PRESERVING AND MANAGING HERITAGE BUILDINGS IN A SUSTAINABLE WAY WITH INTEGRATION OF BIM – A REVIEW

Lina Seduikyte[(a)], Angeliki Kylili[(b)], Jolanta Sadauskiene[(c)] Paris Fokaides[(d)]

[(a), (c)] Kaunas University of Technology, Faculty of Civil Engineering and Architecture, Department of Building Energy System, Kaunas, Lithuania
[(b), (d)] Frederick University, School of Engineering and Applied Sciences, Cyprus

[(a)]lina.seduikyte@ktu.lt, [(b)]res.ka@frederick.ac.cy, [(c)]jolanta.sadauskiene@ktu.lt, [(d)]eng.fp@frederick.ac.cy

ABSTRACT
Heritage buildings through retrofitting are able to minimize CO_2 emission, the use of energy and "work" as sustainable buildings.
For the renovation process and preservation of the heritage building new digital tools such as Building Information Model (BIM) should be used. BIM is also useful for the decision making and choosing the right strategies and materials.
The paper, through literature review, is analysing sustainable implementations during the retrofit process of heritage buildings and analyses the use of progressive BIM tool for preservation and management of heritage buildings.

Keywords: heritage, sustainability, BIM

1. INTRODUCTION
Each country should preserve and investigate the past in order to create the future.
With nowadays technologies and knowledge it can be done in a sustainable and digital way. Figure 1 presents the main components of sustainability: environment, economic and social. This diagram was first launched at the 2005 World Summit on Social Development and continues to be a valid attempt to describe sustainability. Smart retrofitting of existing, equally heritage, buildings can play a significant role in creating a sustainable future.
The increasing use of Building Information Model (BIM) in construction sector because of many benefits and resource savings during design, planning, and construction of new buildings is noticed in the past decades. Moreover, in the last years BIM is applied for conservation and management of heritage buildings as well.
The aim of this paper, through literature review, (1) to analyses sustainable implementations during the retrofit process of heritage buildings and (2) to analyse the use of progressive BIM tool for preservation and management of heritage buildings.
The conclusions and recommendations of this research will be useful for heritage professionals, researchers and decision makers in both governmental and industry level who are involved in preservation of heritage buildings.

Figure 1: Main components of sustainability

2. HERITAHE AND SUSTAINABILITY
Buildings of European countries use almost 40% of the global energy, by generating the 40–50% of the total output of greenhouse gases. The heating requirement is responsible for almost 80% of the energy demand in houses. Demand for cooling is growing as well.
Since historic buildings constitute 25% of the European built environment they have a role to play in delivering CO_2 emissions reduction targets along with the rest of the domestic stock (Moran et al. 2014).
Sustainability of energy systems are related to sustainable energy supply systems, integration of renewable energy, management of energy demand, and sustainable energy consumption. Building sector,

including heritage buildings, has the largest potential for energy saving.

Heritage buildings generally use more energy compared to the buildings which were built recently. However, retrofit of heritage buildings should be done in a different way, with respect to historical, sociocultural and architectural values.

The implementation of sustainable retrofit of historic buildings represents a huge challenge, which gives a significant impact on the global energy consumption.

Heritage buildings, such as churches, should also meet required indoor microclimate conditions. First of all to save artworks and secondly to insure good thermal comfort for people staying indoors. Thermal comfort and the preservation of artworks are often in conflict with each other, so a balance between these two is needed.

Table 1 presents several investigation of heritage buildings and strategies implemented for energy saving (1-7) and preservation of art works (8-9).

Lassandro et al. (2015) made a survey on heritage school building and developed methodology based on a holistic approach that correlates students post occupancy evaluation with instrumental survey and software simulations. The results showed, that the energy audit through virtual tour is an innovative tool that, due to the replicability of the energy retrofitting solutions categories, can be transferred to other school buildings especially with the same construction type and implemented with further evaluations about acoustic comfort and indoor air quality.

The study presented by Ben and Steemers (2014) demonstrates that balanced approaches can be developed to retrofit heritage and meet the requirement of both energy efficiency and heritage conservation.

Pankhurst and Harris (2013) presented “eco” renovation example of Victorian stable yard (Modern Hall Park, south-west London). Building is saving and generating energy. In the presented project it was specified that, where possible, materials must be of low embodied energy, from sustainable resources or recycled materials, locally sourced and have a low environmental impact.

Grytli et al. (2012) examined different short and long term impacts from various energy efficiency measures on a model building by combining life cycle assessment, energy calculations and a self-developed heritage value assessment system. By combining the results from the different analyses in an integrated decision-making tool, it was possible to discuss optimal solutions for energy improvement, taking both environmental and heritage aspects into consideration.

Thermal-energy, environmental, and economic assessment of retrofit solutions and optimized scenarios for energy saving, could present a key answer to strike down the energy requirements in heritage buildings. When smart methodologies are integrated in heritage buildings, these buildings are more “friendly” for public use.

3. HERITAHE AND BIM

BIM is the process of generating, storing, managing, exchanging and sharing building information in an interoperable and reusable way (Vanlande et al. 2008).

BIM can be used for buildings of different size and purpose (residential, commercial, healthcare, educational, heritage and other types).

The use of BIM differs between countries. The increase of digitalisation, sustainability requirements, cloud computing will increase and extend the use of BIM in new and existing buildings.

Volk et al. (2014) presented literature review of BIM used for existing buildings with focus on maintenance and deconstruction life cycle stages.

Khosrowshahi and Arayici (2012) presented roadmap for implementation of BIM in the UK construction industry. The findings suggested three structured patterns - organisational culture, education and training, and information management - to tackle technology, process and people issues in BIM implementation.

Wong and Zhou (2015) made literature review and concluded that green BIM has emerged as a popular energy performance analysis tool during buildings design stage. BIM was applied for emission estimation and monitoring of the carbon footprints of construction projects.

New research integrates BIM with Life Cycle Assessment (LCA) for the maximization of its impact in building project and the demonstration of the benefits that arise from the synergy of the two (Kylili et al. 2015, Ajayi et al. 2015).

The need of retrofit of heritage buildings is becoming as much important as construction of new buildings. New approach, such as implementation of BIM, will improve the way of working with saving of time and money.

Mezzino (2014) discuses digitalization of cultural heritage and connection of BIM and Geographic Information System (GIS), which could provide a platform for creation of new meanings stemming from the interaction of different users and stakeholders engaged in its preservation and enhancement.

Del Giudice and Osello (2013) introduced national InnovANCE project (Italy), which aims to develop the first national database able to share information among professionals through the help of BIM.

Hichri et al. (2013) presents critical analysis of the application of BIM in the field of cultural heritage.

Table 2 present nine case studies on historic building and BIM. In analysed cases implementation of BIM resulted in representation of historical and archaeological objects, creating of BIM models of historic buildings, representation of urban centres, and automation of engineering drawings for conservation process.

Table 1: Investigation of heritage buildings and strategies implemented for energy saving and preservation of art works

Nr.	Authors	Heritage buildings	Tested strategies or implementations	Results
1.	Pisello et al. (2016)	Palazzo Gallenga Stuart, a four story university building, Italy	Building energy efficiency has been pursued through two strategies: - innovative cool tiles with the same appearance of traditional historic tiles; - geothermal heat pump system with water storage tanks positioned in the under-ground unoccupied areas of the building.	Application of the innovative cool tiles lead to a maximum cooling energy saving of 14.0% and 3.8% in the classrooms of the top floor and in the whole building, respectively. The installation of a more effective energy plant leads to an average energy saving of 64.3% and 67.0% in terms of heating and cooling demand, respectively. The combination of the two effects leads to an average energy saving of 64.0% for heating and 69.2% for cooling.
2.	Todorovic et al. (2015)	Museum of Aviation in Belgrade, Serbia	This study encompasses six versions of BIPV (Building Integrated Photovoltaic), including non-transparent opaque type and two types of semi-transparent (with 20% and 30% visible light transmittance). Defined models have been studied by BPS (Building Performance Simulation) and co-simulation coupling BES (Building Energy Simulation) and two domains CFD simulation (outdoor and indoor).	The results of the present study confirm that the total electricity demand of heat pump operation in heating and cooling regimes, as well as the whole HVAC system's power demand, and in addition lighting demand are smaller than potential PV electricity power and produced energy. The Museum's deep RES (renewable energy sources) integrated refurbishment could result in reaching the Museum's Zero CO2 emission status, cost-effectively transforming this historic building in sustainable Energy Plus building.
3.	Burattini et al. (2015)	Historic center of Tivoli, a town close to Rome, Italy	Four passive strategies were examined and applied based on the location of the building and the non-alteration of the structure and the landscape. Energy analyses of historical buildings were done according to recommendations of the UNI TS 11300-Part1. The calculations were performed only on the building envelope, based on passive solutions and alternatives.	Results showed that it is possible to improve the energy performance of an existing building achieving a significant energy saving with the respect of the building architecture, shape, function and the surrounding landscape. The annual energy savings reached a maximum value of 25%.
4.	Sahin et al. (2015)	Basmane Neighborhood Centre, Turkey	Three energy efficient retrofit packages (which included: air tightening of the buildings, indoor air temperature control, changing type of the heating and/or fuel, insulation of the attic floor, additional roof insulation, insulation of walls, additional insulation of the ground floor) were evaluated with respect to their effect on the energy consumption.	Results showed, that energy savings of more than 34% could be obtained without damaging the heritage values.
5.	Ascione et al. (2015)	Educational building of the University of Sannio, Benevento, Italy	Three main steps were conducted: - the building performance assessment and energy diagnosis, - numerical studies by means of hourly energy simulations with a deepening about the calibration of the simulation model, - investigation of potential energy savings and	In the presented research, the most suitable combination of energy efficiency measures has resulted with the replacement of windows with low emissive ones, the application of thermal plaster and the new thermal insulation of the roof slab. Annual primary energy demand for the microclimatic control and the greenhouse emissions was reduced by 38%. The total cost of the package was around 123,610 €.

			environmental benefits, by evaluating their economical profitability.	
6.	Harrestrup and Svendsen (2015)	A multi-storey building Copenhagen, Denmark	Investigation of possibility to carry out moisture safe energy renovations and saving 50% of the building's energy consumption by use of existing technologies.	In the analysed project moisture safety was put prior to energy savings. Internal insulation and mechanical ventilation systems were installed and analysed, and the windows were replaced with new ones. It was found that the measured annual energy consumption was reduced to 47%.
7.	Bellia et al. (2015)	Palazzo Fuga, Naples, Italy	Energy efficiency interventions on the building envelope and its plants.	Results showed, that: - an opaque PV roof results to be more convenient than a semitransparent PV roof, for aesthetic, energy production and the-mal comfort aims; - given the windows' geometry and location, no significant variation in daylight access can be obtained without modifying the envelope's aesthetic; -the presence of thick and heavy external walls requires no intervention of thermal insulation; - the estimated PV energy production with the opaque solution is about 107.9 MWh/year; - interventions on windows and on the floor at the VII level determine estimated energy savings of about 27.1% for the entire heating season; - the estimated annual reduction of carbon dioxide emissions is 32.1 t.
8.	Camuffo et al. (2010)	Church of Santa Maria Maddalena in Rocca Pietore, Italy	The proposed novel heating strategy is based on low-temperature radiant emitters mounted in a pew to provide a desirable distribution of heat to the feet, legs and hands of people occupying it; while leaving the conditions in the church, as a whole, undisturbed.	Due to little heat dispersion, this novel system significantly reduces the risk of mechanical stress in wooden artworks and panel or canvas paintings, fresco soiling and cyclic dissolution-recrystallization of soluble salts in the masonry, but is also energy-efficient.
9.	Samek et al. (2007)	Wooden church of St. Michael Archangel in Szalowa, Poland	Investigation in detail the effect of electric overhead radiators on the indoor environment of historic churches.	The heating system was not found to increase the concentration of SPM indoors; no re-suspension of particles already present in the church was observed. This work has demonstrated that the overhead radiant heaters are capable of providing localised heat to the areas where people congregate without adversely affecting painted walls and the works of arts displayed in churches.

Table 2: Case studies on historic building and BIM

Nr.	Authors	The purpose of use of BIM	Results
1.	Simeone et al. (2014)	To enhance information management during the investigation and restoration activities.	The core of the presented model is the integration of a BIM-based modelling environment and a knowledge base developed by means of ontologies, in order to represent all the semantics needed for a comprehensive representation of the historical artefact. Archaeological investigation process of the Castor and Pollux temple at Cori, Italy was made.
2.	Titomanlio et al. (2014)	BIM is the concrete method allowing the peculiarities of the architectural/restoration design and the structural counterpart to be simultaneously contemplated. In the BIM methodology for structures all the features of the virtual model are suitably contemplated.	In this paper, the BIM for cultural heritage is dealt with, outlining its main steps (inspections, measurements and surveys, non-destructive investigations, integrated structural modeling and s.o.) and configuring the new B.I.M.4S&D methodology. The latter is shown through the application to a historic masonry building.
3.	Rua et al. (2013)	This work is presenting an urban application developed into a GeoBIM tool, ESRI City Engine Software (CE), that integrates GIS (Geographic Information Systems) and BIM concepts.	Spatial analyses were conducted with the use digitalization - interactive representation of urban centres the downtown Lisbon city engine model.
4.	Dore et al. (2013)	For generating digital heritage models from laser scan or photogrammetric data using HBIM.	A library of parametric architectural objects has been designed from historic manuscripts and architectural pattern books. These parametric objects were built using an embedded programming language within the ArchiCAD BIM software called Geometric Description Language (GDL). Procedural modelling techniques have been implemented to create a parametric building facade which automatically combines library objects based on architectural rules and proportions.
5.	Garagnani et al. (2013)	To introduce a methodology destined to process point cloud data in a BIM environment with high accuracy.	Results of experiences on monumental sites documentation, generated through a plug-in written for Autodesk Revit and codenamed GreenSpider after its capability to layout points in space as if they were nodes of an ideal cobweb.
6.	Ludwig et al. (2013)	To counteract the process of disintegration and to get three dimensional building model of the Church of St. Catherine's.	The Gothic Church of St. Catherine was largely destroyed in a devastating bombing raid on January 2nd 1945. For the preparation of parametric architectural mode a heterogeneous set of data was used. The prepared BIM model was perfect for delivering impression of the interior and exterior of the church to present observers.
7.	Apollonio et al. (2013)	To prepare virtual reconstruction of buildings just documented by partial sketches, or partially built, or no more existing.	Conceptual similarity between the treaties and BIM were presented; a new and more robust solutions to the 3D modeling from 2D drawings for cultural heritage artifacts, able to allow the verification of the assumptions used during the reconstruction pipeline were presented.
8.	Baik et al. (2013)	BIM was used as a method to document and manage buildings of historical city of Jeddah.	New approach for heritage recording by using introduced Jeddah Historical Building Information Modelling (JHBIM).
9.	Murphy et al. (2013)	Development of conservation documentation; to automate conservation documentation in the form of engineering drawing and schedules from laser scan and image based surveys of historic structures.	A historic framework for building a parametric library of architectural elements was proposed. Several solutions for the development of parametric and shape rules to reproduce classical elements detailed using geometric descriptive language (GDL) were presented. A design scenario for end users was proposed to assess the suitability of HBIM as a tool for automation of engineering drawings for conservation process.

4. DISCUSION AND CONCLUSIONS

The review and analyses presented in this paper showed that heritage buildings could be considered as high energy performance buildings with innovative retrofit strategies. Such buildings cannot have typical retrofit strategies. However, innovative methods for the energy retrofit of heritage buildings should be implemented in all heritage projects.

Heritage buildings should also ensure required indoor microclimate conditions to save artworks and to insure good thermal comfort for people staying indoors.

As a conclusion of this paper, recommendations could be given to officers working at different levels (continental, EU, country, town) and dealing with preservation of heritage buildings. In order to save, monitor and retrofit these buildings in sustainable and digital way, some actions should be taken. Figure 2 presents fields where BIM could be used to ensure sustainable preservation and implementation of progressive actions during inventory and monitoring, retrofitting and strategical planning.

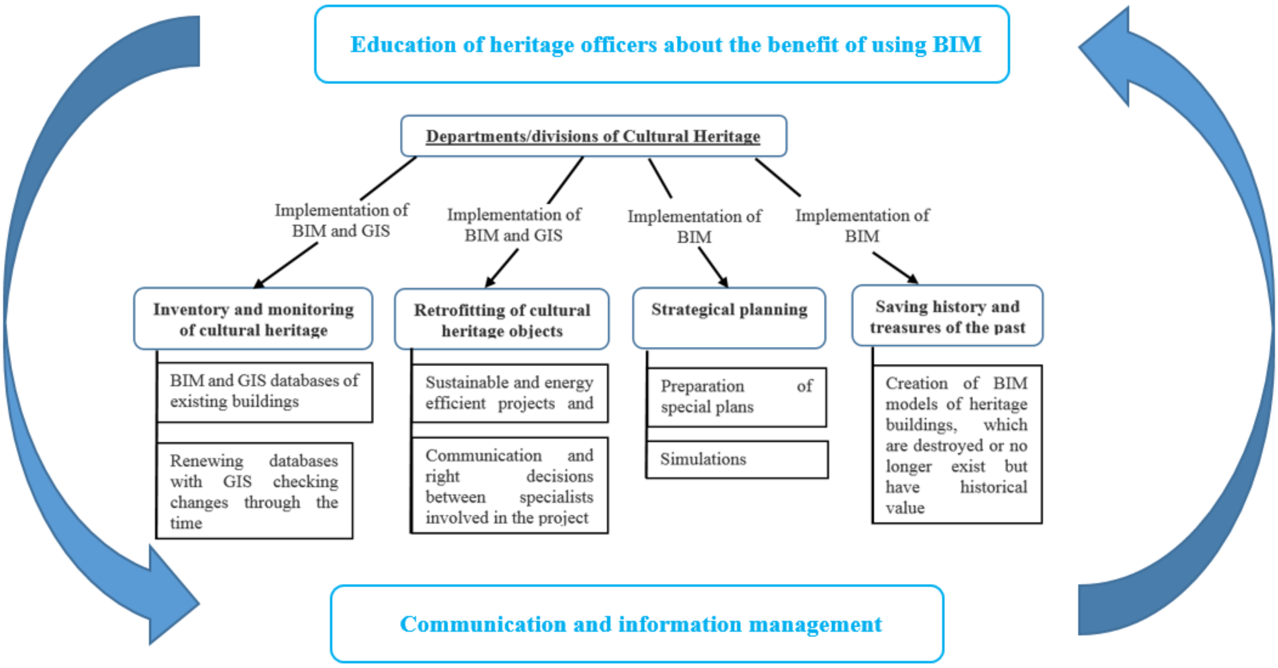

Figure 2: Digitalization of decision making in cultural heritage

Officers working in ministries and municipalities should invite BIM professional in order to ensure sustainable and advance work and decision making. Visualizations of the projects or objects always helps to ensure smooth communication between different specialists.

Using BIM and GIS for inventory and monitoring of heritage buildings will give possibilities to register changes through the time and take actions for preservation of cultural heritage.

BIM could be used in cases when heritage buildings no longer exist or there are only ruins. If the object has high historical value it could be recreated in digital way and presented through web platforms or Aps applications.

BIM could be used for strategical planning, when special plans are prepared. With BIM different simulation scenarios could be prepared for revival of heritage buildings and areas around them. With the right solutions, the functions of heritage buildings could be changed and the area could get "authority".

Each heritage building is unique and all actions should be taken case by case, taking into account all aspects.

The success of BIM depends on the size of the project, skills of team members in BIM, communication within the project team members.

In general, adaptation of BIM would be higher if there would be more experience within the project team and external organisations.

ACKNOWLEDGMENTS

This work was supported by COST Action TD1406 "Innovation in Intelligent Management of Heritage Buildings (i2MHB)".

The author would like to thank colleagues from Faculty of Civil Engineering and Architecture (KTU): prof. K.Zaleckis, asssoc. prof. dr. V. Karvelytė-Balbierienė and asssoc. prof. dr. D.Rekus for consultancy.

REFERENCES

Ajayi S.O., Oyedele L.O., Ceranic B., Gallanagh M., Kadiri K.O., 2015. Life cycle environmental performance of material specification: a BIM-enhanced comparative assessment. International Journal of Sustainable Building Technology and Urban Development 6(1): 14-24.

Apollonio F. I., Gaiani, M., Sun, Z., 2013. 3D modeling and data enrichment in digital reconstruction of architectural heritage. Proceedings of 24th International CIPA Symposium, pp. 43-48. September 2-6, Strasbour, France.

Ascione, F., Bianco, N., De Masi R.F., De'Rossi F., Vanoli G.P., 2015. Energy retrofit of an educational building in the ancient center of Benevento. Feasibility study of energy savings and respect of the historical value. Energy and Buildings 95: 172-183.

Baik A., Boehm J., Robson S., 2013. Jeddah historical building information modelling “JHBIM” old Jeddah – Saudi Arabia. Proceedings of 24th International CIPA Symposium, pp. 73-78. September 2-6, Strasbour, France.

Bellia L., Alfano F.R.D., Giordano J., Ianniello E., Riccio G., 2015. Energy requalification of a historical building: A case study. Energy and Buildings 95: 184-189.

Ben H., Steemers K., 2014. Energy retrofit and occupant behaviour in protected housing: A case study of the Brunswick Centre in London. Energy and Buildings 80: 120-130.

Burattini C., Nardecchia F., Bisegna F., Cellucci L., Gugliermetti F., Vollaro A., Salata F., Golasi I., 2015. Methodological approach to the energy analysis of unconstrained historical buildings. Sustainability 7(8): 10428-10444.

Camuffo D., Pagan E., Rissanen S., Bratasz L., Kozłowski R., Camuffo M., Valle A., 2010. An advanced church heating system favourable to artworks: A contribution to European standardisation. Journal of Cultural Heritage 11(2): 205-219.

Del Giudice M., Osello A., 2013. BIM for cultural Heritage. Proceedings of 24th International CIPA Symposium, pp. 225-229. September 2-6, Strasbour, France.

Dore C., Murphy M., 2013. Semi-automatic modelling of building facades with shape grammars using historic building information modeling. Proceedings of Conference on 3D Virtual Reconstruction and Visualization of Complex Architectures (3D-ARCH), pp. 57-64. February 26-26, Trento, Italy.

Garagnani S., Manferdini A.M., 2013. Parametric accuracy: building information modelling process applied to cultural heritage preservation. Proceedings of Conference on 3D Virtual Reconstruction and Visualization of Complex Architectures (3D-ARCH), pp. 87-92. February 26-26, Trento, Italy.

Grytli E., Kvaerness L., Rokseth L.S., Ygre K.F., 2012. The Impact of Energy Improvement Measures on Heritage Buildings. Journal of Architectural Conservation 18(3): 89-106.

Harrestrup M., Svendsen S., 2015. Full-scale test of an old heritage milti-storey building undergoing energy retrofitting with focus on internal insulation and moisture. Building and Environment 85: 123-133.

Hichri N., Stefani C., De Luca L., Veron P., Hamon G., 2013. From point cloud to BIM: a survey of existing approaches. Proceedings of 24th International CIPA Symposium, pp. 343-348. September 2-6, Strasbour, France.

Khosrowshahi F., Arayici Y., 2012. Roadmap for implementation of BIM in the UK construction industry. Engineering, Construction and Architecture Management 19(6): 610-635.

Kylili A., Fokaides P.A, Vaiciunas J., Seduikyte L., 2015. Integration of Building Information Modelling (BIM) and Life Cycle Assessment (LCA) for sustainable constructions. Journal of Sustainable Architecture and Civil Engineering, 13(4), 28 – 38.

Lassandro P., Cosola T., Tundo A., 2015. School building heritage: energy efficiency, thermal and lighting comfort evaluation via virtual tour. Proceedings of 6th International Building Physics conference, pp. 3168-3173. June 14-17, Torino, Italy.

Ludwig M., Herbst G., Rieke-Zapp D., Rosenbauer R., Rutishauser S., Zellweger A., 2013. The advantages of parametric modeling for the reconstruction of historic building. The example of the in war destroyed church of St. Catherine (Katharinenkirche) in numbering. Proceedings of Conference on 3D Virtual Reconstruction and Visualization of Complex Architectures (3D-ARCH), pp. 161-165. February 26-26, Trento, Italy.

Mezzino D. 2014. The digitalization of Cultural Heritage's tangible & intangible dimensions. Proceedings of 12th International Forum of Studies -The Paths of the Merchants, pp. 115-122. June 12-14, Aversa, Italy.

Moran F., Blight T., Natarajan S., Shea A., 2014. The use of Passive House Planning Package to reduce energy use and CO2 emissions in historic dwellings. Energy and Buildings 75: 216-227.

Murphy M., McGovern E., Pavia S., 2013. Historic building information modelling – adding intelligence to laser and image based surveys of European classical architecture. ISPRS Journal of Photogrammetry and remote Sensing 76: 89-102.

Pankhurst C., Harris A., 2013. Conservation and Innovation - The Challenge of 'Eco' Renovation in Heritage Buildings. Journal of Architectural Conservation 19(2): 18-34.

Pisello A.L., Petrozzi A., Castaldo V.L., Cortana F., 2016. On an innovative integrated technique for energy refurbishment of historical buildings: Thermal-energy, economic and environmental analysis of a case study. Applied Energy 162: 1313–1322.

Rua, H., Falcao, A.P., Roxo, A.F., 2013. Digital Models - Proposal for the Interactive Representation of Urban Centres The downtown Lisbon City Engine model. Proceedings of 31st International Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe), pp. 265-273. September 18-20, Delft, Netherlands.

Sahin C. D., Arsan Z.P., Tuncoku S.S., Brostrom T., Akkurt G.G., 2015. A transdisciplinary approach on the energy efficient retrofitting of a historic building in the Aegean Region of Turkey. Energy and Buildings 96: 128-139.

Samek L., Maeyer-Worobiec A., Spolnik Z., Bencs L., Kontozova V., Bratasz L., Koz1owski R., Grieken R., 2007. The impact of electric overhead radiant heating on the indoor environment of historic churches. Cultural Heritage 8: 361-369.

Simeone, D., Cursi, S., Toldo, I., Carrara, G., 2014. B(H) IM - Built Heritage Information Modelling Extending BIM approach to historical and archaeological heritage representation. Proceedings of 32nd International Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe), pp. 613-622. September 10-12, Newcastle upon Tyne, England.

Titomanlio, I., Faella, G. BIM and Structural Modeling: Application on Cultural Heritage. Proceedings of 12th International Forum of Studies -The Paths of the Merchants, pp. 973-979. June 12-14, Aversa, Italy.

Todorovic M.S., Ecim-Duric O., Nikolic S., Ristic S., Polic-Radovanovic S., 2015. Historic building's holistic and sustainable deep energy refurbishment via BPS, energy efficiency and renewable energy—A case study. Energy and Buildings 95: 130-137.

Vanlande R., Nicolle C., Cruz C., 2008. IFC and building lifecycle management. Automation in Construction 18(1): 70-78.

Volk R., Stengel J., Schultmann F., 2014. Building Information Modelling (BIM) for existing buildings – Literature review and future needs. Automation in Construction 38: 109-127.

Wong J.K.W., Zhou J., 2015. Enhancing environmental sustainability over building life cycles through green BIM: a review. Automation in Construction 57: 156-165.