# An integrated H-BIM approach for energy retrofit of built heritage

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## 1. INTRODUCTION

The latest Green Deal policy, released by the EU, prioritises energy efficiency in the building sector and highlights the importance of digitalisation of the building retrofitting process [1]. Historic buildings are usually excluded from legislation regarding minimum energy performance requirements, yet there is a great potential of energy consumption and greenhouse gas emission reductions thought the energy retrofit of the particular building stock [2]. Over the last decades, numerous guidelines and methodologies have been developed, outlining the procedure of decision-making for historic buildings refurbishment [3]. The stages of the process that are typically outlined in literature are: building survey and analysis including historical significance assessment, indoor environmental monitoring, energy auditing and dynamic simulation. Energy retrofits are often described in the literature as an act of balancing multiple criteria, among which conservation and energy consumption prevail. The criterion of economic viability is emerging, yet, the accessibility to funds is not covered by most methodology approaches, omitting a decisive factor in the implementation of the project.

Building Information Modelling (BIM) is an emerging and promising building asset management technology, able to integrate a broad spectrum of building information, such as object attributes and construction processes, that take place from the building's planning stage to its demolition. BIM supports a holistic modelling and analysis process by simultaneously assigning additional dimensions of information to the model objects, i.e., cost (4D), time (5D) and energy performance results (6D) [4]. The centralised digital platform of information management offered by native BIM software, ensures the minimization of duplicate modelling processes, provides a workflow less sensitive to human errors and eliminates accidental information neglection during the entire building development [4]. Despite the comparative advantages of BIM, its application for heritage refurbishments (HBIM) is rare. This is mainly attributed to the emerging complexities and the absence of standardised processes, namely, the scan-to-BIM intensive modelling process, insufficient software interoperability with third party numerical simulation engines and the inadequate data exchange between native BIM software [5]. Moreover, the lack of sufficient geometrical, historical and conservation state documentation data complicates the modelling and alphanumerical data collection for heritage buildings, since most of the heritage objects' geometry and data complexity impede standardisation and automation [6].

In order to tackle the challenges of an integrated H-BIM approach, the research project "BIM for Energy Efficiency in the Public sector" (BEEP) was launched in 2019, under the framework of ENI CBC MED [7]. BEEP main objective is to create a comprehensive methodology for Energy Efficiency Heritage BIM (EE-

HBIM), while supporting the financial decision-making through the enhancement of the Energy Performance Contracting process. The later mechanism promotes the involvement of private funds through the guaranteed energy savings deriving from the energy retrofit of the building [8]. The research findings and workflow guidelines will be implemented in seven pilot-cases from all the involved partner countries (Italy, Cyprus, Spain, Jordan, Palestine, Lebanon and Egypt). Through these pilot actions in public historic buildings, BEEP objective is to demonstrate the applicability of BIM technology in heritage buildings. This paper discusses the methodology of BEEP, along with its implementation stages in the pilot case-study in Nicosia, Cyprus.

## 2. AN INTEGRATED METHODOLOGY FOR EE-HBIM

BEEP project promotes two key elements for enriching the existing approaches regarding the energy retrofit of historic buildings, namely, the integration of digital technologies and the accessibility to funds. With regards to the latter, the objective of BEEP is to promote BIM use as trustworthy tool for financial evaluation of the return of investment (ROI) of the refurbishment project, and to foster the access of public administration to credit from private financial services. The project will provide guidelines, contributing towards new public administration practices by developing a single common approach for a) documenting and archiving heritage building's geometry and related construction attributes, b) performing dynamic energy performance analysis and selecting the energy retrofit measures, and finally c) preparing necessary documentation for pursuing private investments for retrofit implementation. Figure 1 presents the general outline of the concept and workflow of BEEP project.

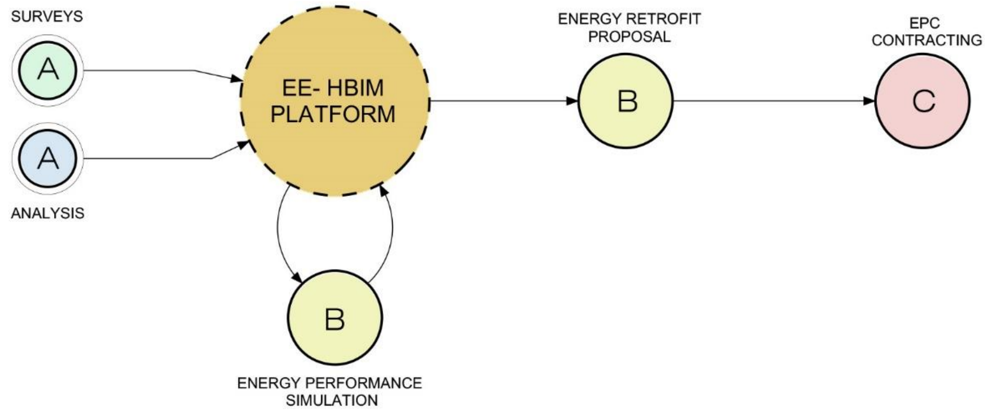


**Figure 1. Schematic representation of BEEP's project workflow.**

In addition, Figure 2 explains the BEEP methodology for achieving these objectives. The first step in the development of the Heritage Building Information Model (H-BIM) is the historic, geometric, and environmental data acquisition, i.e. *Building Analysis and Documentation* (*A*). In the consecutive Energy-Efficiency H-BIM model (EE-HBIM) preparation phase, additional integration of alphanumerical information of energy related analyses, is required, for passing on to the second step of *Energy Performance Assessment (B)*. Building Performance Simulations (BPS) enable the estimation of the environmental performance of the existing building and the selection of suitable energy retrofit measures. In the framework of the proposed pilot actions, three retrofit scenarios will be examined based on financial and energy consumption criteria, while accounting for compatibility with heritage building conservation constraints. The integration of the 4D and 5D dimensions (time and cost related metadata) in the subsequent enriched EE-HBIM model stage, focus on providing additional assessment features for the selection of the most cost-efficient rehabilitation strategy (cost-analysis indicators).

Finally, having concrete results regarding the guaranteed energy savings, the respective payback period and the projects' implementation timeframe, enhances the approach of Energy Service Providers (ESPs). The final stage, i.e. *Design and deployment of financing mechanisms (C)*, entails the respective actions for the preparation of the legal and technical framework documentation for proceeding with a potential Energy Performance Contract.

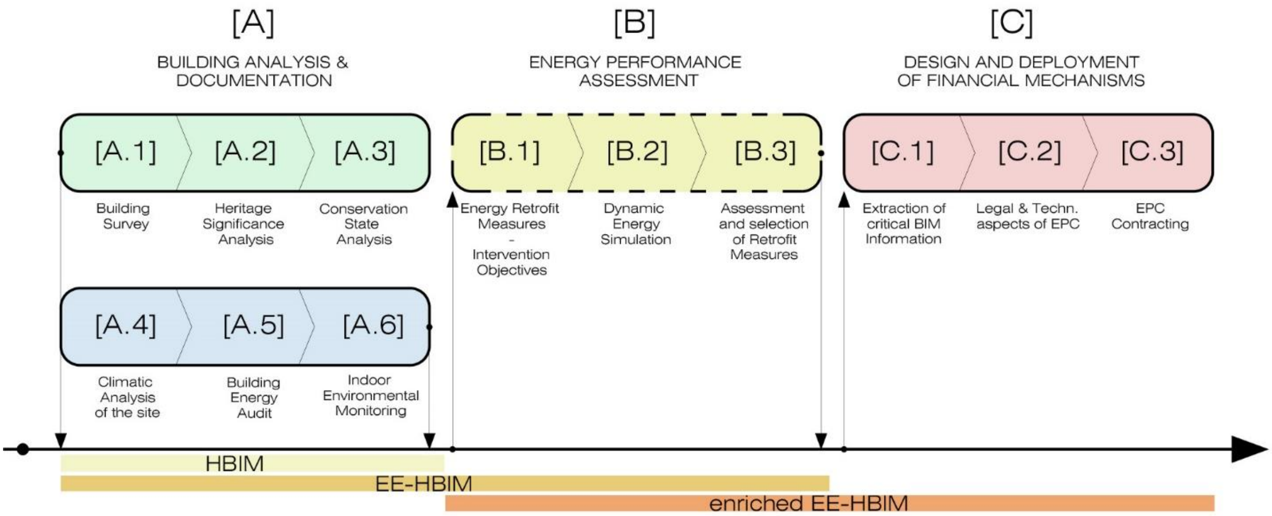


**Figure 2. Analytical EE-HBIM workflow**

## 2.1 BUILDING ANALYSIS AND DOCUMENTATION (A)

- Building survey:

  The careful documentation of the building involves the following: identification of legislative information, national zoning plans and other regulations, designation of heritage, technical documentation of the building geometry based on traditional and innovative techniques.

- Heritage significance analysis:

  The analysis entails archival research regarding the history and development of the building and its elements. This includes the study of historic layers (present and previous uses), the assessment of the heritage significance and vulnerability to change, as well as the conservation priorities or constraints on behalf of the heritage authorities.

- Conservation state Analysis:

  Documenting the building's structure and condition entails brief reporting regarding the construction materials, finishes, hygrothermal properties, decay phenomena and crack pattern analysis, identification of air leakage and moisture presence. These data are integrated in the HBIM model in the form of spreadsheets and general report sheets.

- Climatic analysis of the site:

  This set of data regard information about the local environment, climatic and topographic conditions of the area, physical interaction with adjacent objects (e.g. building, trees etc.) and assessment of the inherent passive strategies with regard to the local microclimate and the prevailing outdoor climatic conditions.

- Energy audit:

  The energy audit provides written documentation of the condition of the building and its energy-source systems. This involves the record of the technical characteristics of the existing mechanical systems, the lighting and plug loads, the water service systems, the setpoint and setback temperatures, as well as the operation and occupancy schedules.

- Indoor environmental monitoring:

  The current indoor environment should be documented through in-situ measurements and user surveys. The recommended monitoring period is one full calendar year. Indoor environmental data may involve the use of thermographic techniques, the installation of temperature, relative humidity, air movement, lighting and CO2 sensors in characteristic thermal zones.

## 2.2 HBIM MODELLING

BEEP methodology employs a dual building survey technique for creating a HBIM model at BIM Level 2. This is achieved by combining both traditional and innovative surveying techniques, i.e., topography, technical documentation and terrestrial laser scanning or photogrammetry. This collaborative documenting process can supply an accurate 3D point cloud with critical representation of its graphical rendering (points carrying RGB colour information) and a validating two-dimensional drawing file; together these two data types comprise the resources for the HBIM modelling initiation. This approach ensures the accuracy of the primary building structure orientation and scale, while maintaining important building details, such as artefacts or other decorative elements. In order to avoid time-consuming modelling processes, standardised modelling tools are used in the native BIM software. Mesh or irregular model geometry is not integrated. Modelling of building components characterising historic buildings, following conventional modelling tools of native BIM software could form the basis for establishing a rich database of intrinsic parametric BIM components contributing to international efforts on built heritage retrofitting.

## 2.3 ENERGY PERFORMANCE ASSESSMENT (B)

- Energy retrofit measures – Intervention objectives:

  Defining the objectives of intervention is of prime importance. Energy improvement measures can refer to alterations of the building envelope, energy supply and control, as well as, user's indoor occupancy and behaviour. In the framework of BEEP pilot actions, three scenarios will be assessed (short, middle and long term) with variable level of the scale of intervention, energy consumption reduction and financial requirements. Passive and active technologies are promoted, as long as they are compatible with international restoration policies.

- Dynamic energy simulation

  A whole-building energy model is used to estimate the energy performance and consumption of the proposed retrofit measures. Dynamic numerical simulations are performed, calibrated on energy bills, occupation patterns, and environmental monitoring.

- Assessment and selection of retrofit measures

  The assessment criteria for the selection of the retrofit measures is based on a risk-benefit scheme expanding to the categories of technical compatibility (e.g. hygrothermal and structural risks, reversibility), heritage significance, economic viability and energy savings potential.

## 2.4 EE-HBIM DEVELOPMENT

The data from the analysis of the existing building already in the HBIM platform, contain a series of input parameters for the dynamic energy performance simulation; i.e. properties of building materials, occupancy schedules, technical characteristics of systems and equipment etc. The rightful semantic organization of data and metadata in the EE-HBIM platform constitutes a major asset of the process, as this can become accessible to all involved professionals and building stakeholders at intra-business level. The Level of Detail (LoD) used in BEEP is L400. LoD 200 is applied in objects that have been severely damaged or removed, and their geometry is approximated based on historical documentation, i.e. historical photos.

Environmental and building performance evaluation through an interoperable workflow between the HBIM model and static or dynamic simulation tools is still at experimental stage. Energy Performance simulations enable the examination and optimisation of a historic building's performance, through the creation of behavioural models. These models however should only carry reduced building data and a building geometry simplified to a certain level of abstraction necessary to perform the simulation. In the pilot action presented here the exporting techniques that are being tested rely on IFC or gbXML data exchange schemas, which are also constantly under development. The BEEP project focuses on providing a functioning, semi-automatic data exchange process between the two steps, based on best practices and experimental feasibility tests.

## 2.5 ENRICHED EE-HBIM DEVELOPMENT (4D & 5D BIM IMPLEMENTATION)

At this stage, the operations execution schedules (4D) and the cost estimation (5D) of the three energy retrofit intervention scenarios are added to the BIM model. The cost of materials and products together with the work force and time estimation needed to retrofit the heritage building will be introduced to the BIM information model. These will secure the production of a trustful planning of the intervention.

## 2.6 DESIGN AND DEPLOYMENT OF FINANCING MECHANISMS (C)

- Extraction of critical BIM information to be used by financial institutes for EPC contracting.

  The aim at this stage is to find the information necessary to be exported from the BIM datasets to be used for EPC contracting. The information should be exported in Open format and should carry only the information which is crucial for financial institutes in evaluating the feasibility on signing an EPC for the building's energy refurbishment. Using this information, a WBS and a GANNT chart will be generated to further support the BIM preparation for EPC contracting.

- Technical Documentation of legal and technical aspects for EPC implementation.

  At this stage, the overall results will be analyses in order to define a common base for the evaluation of the ROI. This includes the analysis of the legal, economic and technical aspects in order to facilitate the process of approaching Energy Services Companies (ESCOS).

- EPC Contracting.

  The desired outcome of the proposed methodology is the financing of the refurbishment. In the framework of BEEP, a series of guidelines for both Public Administration and Financial Institute will be drafted. Two different guidelines, Strategic and Technical offers, are necessary as the decision makers (e.g. owners of the building) do not always have technical background to understand the EE-HBIM approach, while they need to be informed in a clear way about the great opportunities that this method brings to refurbishment mortgage market.

## 3. METHODOLOGY IMPLEMENTATION

The data collection and analysis regarding step *A: Building analysis and Documentation* of the presented methodology is fully implemented on the pilot case-study in Nicosia, Cyprus, while the activities of step *B: Energy Performance Assessment,* and the creation of EE-HBIM model are ongoing. Critical considerations and challenges faced so far regarding their implementation are presented below.

### 3.1 THE PILOT CASE STUDY BUILDING

The Cyprus pilot building is located just outside the walled city of Nicosia. The building hosted the British Cavalry club and was later used as the barracks of the Danish Canadian extract in Cyprus. It has been abandoned since the 1960s and is currently in dilapidated condition. It is a listed building and unique example of Cypriot architectural heritage, as it combines features of colonial architecture (1878-1929) and local rural architecture. It is rich in architectural features of the period, including fireplaces, arched openings, stone ornaments, courtyard and many details with significant historical value, such as the tall, angular stone turret that dominates the facade.

**Figure 3. The British Cavalry Club in Nicosia. Photographic archive from 1964 (left) and 2013 (right).**

### 3.2 MODELLING AND SIMULATION PROCESS

- A: Building survey & Documentation

  The H-BIM model development (Figure 4) included both 2D documentation of the complete georeferenced topographical and architectural survey and the generated 3D point cloud of the terrestrial photogrammetric survey, which have been linked to the BIM model. Although the level of accuracy of a Lidar system survey is higher compared to photogrammetric methods, the later was found as a more suitable solution, since it can capture narrow spaces and halls (common building attribute in heritage structures), while simultaneously supports colour registration to post-processing process for point cloud generation, and direct processing of image textures. The technique of photogrammetry was principally used to capture the entire building geometry, achieving an acceptable level of accuracy of the building's details, e.g. stone pediments, decorative stone profiles and artefacts, false ceiling decorative details, etc. The creation of a 3D point cloud model with reality capture tools accelerated the construction of various thematic maps, necessary for the conservation documentation and study of the building. All hosted model objects (families), such as doors, windows, stone ornaments and artefacts were parametrically designed to avoid mass modelling of similar objects. Severely damaged or removed objects were modelled as individual objects based on information collected during the step of the *Historical Significance Analysis*. The integration of the non-geometric information involved two separate categories of data: the information linked to the entire project model, i.e. conservation reports, and the information linked and assigned to particular project families/model objects, i.e. historical photos of damaged stone artefacts. For both data categories, open file formats were adopted.

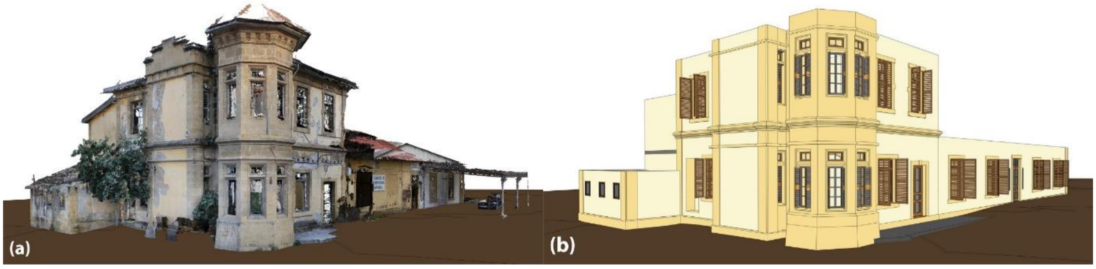


**Figure 4. EE-HBIM model development: a) reality capture point cloud model; b) BIM model.**

- B: Energy Performance Assessment

As a number of questions regarding the compatibility of software interfaces, remain open for the scientific community, the authors' efforts focused on implementing the most efficient semi-automatic workflow, in order to streamline the process of BIM to BPS and avoid repeating modelling processes, or user errors during the exchange of data between the two software tools. The gbXML data exchange schema was adopted, while feasibility studies are currently conducted between the project partners to test the applicability of the approach on the pilot buildings selected. The complete implementation of the BEEP integrated EE-HBIM approach is estimated by the end of 2022. Custom tasks and processes are still under investigation and additional observations will be extracted.

- C: Design and Deployment of Financing Mechanisms

The level of activity of energy auditors and ESPs in Cyprus is very low, despite the great potential for market development. The ESCO market penetration so far is considered to be at its initial stages. This may be due to a lack of confidence on the part of end users in the process and to a lack of know-how and experience on the part of ESPs and banks [9]. A preliminary assessment of the challenges in developing energy services in Cyprus has pointed to: the lack of information and awareness of the key actors and stakeholders, as well as of the public (property owners), institutional and legislative obstacles, financial obstacles and technical and administrative obstacles. In this environment, the implementation of BEEP is expected to benefit the market, as through its planned actions it will contribute to:

a) strengthening the current legal and institutional framework by removing obstacles to public procurement and making the recording of energy consumption in public buildings mandatory;
b) introducing new practices in the professional market, the benefits of which will be multiplied by the already secured engagement of local policy promoters, such as the Cyprus Energy Agency and the Scientific and Technical Chamber, as associate partners of BEEP;
c) promoting training and information by creating standard EPC forms and setting up an information platform for ESPs.

## 4. CONCLUSIONS

Building Information Modelling is increasingly recognised by the construction industry as a promising set of technologies. Built heritage is a great case to demonstrate the scalability and benefits of using BIM technology (in producing a H-BIM model) towards energy upgrading Europe's existing building stock. In this framework, the research project BEEP aims to create a comprehensive methodology for Energy Efficient HBIM, while supporting the financial decision-making through the enhancement of the Energy Performance Contracting process. The overall benefits focus on the promotion of digitalisation of energy refurbishments projects and the increasing of the volume, flow and access to financing mechanisms. The current implementation state of the integrated EE-HBIM approach in the Cypriot pilot building was presented, along with the encountered challenges. The central information model was used for incorporating data related to *A. Building Analysis and Documentation*, i.e. heritage significance information, building technical documentation (geometric survey) and environmental monitoring data. A semi-automatic iterative process regarding the incorporation of energy-related data was followed in stage *B. Energy Performance Assessment*. The activities regarding stage *C. Design and Deployment of Financing Mechanisms* are ongoing; along with the incorporation of time and cost related data, towards the creation of an enriched EE-HBIM model. Concluding, the paper presented how the BIM environment can become a valuable tool for the elaboration of all the geometrical and alphanumerical information for critical decision making during the retrofit scenario selection, and the financial evaluation of the intervention. Further investigation on the implementation of EE-HBIM is required in order to consolidate all the stages in the workflow.

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