TLS data that is now located on the web-based BimServer and can be visualised and used for simulations in the counterpart open system, the CityGML IFC BIM VE. Once the semantic rich BIM model is to this stage, bi-directional interoperability can now take place between the BIM model on the server and its virtual visualisation counterpart in the IFC BIM VE. Remember that the BIM model on the server and the BIM model being visualised are the same single model.

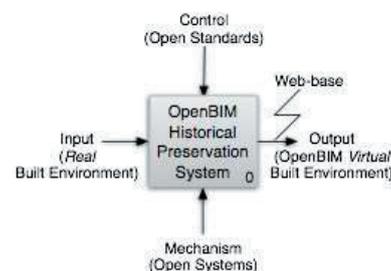


Fig. 1: First Level Process Model

The theoretical model in figure 1 can be utilised by other researchers to replicate the process. However, it is not necessary for the control and mechanism to use the same open tools and standards, nor is it necessary to constrain other

developments to the use of CityGML. The phase 0 IDEF model for the historic preservation system is *generic*, i.e. a universal theoretical model.

Figure 2 shows the second level IDEF0 model for the OpenBIM Historic Preservation System framework. The second level phase 1-5 model takes one within the theoretical framework to a space where one can now apply the theory to create a tangible system. First, notice in phase 1-5 the controls and mechanisms change but remain within the constraints defined by the theoretical model. The open standards chosen by the author for the controls are e57, obj, IFC, and GML. Second, notice the open source and OpenBIM tools chosen by the authors that also change but maintain the openness. The exchangeability of the open controls and mechanisms is proof that the theoretical model is universal and future researchers do not need to use the same standards and tools as the authors, as long as the tools chosen are open ones. Prior research shows the utilisation of open standards and tools for a very similar open source system except the prior research does not enable the use of point clouds [14]. The previous study was focused on LEED for energy assessment, which is also an open global standard, and utilised the open source Torque 3D Game Engine (T3D) for the VE versus the open source CityGML proposed herein.

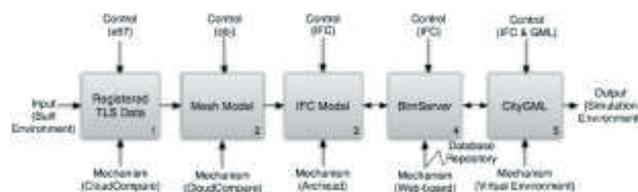


Fig. 2: Historic Preservation System Framework

Phase 1 in the framework is the reality data capture stage. The first step is to capture the built environment data one wants to historically preserve, e.g. the authors first had to capture data of the Abu Simbel Temple heritage monument. The data is registered, saved as e57, and cleaned accordingly not to omit any critical data that may be of interest for preservation, conservation, excavation, etc. *Phase 2* is the beginning of the Scan-to-BIM process where the authors converted the registered TLS data into a mesh model. CloudCompare, an open source point cloud data tool, was utilised during the integration of phases 1 and 2. It is important to note that MeshLab is an open source alternative to utilising CloudCompare in these regards. *Phase 3* is the development of the semantic rich 3D IFC BIM model. During this stage the 3D mesh is converted into an IFC model and embed with semantic rich data. *Phase 4* is where the IFC BIM model is loaded

into the web-based repository, which facilitates the ability to remotely query the model by multiple actors sentimentously, e.g. museum curators, engineers, preservationists, conservationists, etc. *Phase 5*, the CityGML IFC and GIS VE, can then be accessed from the BimServer via the same method as provided in the research of [14]. It is envisaged by the authors that in Phase 5 is where others can contribute most to the open source system framework by developing new methods, i.e. virtual tracking of monument movement and erosion, simulate excavation practices, etc.

V METHODOLOGY

a) TLS Reality Data Capture

A terrestrial laser scanner (TLS) was utilised to capture the required data from the site of interest. Laser scanning is *contact free* which is why it is recommended for use in historical preservation as the object will not be touched or damaged in the process. Laser scanners work by measuring three dimensional X, Y, and Z coordinates at high speed in a systematic manner, while also using an on-board camera to that takes high quality photos. The images are then combined by the scanners embedded computer to create what is known as an xyzrgb file. These files allow photorealistic point cloud data of high quality that looks much like a 3D model. However, it is not a 3D model. It is actually a digital 3D dataset of points in a given space.

Comprehensive data capture of the heritage monument object requires multiple scanner set ups, and possible use of UAVs and photogrammetry, ensuring all data needed can be provided for complete and accurate point clouds. For this research the authors only utilised TLS data capturing methods. The TLS data is the foundation for the whole process so data of the highest quality and lowest tolerance of accuracy is imperative. Points per second, field of view, and range in meters are all factors to consider when choosing the TLS right for the job. If the scanner is positioned far away from the object, then the less points are taken over a known size grid and the more accuracy is compromised. Since historical features are imperfect the accuracy cannot be compromised. Important details and features will be lost if the mesh model is created from inaccurate data. In relation to the object modelled in this paper a loss in accuracy could result in point data such as facial features or hieroglyphics going unnoticed and being converted into a flat mesh during the modelling process.

TLS software is needed to process the data sets which can be billions of points, dependant on the area covered and setting chosen on the scanner. This software can be specific to the brand of laser scanner

used or it can be open source. Most of the major TLS software have the export option of e57 file format which enables seamless interoperability with software packages. The authors used the open source CloudCompare software for creating the mesh model. If one uses CloudCompare or MeshLab, then the mesh can be saved in a standard such as obj. Figure 3 shows the raw data after being processed and the mesh model created from the processed data. The authors recognise further research is need in the area of creating highly accurate virtual models from the processed real world data. It is very important to get highly accurate data for a historic preservation system that is foreseen to be utilised for monitoring decay/erosion, preservation, conservation, excavation, etc.

b) Scan-to-IFC BIM Process

The authors have developed a semantic rich IFC compliant model prototype utilising the Geometric Description Language (GDL) and a unique Scan-to-IFC BIM methodology designed specifically for historic monuments. First, the captured reality data must be pre-processed. The e57 pre-processed data is then converted into a mesh model utilising the CloudCompare software. The mesh model was then converted into an IFC BIM model using GDL in an OpenBIM BIM authoring tool available from Graphisoft. The BIM authoring tool facilitates an IFC manger, and GDL script writer and viewer that can be used to embed data into the model. The model should be saved as IFC 2X3 and *round tripped* to ensure data is not lost during interoperability with other IFC 2X3 compliant tools. Solibri was also utilised to check and validate the models IFC parameters.

c) Background to methods for embedding data into an IFC BIM model for historical preservation

[15] and [16] developed a method utilising GDL that was used to embed critical data into the model for LEED certification review in a virtual environment. Furthermore, then focused on embedding critical data into singular objects utilising GDL and IFC Property Set Configurations (Psets) for bi-directional interoperability of 6D energy informatics. This background knowledge was utilised to create the novel model element of the Abu Simbel Temple monument used for the OpenBIM historic preservation framework and system prototype. [13] also provides a future vision for a nD dimensional domain for *Archaeology* utilising the created unified nD model framework and ontology for an *as-is* IFC BIM model of the Abu Simbel Temple in conjunction with recognition algorithms to preserve the ancient structure by tracking deterioration taking

into account the variables materials and climate. This knowledge was taken into account when developing the 3D IFC BIM model in this paper. The prior knowledge was specifically utilised to prepare the model for interoperability and its potential future use via the web-based repository and within the VE.



Fig. 3: First Level Process Model

c) Web-based database repository

The web-based repository was developed using the open source BimServer. The BimServer was chosen due to its high level of IFC compliance. In fact, the core of the BimServer was built utilising the IFC. This web-based repository enables models to be stored, versioned, queried, visualised, etc. Collaboration among actors takes place via the BimServer. Other databases and VE's can be linked and accessed via the BimServer as shown in [14]. The authors envision that CityGML, due to its GIS and IFC integration, is an optimal choice for a VE for historic preservation purposes.

VI PROTOTYPE

The current prototype includes one heritage monument that was laser scanned and converted into an IFC compliant BIM model, and a customised BimServer with VE that was used to test the IFC BIM model. The BimServer was utilised to query and store the IFC BIM model. Furthermore, the authors developed a VE linked to the BimServer for model visualisation and tested the current system remotely. A fully functional system for historic preservation seems promising in the future based on the research conducted thus far. Also, CityGML has not fully been integrated into the current prototype. Further research is underway to fully link a CityGML VE to the BimServer that allows bi-directional interoperability between the IFC BIM model and GIS VE via the BimServer. The authors have not utilised the developed IFC BIM model for model tracking using IFC and GIS in a VE as of yet, nor are the authors able to conduct any virtual excavation. However, based on the conducted research, the authors are very confident in the feasibility of such techniques to be employed in the near future. The aim of this research is to 'connect the dots' and provide a system framework to allow others to investigate and test similar ideas, and

develop their own systems or add to this one in the future. Once the authors have fully created a system with a stable software platform for historic preservation, the goal is to make it available to others as a free open source application.

VII MODEL VALIDATION

IFC BIM Model Validation is critical to ensure the model created from TLS data is as accurate as the real world monument undergoing preservation. Two types of model validation are coupled together in relation to model checking for historic preservation when modelling from point clouds have been identified: 1. The geometry must be accurately modelled and represent within a very low tolerance of $\sim 1\text{mm}$ for the tracking of erosion, or excavating the object if it has been covered by debris or soils, etc., and 2. The information must be properly embedded into the model, i.e. the information embedded must be in the appropriate IFC *class*, and this information must be able to be freely harvested. All stakeholders must be able to have access to the data. The authors proposed method for data harvesting is the BimServer as shown in the framework in figure two in section four. If there are not appropriate IFC classes for the data, then currently the authors create custom IFC Property Set Configuration (Pset) for the data as demonstrated by [16]. The disadvantage to this methodology is that the classification of the data deviates from the certified schema, i.e. deviates from IFC 2X3, which makes harvesting of the data more difficult. If the data follows the schema verbatim, then IFC 2X3 compliant tools can immediately utilise the data, e.g. the user/stakeholder can query the IFC BIM model via the BimServer for historic preservation information without needing to customise the current freely available BimServer. In [14] and [17] the researchers demonstrate how to query custom IFC Pset's via an open source BimServer. The nD BIM system facilitates a web-based GUI for user queries via the IFC 2X3 schema and interaction and visualisation of the nD BIM via the "linked" virtual environment that was created using an open source game engine.

Currently, there is no IFC Model View Definition (MVD) to check the quality of data within an IFC BIM model for historic preservation purposes. MVD's such as COBie for facilities management (FM) data interoperability and extraction is common practice in the AEC/FM [18], but in the case of historic preservation there are no MVD's to assure the validity of information exchanged. Furthermore, it is not clear what information should be embedded into the model, nor whom shall collate the data and when should the information be embedded, e.g. is it a granulated process similar to levels of detail? The author's

believe this is a granulated process. Perhaps data collection begins upon excavation or the data already exist and is readily available in existing "open" systems, e.g. an open source such as data.europeana.eu. Conversely, embedding the critical data in relation to the objects preservation begins on the "first day" the mesh model has been converted into an IFC model. The authors have derived this philosophy from their current AEC/FM integrated best practices, e.g. if you begin a project implementing the BIM process, then you should begin with IFC zones (*ifcspace*) and input relevant data early in the process. The reader should investigate more about the Vico Office software and the MVD COBie to see similar practices and approaches.

Model validation method are in high demand and the importance of integrating Scan-to-BIM and Scan-vs-BIM are highlighted in [19]. The authors propose that a technique similar to Scan-vs-BIM should be utilised for tracking erosion and damage of structures in the validation of the BIM model created from the point cloud [20][21][22]. The difference in our technique versus the latter is there is no model (Design BIM) ahead of time and we focus on the utilisation of an IFC BIM specifically. However, it is the same exact theory that applies in our framework, i.e. we want to compare the BIM model to the TLS data capture to track differences and deviation. Our method requires reality data to be captured and converted into an IFC BIM model prior to implementing the full system framework. Overall, model validation plays a critical role in historic preservation utilising BIM methods and tools, and in the AEC/FM in general.

VIII CONCLUSION AND FUTURE WORK

The authors have provided a roadmap for open standards in conjunction with open source tools for historic preservation. It is believed the correct approach to preserving the built environment, e.g. monuments, etc., is to leverage off the rapidly growing integrated practice "BIM-approach" of the AEC/FM. The IFC schema can be utilised for the historic preservation BIM model and act as the "container" the models data should live. The authors demonstrate how to create open standard models using scan-to-IFC BIM methods, how to embed information into these models, and how to utilise open source tools to store, share, harvest, query, etc. the IFC data model. A methodology and framework for creating IFC compliant models for historic preservation purposes is demonstrated in this paper. The next step is to determine what information is the critical data to be embedded into the model, by whom, when, etc.? This question has yet to be answered. The authors are aware of the need to

answer this question and are looking into the correct approach and methodology to solve these question by integrating an open solution into our framework. Our current hypothesis is that the data will come from international open source libraries and this library data will be merged into the framework provided by this paper. The open europeana data model is a great example of where to begin thinking of how to integrate existing open libraries into an open historic preservation system.

It is also not clear who is qualified to determine what critical data to be embedded into the IFC model. Perhaps it will be an Archaeologist? Also, who will embed the information into the model? Maybe it will be Architects or qualified Engineers. The extraction of the data (data harvesting) will be a key focus once these questions are answered. The correct approach in regards to data retrieval via IFC would be to create a new IFC subset schema, i.e. model view definition (MVD), for preservation and conservation. The MVD would allow precise access to the critical data using IFC models. Hopefully in the future the OpenBIM system framework herein can be of great benefit for the AEC/FM in conjunction with the preservation of heritage buildings and monuments. The authors hope a new way of thinking and application can now be employed through the new methods provided by this research.

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