ASSESSING THE POTENTIALS OF HERITAGE BUILDING INFORMATION MODELLING (HBIM) IN DAMAGED HERITAGE RECONSTRUCTION

Fatimah Al-Muqdadi[1]

Faculty of Engineering and Computing, Coventry University, Priory Street, Coventry, CV1 5FB, UK

Recent catastrophic events that destroyed valuable monuments, like Isis attacks on ancient cities in Syria and Iraq in addition to Notre Dame's fire in France, did not only cause a significant cultural loss but also immense economical damage. Moreover, the rapid growth of urban development projects across the globe further raises questions about damaged heritage management. As a result, there is a need for a sophisticated framework that can facilitate accurate virtual reconstruction of lost structures and support their cultural management to initiate cultural healing. Using Heritage Building Information Modelling (HBIM) could provide enriched platforms that store and exchange knowledge crucial to reconstruct and operate damaged structures. Yet, there is little research about adoption and implementation of HBIM in lost or damaged heritage. Thus, this study seeks to investigate HBIM adoption in reconstructing damaged historical assets using published case studies as a source of secondary data. The aim is to critically review approaches in post-destruction HBIM, analyse their methodologies, identify common challenges and finally formulate recommendations. A phenomenological research approach was adopted through systematic literature search to identify cases that responded to such events, ten case studies with various building morphology and HBIM methods were identified. Thematic data analysis was used to analyse how cases adopted HBIM in creating supplemented digital data and exchanging heritage sites knowledge. Initial findings show that HBIM has potentials to enhance virtual reconstruction and restoration of heritage monuments; but its implementation indicate gross lack of procedure and workflow concerning transition from data collection to modelling. The research also highlighted key specific issues confronting adoption of HBIM's in the recovering of damaged historic buildings.

Keywords: case studies, digital data, HBIM, heritage reconstruction

INTRODUCTION

Natural occurrences or human-influenced catastrophes often damage archaeological and historical sites. Heritage that represents a crucial part of communities' identity is often destroyed by development pressures, untenable tourism, poor management, robbery, and political conflicts (Global Heritage Fund 2010). Cultural heritage "stands at the frontline of conflicts", losing heritage often results in powerful social and economic consequences due to their irreplaceable value (UNESCO 2013). It could be seen as an act of depriving people of their collective memories, identities,

[1] fatimah.almuqdadi@gmail.com

Al-Muqdadi, F (2020) Assessing the Potentials of Heritage Building Information Modelling (HBIM) in Damaged Heritage Reconstruction *In:* Scott, L and Neilson, C J (Eds) *Proceedings of the 36th Annual ARCOM Conference,* 7-8 September 2020, UK, Association of Researchers in Construction Management, 25-34

and belongings which could be seen in ISIS attacks on Nimrud and Palmyra. How could destroyed sites be recovered to initiate cultural healing within affected communities and restore their economic resources? Reconstruction procedures could be very demanding due to the complexity of lost historical recovery. Such demands could be found in Building Information Modelling (BIM): A multi-disciplinary process that conceptualizes projects by using parametric objects which contain geometrical and non-geometrical information (Baik *et al.,* 2014). However, BIM is often developed towards new projects with simplistic libraries containing primary elements (Bryde *et al.,* 2013). Hence, Murphy *et al. (*2009) identified Heritage Building Information Modelling (HBIM): A process that combines data acquisition technologies, such as photogrammetry and 3D scanning, with BIM platforms to produce accurate heritage models. Spatial data concerning historical assets is collected through scanning technologies to produce point clouds, those clouds are processed and filtered to be incorporated and developed within BIM environments. Despite HBIM being researched often, there seems to be a little examination of how it could be used in reconstructing lost heritage. Hence, this research seeks to identify the methodologies currently used in post-destruction HBIM by reviewing practical case studies references, distinguishing common issues, and forming recommendations. For a better understanding of the study's variables, a detailed literature review is needed.

LITERATURE REVIEW

Key definitions

Reconstructing damaged assets often refers to the process of rebuilding what was lost or destroyed due to natural disasters, such as earthquakes, or human-induced events such as armed conflict (Jokilehto 2013). In such events, recreating the physical asset may not always be the goal, but the regenerating the social-economic value of the location. Heritage has long been on the frontline of disasters, the 1976 UNESCO Recommendation concerning the Safeguarding and Contemporary Role of Historic Areas illustrated the urgency of such matter in assessing the Second World War severe damage on global sites. It also highlights how destroying heritage sites leave their social fabric with deep economic and cultural loss. Furthermore, the Global Heritage Fund (2010) asserts that events such as the Bamyan's Buddha's destruction, Notre Dame Cathedral fire, and Palmyra attacks, to mention but a few, represent a substantial economic and cultural loss to their societies. A loss that current research seeks to recover through Heritage Building information modelling (HBIM).

HBIM was first mentioned by Murphy *et al. (*2009) as a process where parametric objects are built from historic information to represent architectural elements of the historical asset. These objects are mapped using data acquisition technologies onto a point cloud survey and then imported to a BIM environment. The term has since been broadened to mean the libraries, 3D models and digital databases representing historical buildings, which are used to manage heritage projects in a similar digital setting (Cooperative Research Centre for Construction Innovation, 2009). The word "Information" in HBIM is key, a central digital platform that does not only resemble the geometrical attributes of the historic asset, but also the identity, history, culture and construction logic (Hichri *et al.,* 2013).

HBIM's in Context

Contrast to new construction BIM, where the asset is not yet realized, HBIM raises the question of modelling necessity when the asset could be experienced in reality. This question soon is answered when projects of post-disaster reconstruction are in question, the motivation to virtually document heritage manifested in the last century as a response to many sites lost due to World Wars. Sutherland (1963) is often named the initiative of CAD, followed by Intergraph and Calcomp around the 1980s who are perceived to produce the first fully rendered 3D model. In Heritage, Worthing and Counsell (1999) critically analysed the 1996 London Tower and modelled it which served as a detailed database for development proposals. Yet, the first major implementation is often considered the 1995 full-colour virtual reconstruction of UNESCO site Lascaux Caves (Arayici *et al.,* 2017). It may be said that the HBIM concept started emerging in the mid-1990s where heritage projects started using scanning technologies combined with 3D models. In the following two decades many research projects emphasized digitalising heritage, using different approaches such as Geographic Information System (GIS) to reconstruct sites. In 2012, UNESCO further deployed HBIM concept in "The Memory of the World in the Digital Age: Digitising and Preservation" conference, further enhancing the argument that HBIM is capable to respond to the needs of heritage sites.

BIM in Heritage (HBIM)

Despite BIM's constant development concerning newly built projects, HBIM research illustrates its limitations concerning historical modelling. Modelling historical assets is not a simple procedure due to the complex and irregular objects involved which are often not presented in BIM libraries (López *et al.,* 2018). Thus, it is crucial to adopt survey technologies into BIM to produce accurate digitalised reconstructions of heritage projects. Although HBIM is commonly identified as historical parametric libraries, the first papers which discussed it (Murphy *et al.,* 2009, Chenaux *et al.,* 2011, Murphy *et al.,* 2013) described it as a three phases process:

1. Data survey carried through Laser scanning, photogrammetry or both;
2. Surveyed data processing through various procedures such as noise filtering, re-sampling and point clouds registration;
3. Modelling phase where point clouds are imported into BIM environments, assigned mesh surfaces and textures.

In contrast, Hichri *et al.,* 2013 describe the process as three different stages: the existing data survey followed by virtually reconstructing the geometrical elements, attribution of information and materials to the elements and lastly establishing relationships between them. Both descriptions provide an insight into the process yet lack the flexibility that is needed due to heritage buildings unique nature. For instance, destroyed sites may not offer physical elements to be scanned and thus there could be no survey phase, only modelling while relying on historical documents. Other projects may require special uses such as analysis, structural or thermal analysis, or visualization which would require the addition of a fourth phase that includes the usage of the HBIM created according to its purposes. It could be said that the HBIM stages are shaped by the goals and conditions of each project.

HBIM Survey Technologies

Surveying a heritage building means detecting its dimensions, geometrical elements and more. Traditionally, surveys were conducted using a triangulation method which consists of on-site manual measurements (Carpiceci 2000). This section seeks to briefly explain the current trends of data acquisition technologies and their contribution to HBIM.

- Laser Scanning: widely adopted due to its ability to accelerate data collection of complex components and buildings, as well as providing high levels of precision. Laser scanners can be terrestrial (TLS) or aerial, each differentiating according to the range and coverage distance (López *et al.,* 2018). Laser scanners use laser beams which travel towards the scanned area and back, measuring distances and angles to obtain a precise reconstruction of the three-dimensional elements in the form of millions of points (a cloud of points) with different coordinates (X, Y, Z) forming the asset (Martín Lerones *et al.,* 2010).
- Photogrammetry: is a contactless 3D measurement method based on several high-quality images used as a reference when creating historical buildings' models (Historic England 2017). Using triangulation principles, shots are taken in several places while having overlapping points. The photographs captured go through various processes individually such as intersecting characteristics and scaling, later they are combined and imported into specific software to generate a point cloud. (Furukawa *et al.,* 2009). This method is becoming increasingly accessible as a cheap and fast way to capture reality due to available software and free quality photographs available online.
- Point Clouds: produced as discussed earlier, point clouds accurately represent the elements surveyed. Yet, they hold no information beyond the physical attributes they portray. Thus, post-capturing processing is crucial to correctly recognize elements.

Murphy *et al.,* 2009 describe the common processes as:

1. Noise filtering: detecting and deleting scanned elements that are not required.
2. Point cloud registration: multiple scans conducted generate several "partial-point clouds" that overlap with a percentage (usually 20-30%), those clouds are merged to produce a "global cloud" that represents the site (López *et al.,* 2018).
3. Meshing: creating surfaces to be transformed into three-dimensional elements later in BIM platforms.

It should be noted that the suitable survey method depends on the project's nature, as they hold disadvantages to be considered. For instance, the high cost of laser scanning technologies and specialised labour and the laborious processing and photographic reconstruction in photogrammetry. In projects concerning lost or damages heritage, one can only rely on archival information to reconstruct missing parts while in other instances. Thus, techniques adopted should be chosen according to the nature of the project concerned.

BIM Platforms for Heritage

BIM platforms which can be used to maintain, document and operate heritage can be classified into three sets (López *et al.,* 2018):

- 3D Modellers: platforms to virtualise the physical components of historical buildings such as Revit, Tekla Structures, ArchiCad and Bentley System.
- 3D Viewers: platforms used to view spaces within buildings in a virtual reality setting such as SketchUp, Navisworks Freedom and Tekla BIMsight.

- Analysers: tools that are usually external to BIM used to analyse 3D models such as DAYSIM, Energy Plus and Ecotect Analysis.

Furthermore, these sets can be classified according to accessibility into free, commercial and open source depending on the supplier. BIM tools allow constructing parametric elements which hold geometrical and historical information. These elements could be adapted and used in future cases where a similar architectural vocabulary is documented. Many attempts were conducted to construct HBIM libraries such as Murphy *et al. (*2013) and Baik *et al. (*2014). Although such attempts could reduce the time of producing HBIM models, it may be considered that such standardisation approach does not fit heritage nature as historic elements are considered unique and valued accordingly.

RESEARCH METHODLOGY

To offer insight into the application of HBIM in the reconstruction of damaged sites, systematic literature research was conducted to identify any published case studies that responded to this condition. Keywords were used such as “HBIM”, “Heritage Reconstruction”, “Heritage Restoration”, “Digital Historical Reconstruction”, and “Virtual Reconstruction” in Google and Google Scholar engines. The aim was to identify the various methods and procedures that were used in reconstructing assets after destruction events. Cases deemed eligible to be included were ones that represented a practical example of applying HBIM to a damaged heritage asset. This research was conducted from October 2019 to May 2020 at which time the database was 10 cases (see Table 1). Out of which 1 is a journal paper, 7 were conference proceedings, and 2 a result of support from software commercial suppliers. The small number of eligible cases indicates that little research is conducted at the time of this study concerning post-destruction heritage recovery using HBIM.

Table 1: Information of HBIM reconstruction case studies

Case Study	Location	Historical Period	Destruction Period	Destruction Factor	Reference
Aceh’s heritage	Aceh, Indonesia	17th - 20th Century	2004	Tsunami	(Nichols *et al.*, 2016)
Aleppo's Citadel	Aleppo, Syria	8th to 14th Century AD	2012-2016	Syrian Conflict	(Fangi 2019)
Altai mission churches	Altai, Russia	19th Century	1920-1930	Anti-Religion Campaigns	(Kreydun 2014)
Basilica di Collemaggio	L’Aquila, Italy	End of 13th century	2009	Earthquake	(Oreni *et al.*, 2014)
Castillo de San Jorge	Seville, Spain	12th century	19th century	Urban development	(Saviello 2018)
The Ice House	Milan, Italy	17th Century	1940-1945	Heavy Bombing in World War II	(Oreni *et al.*, 2017)
Notre Dame Cathedral	Paris, France	1163-1345	2019	Fire during maintenance	(Milburn 2019)
St. Catherine’s Monastery	Nuremberg, Germany	1297	1945	Bombing raid	(Ludwig *et al.*, 2013)
Turin's Thirties Fascist Houses	Turin, Italy	1920s to 1940s	After 1943	Destruction campaigns	(Bruno Jr. and Spallone 2015)
Vinohrady Synagogue	Prague, Czech	1896 - 1898	1945 - 1951	Nazi Air Raids	(Boeykens *et al.*, 2012)

Data from each case study was extracted to examine the site studied, project output, methods, and software used in the HBIM production process. This resulted in identifying two sets of variables concerning the case studies analysis, the first relating to the site and the other related to the publication (see Table 2). These variables were the unified measurement tools used in a spread sheet to qualitatively analyse and compare the HBIM methodologies.

Table 2: Case studies Variables

Site Variables			Publication Variables
Heritage Site	Historical Period	Project Output	HBIM Methodology
Location	Destruction Period	Software	Advantages
Destruction Factor		Disadvantages	Publishing Platform

DATA ANALYSIS AND FINDINGS

A detailed analysis was conducted via a spread sheet using tabulation analysis method. Tabulation was chosen due to its cross-comparative nature and ability to demonstrate the different decision-making procedure within each case. The resulting table is mostly textual to provide direct reference for the variables in each approach, sections of this analysis will be discussed in the points below.

Case Studies Output

HBIM provides many possibilities of usage such as 3D, 4D and 5D models, analysis, visualization, augmented reality and even interactive experiences. Analysis of case studies identified the outputs in Table 3.

Table 3: Stated output of HBIM case studies

Site	Project Output
Aceh's built heritage	Proposing a methodology for re-creating Aceh's destroyed built heritage
Aleppo's Citadel	Perform 3D surveys and comparisons of monuments affected by the war
Altai mission churches	Recreating the look of the lost buildings using archive documents
Basilica di Collemaggio	Produce a detailed HBIM to manage the analysis, simulation of structural behaviour, economic evaluation and final restoration
Castillo de San Jorge	Produce a virtual reconstruction of the medieval configuration of the castle.
The Ice House	a. Fully document the existing condition of the Ice House b. Develop two BIMs in two leading software to compare the parametric capabilities and modelling conditions
Notre Dame de Paris	Collaborative research through architectural history and BIM.
St. Catherine's Monastery	Deliver a representation of the interior and exterior to present observers
Turin's Thirties Fascist Houses	a. Conserving the memory of this part of the Italian architectural history b. analysis of architectural language and reinterpretation of architectural works. c. Visualization by producing Photos and Videos
Vinohrady Synagogue	a. Documenting the existence of the lost heritage b. Visualization photo-realistic rendering c. Comparison between archive documents and realistic rendition

The three most common purposes were documenting the original state prior to damage, producing visualizations to initiate interactivity, and finally, to preserve the memory of a certain architectural style that no longer stands. There were cases such as the Ice House (Oreni *et al.,* 2017) which provided technical outputs such as comparing two BIM software, Revit and ArchiCAD, in HBIM reconstruction. Another is the Notre dame (Milburn *et al.,* 2019) which sought to test the collaboration of BIM with a global team using BIM 360 platform. All cases describe that those outputs have been achieved incompletely and illustrate more future potentials for HBIM purposes.

HBIM Methodology

What can be seen from Table 4, is that there were various methods of Data acquisition depending on the state of the damaged asset, output required, and available expertise. Reconstructing sites that no longer stand provides several challenges that may vary on case to case bases. Four cases show the integration between laser scanning and photogrammetry as a method to produce a textured point cloud that could be converted afterward into a BIM platform. On the contrary, cases, where assets were lost, could not use those technologies and have used various processes.

Table 4: Methodologies used in HBIM case studies

Site	Methodology
Aceh's built heritage	1. Capturing tangible and intangible data using VERNADOC; 2. Digitalising images and drawings to produce models; 3. Incorporating stakeholders through online exhibition.
Aleppo's Citadel	1. Data acquisition using Spherical Photogrammetry in three methods: existing and old scans, existing scans and old photographs, only existing scans; 2. Processing of Data acquired; 3. 3D reconstruction was done by various researchers.
Altai mission churches	1. Surveys using photo fixation, archaeological clearing and on-site measurements; 2. Topology analysis conducted through GIS and using old photographs; 3. 3D models generation based on GIS analysis.
Basilica di Collemaggio	1. Scanning the available structure by laser scanning and photogrammetry; 2. The interpretation of information; 3. Modelling structural elements using Rhinoceros, Bentley Pointools and Revit; 4. Analysing HBIM produced to identify structural integrity and state.
Castillo de San Jorge	1. Accurate historical analysis to understand the origin of the ruins; 2. Using Laser scanning and photogrammetry followed by processing the point cloud; 3. Modelling in Revit and adding complex details through 3Ds MAX; 4. Sharing the HBIM model with stakeholders.
The Ice House of	1. Data collected by laser scanning and photogrammetry; 2. Point clouds processed using AutoCad and modelled in Revit and ArchiCad; 3. Testing cloud-based approach by Autodesk 360.
Notre Dame de Paris	1. Thorough research of the cathedral by studying available documents; 2. Creating and developing parametric families using Revit and 3Ds Max; 3. Visualization using Enscape and Photoshop.
St. Catherine's Monastery	1. Thorough investigation of the available historic data; 2. Laser scanning and photogrammetry data collection on site; 3. Point clouds processing using Elcovision 10; 4. Modelling parts using ArchiCAD, Vectorworks and Revit.
Turin's Thirties Fascist Houses	1. Analysis of all the preserved documentation; 2. Interpretation of the documents and establishing relationships; 3. 2D and 3D Models realization; 4. Texture mapping, addition of lights and rendering.
Vinohrady Synagogue	1. Historical archives search; 2. Comparing the documents with available drawings; 3. Modelling and constructing the elements library using ArchiCAD; 4. Archiving files.

Such unconventional methods can be seen in Aceh's heritage (Nichols *et al.,* 2016) case where Vernacular Documentation (VERNADOC) was used, a method of applying information directly to paper on-site and later translating it into digitalized models. However, this can be challenging and faulty, moving information from paper to digital platforms may cause errors and be consuming time. Another method is Archaeological Clearing used in Altai mission churches (Kreydun 2014) where the author collected old resident's memories of the assets' appearance. Yet, basing reconstruction on residents' memory and building style speculation may result in inaccuracy. Lastly, Vinohrady Synagogue's case (Boeykens *et al.,* 2012) based all reconstruction information on available city archives. The particular cases mentioned above discussed the issue of incomplete information in lost heritage recovery, the process is often based on archive information and influenced by speculations, personal expertise, and decisions resulting in issues of historical validity. Thus, a key element in the process is properly documenting all decisions made to clarify interpretations adopted in historical models.

For software, the cases highlighted limitations in BIM software towards heritage modelling. For instance, The Ice House study provides a comparison of two BIM software, highlighting that the process of importing point clouds into Revit is laborious and requires using non-BIM software. While the same process is much more direct in ArchiCad where point clouds can be directly imported. Furthermore, multiple cases (Basilica di Collemaggio, Castillo de San Jorge, Ice House, and the Notre Dame) illustrate the lacking ability of BIM software in modelling irregular shapes associated with heritage. The cases used external modelling software, such as Rhinoceros, Maya, and 3ds Max, to model irregular elements and then import them as mesh elements into BIM environments. Hence, those cases illustrate that historical reconstruction in BIM software could be difficult, lengthy and costly. Finally, all cases raised the importance of non-physical data collection in the process of reconstruction. Thorough historical archive research appears to be the first step in all cases discussed to understand materials, structure and state of buildings.

CONCLUSION AND RECOMMENDATIONS

This research introduced a review of HBIM in documenting and modelling damaged heritage. The attention was positioned on illustrating different approaches to properly assess HBIM reconstruction workflow. Despite positive additions to BIM's platforms, it still shows lacking technical support for heritage's complex geometry, existing HBIM libraries seem to be fairly limited and not internationally adapted. Furthermore, the lack of medium platforms between data acquisition technologies and modelling platforms often causes segmentation and error. Thus, there seem to be two main steps towards active historical digitalising: developing libraries that facilitate the management of historical data with other information sources and creating platforms that connect information collection devices with BIM software on common bases of processing data. Perhaps, other lessons that can be learnt the cases is that there should be a proactive recognisance survey on existing monuments that has cultural values; with the intention to commence their digitalisation and documentation. This could provide crucial information in post-damage cases like the Notre Dame which is currently being restored based on laser scans that were done previously. Moreover, the use of HBIM to re-create and restore important cultural edifice has potentials to enhance their commercial quotient, Digitalisation can help museum tourists to access restored edifices in the comfort of their houses, which proved its importance in the COVID-19 epidemic in addition to valuable in sites belonging to risk zone countries.

REFERENCES

Arayici, Y, Counsell, J, Mahdjoubi, L, Nagy, G, Hawas, S and Dweidar, K (Eds.) (2017) *Heritage Building Information Modelling*, Abingdon, UK: Taylor and Francis.

Baik, A, Alitany, A, Boehm, J and Robson, S (2014) Jeddah Historical Building Information Modelling JHBIM-Object library, *International Society for Photogrammetry and Remote Sensing*, **2**, 41.

Boeykens, S, Himpe, C and Martens, B (2012) A case study of using BIM in historical reconstruction: The Vinohrady Synagogue in Prague, *In*: *Proceedings of the 30th International ECAADe Conference (Education and Research in Computer Aided Architectural Design in Europe)*, 12-14 September, Prague, **1**, 729-738.

Bruno Jr, A and Spallone, R (2015) Cultural heritage conservation and communication by digital modelling tools: Case studies: Minor architectures of the thirties in the Turin area, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **2**(5)/W3, 25-32.

Bryde, D, Broquetas, M and Volm, J (2013) The project benefits of Building Information Modelling (BIM), *International Journal of Project Management*, **31**(7), 971-980.

Carpiceci, M (2000) *The Relief of the Architectural Space: Geometric and Graphic Principles (Italian)*, Rome, Italy: Kappa.

Chenaux, A, Murphy, M, Keenaghan, G, Jenkins, J, McGovern, E and Pavia, S (2011) Combining a virtual learning tool and onsite study visits of four conservation sites in Europe, *Geoinformatics FCE CTU*, **6**(0), 157-69.

Cooperative Research Centre for Construction Innovation (2009) *National Guidelines for Digital Modelling Icon*, Brisbane, Australia: Net Pty Ltd.

Fangi, G (2019) Aleppo - before and after, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, XLII-2/W9, 333-338.

Furukawa, Y, Curless, B, Seitz, S M and Szeliski, R (2009) Reconstructing building interiors from images, *In*: *Proceedings of the 12th IEEE International Conference on Computer Vision*, 29 September - 2 October, Kyoto, 80-87.

Global Heritage Fund (2010) *Saving Our Vanishing Heritage: Safeguarding Endangered Cultural Heritage Sites in the Developing World*, California, USA: World Heritage Encyclopaedia.

Hichri, N, Stefani, C, De Luca, L and Veron, P (2013) Review of the As-Built BIM approaches, *In*: Proceedings of the 3D-ARCH conference: 3D Virtual Reconstruction and Visualization of Complex Architectures, 25-26 February 2013, Trento, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Vol **40**(5)/W1, 107-112.

Historic England (2017) *Photogrammetric Applications for Cultural Heritage: Guidance for Good Practice*, Available from https://historicengland.org.uk/images-books/publications/photogrammetric-applications-for-cultural-heritage/ [Accessed 6th December 2019].

Jokilehto, J (2013) *Reconstruction in the World Heritage Context, European Association for Architectural Education*, Available from https://engagingconservationyork.files.wordpress.com/2014/02/reconstruction-in-wh-context-rev.pdf [Accessed 5th December 2019].

Kreydun, Y (2014) Virtual reconstruction of the lost listed buildings in the case of the Altai mission churches, *Journal of Life Science*, **11**(10), 394-398.

López, J, Lerones, P, Llamas, J, Gómez-Garcia-Bermejo, J and Zalama, J (2018) A review of Heritage Building Information Modelling (H-BIM), *Journal of Multimodal Technologies and Interaction*, **2**(21).

Ludwig, M, Herbst, G, Rieke-Zapp, D, Rosenbauer, R, Rutishauser, S and Zellweger, A (2013) The advantages of parametric modelling for the reconstruction of historic buildings: The example of the in war destroyed church of St Catherine (Katharinenkirche) in Nuremberg, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **40**(5), 161-5.

Martín Lerones, P, Llamas Fernández, J, Melero Gil, A, Gómez García-Bermejo, J and Zalama Casanova, E (2010) A practical approach to making accurate 3D layouts of interesting cultural heritage sites through digital models, *Journal of Cultural Heritage*, **11**(1), 1-9.

Milburn, A (2019) Discovering History with BIM-Project Notre Dame, *In*: *Proceedings of Autodesk University Conference*, 18-21 November 2019, Las Vigas, Autodesk Available from https://www.autodesk.com/autodesk-university/class/Discovering-History-BIM-Project-Notre-Dame-2019-0 [Accessed 6th December 2019].

Murphy, M, McGovern, E and Pavia, S (2009) Historic building information modelling (HBIM), *Structural Survey*, **27**(4), 311-327.

Murphy, M, McGovern, E and Pavia S (2013) Historic Building Information Modelling: Adding intelligence to laser and image-based surveys of European classical architecture, I*nternational Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **76**, 89-102.

Nichols, J, Fong, D and Avey, S (2016) Re-envisioning lost built cultural heritage: Post-Tsunami Aceh, *In*: *Proceedings of the 7th International Conference on Engineering and Science for Research and Development (ICESR&D)*, 25-26 October, Banda Aceh, 83-93.

Oreni, D, Brumana, R, Della Torre, S, Banf, F, Barazzetti L and Previtali, M (2014) Survey turned into HBIM: The restoration and the work involved concerning the Basilica di Collemaggio after the earthquake (L'Aquila), *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **2**(5), 267-73.

Oreni, D, Karimi, G and Barazzetti, L (2017) Applying BIM to built heritage with complex shapes: the Ice House of Filarete's Ospedale Maggiore in Milan, Italy, *The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, **42**(2), 553-560.

Saviello, S (2018) *Survey Project: Castillo De San Jorge*, Available from https://academy.autodesk.com/portfolios/survey-project-castillo-de-san-jorge [Accessed 12th May 2020].

UNESCO (1976) *Recommendation Concerning the Safeguarding and Contemporary Role of Historic Areas*, Available from http://portal.unesco.org/en/ev.php-URL_ID=13133&URL_DO=DO_TOPIC&URL_SECTION=201.html [Accessed 12th May 2020].

UNESCO (2013) *World Heritage Sites Attacked During War*, Available from https://issuu.com/unesconow/docs/unesco_protect_culture_in_times_of_war [Accessed 12th May 2020].