GUIDELINES FOR EE-HBIM DEVELOPMENT OF EXISTING BUILDINGS

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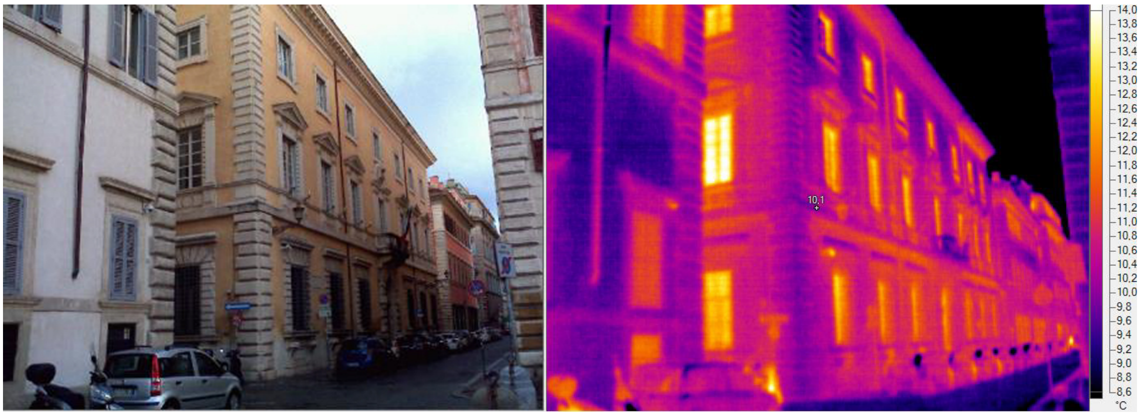
Abstract

The output constitutes the first part of a guideline for an energy audit of a historical building to promote its energy and environmental improvement, to be financed with private funds through Energy Performance Contracting (EPC). With its practical approach, the guideline supports the building's owners and managers through the whole process, from the analyses to the renovation project up to the EPC implementation, helping them decide the best course of action for each phase depending on their aims and resources.

This first part focuses on the analysis phase, which is paramount when dealing with built heritage, which are heterogeneous, complex and precious and generally have a distinct energy behaviour, optimized for climate with the use of passive strategies that should be taken into account in an energy improvement. Key analysis are: historical and architectural analysis, geometric survey, general conservation state, environmental and energy analysis and monitoring. All these information are collected and incorporated into a Heritage Building Information Model (HBIM) that is the digital representation of physical and functional characteristics of a historical building, creating a shared knowledge resource for information about it.



Photography and corresponding thermography analysis of the Italian case study Palazzo del Clementino – Maffei Borghese (BEN ISPC-CNR)

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1. INTRODUCTION

1.1 Document purpose

This document provides a technical guideline for an energy audit of a historical building to support its energy and environmental improvement (as shown in the Energy Audit Process Flow schema based on the EN 16247-2:2014, see par 1.4), from the analyses to the design stage up to the Energy Performance Contracting implementation.

Each section of the guideline can also be used as technical specification for tender activities, along with the related template Annex.

1.2 General Project Information

This guidelines' document was developed within the ENI CBC Med BEEP project and aims to enhance the capacity of public local administrations to design, and realise innovative energy and environmental improvement on historic public buildings, through a multidisciplinary and integrated digital approach (using Building Information Modelling and performance-based design to develop an Energy Efficient Heritage Building Information Model - EE-HBIM). The guideline is based on the testing of this emerging technology on built heritage in eight different EU and non EU Mediterranean countries to demonstrate its scalability to the entire building stock of the Med area. The project will provide public administrations with a powerful method for the energy rehabilitation of public buildings to be supported with private funds through the Energy Performance Contracting.

The HBIM model should integrate previously collected information on the building (geometric, diagnostic, environmental data), to create a comprehensive documentation of the building's current state. Moreover, the HBIM model will be used as a basis to inform the subsequent simulation-based energy-environmental improvement concept, through energy renovation scenarios that are both compatible with the identified historic buildings and capable to enhance its energy and environmental performance.

1.3 Energy and Environmental Performance Improvement of Built Heritage: a framework

On this very subject it should be remembered that any protection order placed on cultural assets must be accepted as one of the many limitations (economic, respect of norms, functional, energy usage etc.) which an architectural design is constantly held to abide by and resolve. It is an arduous and stimulating, but by no means impossible, challenge.(G Carbonara 2017)

The construction sector plays a decisive role in the challenge for sustainable development: in Europe and the US, it is responsible for a final energy consumption of around 40%, which drops below 20% in China and is slightly above 30% as the world average (Belussi et al. 2019). The low cost of energy, together with the development of modern air conditioning systems for indoor spaces, has led in the last century to the overshadowing of investments in the energy efficiency of buildings. The situation began to change with the oil crisis of 1973 and the rise in energy prices after 2000, which made the investment in energy efficiency more convenient and demonstrated how the strong dependence on imports of fossil sources from external countries could pose a threat to a country's political independence and prosperity (Troi, Zeno, and Wedebrunn 2015). In parallel, awareness has also grown on the devastating risks associated with human-caused climate change (IPCC 2014). This has triggered a series of international actions that started with the Earth Summit in Rio de Janeiro in 1992, continued with the Kyoto protocol of 1997 and reached the Paris agreement of 2015. Sustainability has thus become a central pillar in contemporary life (Laine et al. 2019) from which derives the key role of energy efficiency in the 2030 Agenda for Sustainable Development (UN 2015), and its sub-theme related to improvement of the energy performance of buildings which is now a central aspect in energy policies around the world. In this framework the EU released in December 2019 the European Green Deal, capturing its commitment to tackle climate change. Among other actions, it prioritises energy efficiency in the building sector, as the largest single energy consumer (European Commission 2020).

The energy retrofit of a building refers to the set of actions needed in order to improve its energy and environmental performance. The challenge of the energy retrofit of a building consists in applying the most profitable set of technologies to obtain an improved energy performance, while maintaining satisfactory levels of service and internal thermal comfort under a given set of operating constraints (Ma et al. 2012). The heterogeneity of the existing building stock, the continuous evolution of technologies and markets and the variability of the actors are responsible for the complexities linked to the decision-making process concerning energy retrofits (De Boeck et al. 2015; Murto et al. 2019). Despite the numerous actions taken at the public level, the energy retrofit rate is still lower than expected (Friege and Chappin 2014), to the point that in order to achieve the 2050 objectives the pace should be doubled if not tripled (BPIE 2019).

1.3.1 Energy improvement of built heritage

Although Europe is one of the "early mover" markets for energy retrofit of buildings, the built heritage is still substantially exempt from the Energy Building Performance Directives because of the difficulties in finding energy efficiency solutions compatible with historical and architectural values. As stated in the EBPD (EP 2010), "*Buildings and monuments officially protected as part of a designated environment or because of their special architectural or historic merit, where compliance with the requirements would unacceptably alter their character or appearance*" may in fact be excluded from attaining energy performance requirements. Moreover, historical buildings are usually protected both by national regulation and international conventions, which introduces additional levels of protection that hinder energy retrofit interventions. Historic buildings are neither the largest portion of buildings (Economidou et al. 2011) in the European building stock, nor the most energy-intensive (Martínez-Molina et al. 2016; Historic England 2018; Pretelli and Fabbri 2016). Thus, the concerns that potential measures for energy efficiency would damage the historical building, have slowed down the disciplinary integration process between conservation and sustainable design.

1.3.2 Approach to energy improvement of the built heritage

A key element in drafting an energy improvement process of a historic building is the search for the right balance between interventions and building context, historical-artistic values, passive behaviour and energy use, which requires a holistic view (Historic England 2018; G Carbonara 2017). This approach allows the creation of a shared knowledge framework between the actors involved in the process (Historic England 2018) and guarantees that the chosen solutions are appropriate for the historic building framework.

In dealing with a historical building, we can make at least two fundamental clarifications regarding the energy retrofit approach and the guiding principles of restoration:

1. According to the current Italian debate on the topic (de Santoli 2015; Giovanni Carbonara 2015), the concept of “energy improvement intervention” is to be preferred to “energy regulatory compliance/ adjustment/ adaptation”. The Architectural Restoration scholar Giovanni Carbonara argues that the concept of “improvement” is antithetical to the one of “adjustment” that refers to regulatory compliance, including safety and comfort. The “improvement concept” has been firstly introduced in the field of structural consolidation of the built heritage with excellent results, i.e. without losing the general scope of an intervention on the built heritage that is its preservation for the future generation (or the ones related to the concept of “Integrated conservation” expressed in the Declaration of

Amsterdam (AA. VV. 1975). In the same way, the concept of improvement can also be applied to energy efficiency and historical buildings as the energy and environmental behaviour of an historical building (both active and passive), can be improved through appropriate and well-balanced solutions without leading to a disruption of the building, which would be the case should one wrongly assume that the building has to be "adjusted" to current legislations and requirements, as if it were the case of a new or recent construction. If the "adjustment" can change the building and make it unrecognizable, destroying or impairing its cultural values (Giovanni Carbonara 2015), the improvement can help rebuild the natural functioning processes of historical and architectural structures, enhancing at the same time their distinctive characteristics and identities linked to the local microclimate (Gigliarelli, Calcerano, and Cessari 2017; GBC 2017a). The conflict between environmental design and heritage conservation is finally over and energy efficiency measures are now fully recognised as a key protection tool to support the conservation process (Giovanni Carbonara 2015).

2. The solutions adopted must be in line with the guiding principles introduced by the international restoration charters. These are universally recognised principles produced by the critical debate on restoration, starting around the nineteenth century and developed through the international restoration charters. A brief summary of these principles is given below (G Carbonara 2017):
    a) *minimum intervention:* the energy improvement design should aim at preserving the original material as much as possible and avoid unnecessary interventions;
    b) *reversibility:* the interventions must be reversible in the future, whenever possible;
    c) *distinguishability:* new works should be distinguishable against the existing one;
    d) *physical-chemical and figurative compatibility:* the interventions must guarantee compatibility between ancient and new materials, new design solution and historical and architectural features. This applies also to energy improvement project (for example, understanding the building's bioclimatic functioning - also through historical and architectural insights on the technologies used - is vital to reconstruct and optimise its passive behaviour);
    e) respect for the material and figurative authenticity of the building.

Further references on can be found in Annex 4.1 and BEEP Deliverable 3.1 (AA. VV. 2020).

1.4 Energy Audit Process Flow of historical buildings - BEEP Project

The energy audit is one of the fundamental process of the energy upgrade of a building (de Santoli 2015). The EN 16247 defines the Energy Audit as a "systematic inspection and analysis of energy use and energy consumption of a site, building, system, or organization with the objective of identifying energy flows and the potential for energy efficiency improvements and reporting them" (CEN 2012). This guideline is based on the Energy Audit process of the EN 16247-2:2014 and introduces some adjustments in order to tackle the specificity of historical buildings, capitalise on the potential of new digital technologies applied to the construction sector for the built heritage (mainly, Heritage Building Information Modelling and Numerical Simulation of the energy and environmental performance of buildings), and promote the use of the Energy Performance Contracting scheme.

The results of the analysis of the innovative energy rehabilitation intervention will be incorporated into a Heritage Building Information Modelling (HBIM) environment that is the digital representation of physical and functional characteristics of a historical building, creating a shared knowledge resource for information about it.

Environmental and energy analysis will help to develop the historical building energy audit, as well as the three energy-environmental improvement scenarios. The passive behaviour of the building will be taken into consideration, in order to enhance its distinctive features and embedded passive strategies, closely linked with its climate and microclimate context, and also increase its energy performance and comfort conditions.

The proposed process flow is shown below. Each step is further analysed in the following Chapters.

Analysis of the innovative energy rehabilitation intervention (BEEP Output 3.2)

pre-planning (also energy performance indicators);

technical documentation survey;

field analyses

→ to go into WP3 HBIM model **(EE-HBIM BEEP Output 3.3)**

Energy simulation and assessment (WP4)

Calibrated simulation of the current state of the building (Output 4.3)

Development of energy concept with three energy improvement scenarios (Output 4.1)

Simulation of the three scenarios to obtain the energy requirement and the savings achievable (Output 4.3)

technical-economic evaluation of the scenarios and relative ROI (Output 4.2, Output 5.1)

→ to go into WP4 HBIM model (Output 4.4)

Final technical report on the Energy Audit

Energy Performance Contracting implementation (Output 5.3)

1.5 Glossary

AEC	*Architecture, Engineering and Construction*
BCF	*BIM Collaboration Framework*
BEP	*BIM Execution Plan. Plan that explains how the information management aspects of the appointment will be carried out by the delivery team.*
BI-EM	*Building Information-Energy Model. A BIM-based energy model that automates the energy modelling process within the BIM software (Revit Energy Model)*
BIM	*Building Information Modelling. Use of a shared digital representation of a built asset to facilitate design, construction and operation processes to form a reliable basis for decisions.*
BIM-BEM **BIM-BPS**	*Building Information Model to Building Energy Model. A converted energy model using exported information from a BIM model*
BPS or BEM	*Building Performance Simulation or Building Energy Modelling (generally used as synonyms)*
bSDD	*buildingSMART Data Dictionaries*
CDE	*Common Data Environment. Agreed source of information for any given project or asset, for collecting, managing and disseminating each information container through a managed process*
CFD	*Computational Fluid Dynamic*
COBie	*Construction Operations Building Information Exchange. International standard for information Exchange about construction data focused from a BIM methodology point of view*
DTV	*Design Transfer View*
DES	*Date Exchange Schema*
FM	*Facility Management*
GBS	*Green Building Studio*
gbXML	*Green Building eXtensible Markup Language. A format used in order to allow a smooth transfer of BIM model properties to energy calculation applications.*
HVAC	*Heating, Ventilation and Air Conditioning*
IAI	*International Alliance for Interoperability*
IDM	*Information Delivery Manual*
IFD	*International Framework for Dictionaries*
IFC	*Industry Foundation Class. A neutral, non-proprietary data format used to describe, exchange and share information, smoothing the information exchange and interoperability between software applications in a BIM workflow*
Information	*Reinterpretable representation of data in a formalized manner suitable for communication, interpretation or processing*
Information model	*Set of structured and unstructured information containers, that is named persistent set of information retrievable from within a file, system or application storage hierarchy*
ISO	*International Organization for Standardization*
LCC	*Life cycle costs*
LOD	*Level of Development LOD. It defines the development level of information that a BIM model has, and this one is the composing part,*

	constructive system or assembly of the building.
Level of Information Need	*Extent and granularity required for a particular information deliverable at a particular plan of work stage. According to ISO 19650 it should substitute LOD.*
MEP	*Mechanical, Electrical, and Plumbing*
MVD	*Model View Definitions*
Plenum	*A plenum is a non-occupiable space between a ceiling and the floor above* *specifically intended for mechanical systems and other systems that require ceiling space*
Point cloud	*The result of a data collection of a building or object by laser scanner of photogrammetry, consisting in a set of points in the space that reflect its surface.*
R-value	*Thermal Resistance*
RV	*Reference View*
SHGC	*A value describing the solar heat gain coefficient in a glazing (window) material*
Space	*A space is defined as a building volume enclosed by ceilings, floor, walls or by another space's boundary. Space has a plethora of properties assigned to it to describe its energy resources, such as loads from people, lighting and equipment*
U-value	*Heat Transfer coefficient or Thermal Transmittance*
Weather File (epw)	*A single file in a format called an .epw that contains a collection of information to describe the environment of a location for each hour of the year, supplying data such as temperatures, luminescence data for sunlight, heating, and more*
XML	*eXtensible Markup Language*
XSD	*XML Schema Definition*

2. ANALYSIS PHASE FOR THE INNOVATIVE ENERGY REHABILITATION INTERVENTION

The activities shown below encompass the analysis phase following the energy and environmental improvement approach on historical buildings (see §1.3):

2.1 Preliminary analysis;

2.2 Historical and architectural analysis;

2.3 Geometric survey;

2.4 Energy and environmental analysis;

2.5 General conservation state.

2.1 Preliminary analysis for the energy rehabilitation intervention

This paragraph describes the preliminary analysis as intended to support the energy audit process of a historical building, as well as the historical and architectural analysis.

2.1.1 Purpose of the analysis

The first activity to be performed is the preliminary analysis. The aim of this activity is to establish a first contact with the historic public building, its owner and occupants, in order to plan the subsequent analyses. The first step is the documentation analysis and the photographic and visual survey, that will provide an overview of the building. Establishing contact with the building's occupants is also essential to start analysing the building’s key features in terms of environmental and energy performance.

2.1.2 Pre-planning

Pre-planning in this activity should be very lean and allow to optimise the first field surveys and the first contacts with the involved stakeholders

2.1.3 Data acquisition

The analyses should gather general data of the building, information on recent works (if any), its use and current condition, as well as a brief overview of its active systems (HVAC, DHW, etc. .)

The main tasks to be performed during the preliminary analysis are:

- to identify the contact people for maintenance, facility management, design, documentation;
- to verify the availability of the building for surveys and diagnostics, depending on the building usage (for example, environmental monitoring can be disrupting for the normal building usage and requires at least one year of continuous measurements);
- to carry out preliminary surveys and photographic report of the building.

The main information to be retrieved includes:

- city planning regulation – urban plans - cadastral documentation – building prescriptions;

- drawings (plans, sections, elevations) (in printed and digital form: .dwg, .pdf, BIM models);
- documentation for the historical analysis: bibliographical and archival documentation, maps and historical cartography, studies on similar and/or coeval buildings;
- information from the occupants concerning comfort conditions (interviews);
- documentation on previous interventions on the building: maintenance, renovations, diagnostics;
- documentation on HVAC and installations: functional schemes, technical documentations, security documentation, plans;
- documentation on maintenance and facility management (maintenance plan, etc.);
- energy bills (electricity and gas) for at least one year operation;
- energy contracts.

2.1.4 Output

Al the data collected must be organised in minutes, reports and digital folders to support the subsequent analyses.

2.2 Historical and architectural analysis

The following paragraphs describe the historical and architectural analysis as intended to support the energy audit process of an historical building.

2.2.1 Purpose of the analysis

The activity will perform onsite study and archival research that are the fundamental core of the historic building analysis, as they provide a first understanding of the changes that the building went through over time and constitute a historical-critical guideline for subsequent analyses and intervention.

2.2.2 Pre-planning

Pre-planning activities to support historical and architectural analyses are already tackled in the preliminary analyses (§ 2.1), as among the main information that should be retrieved are: bibliographical and archival documentation, maps and historical cartography and studies on similar and/or coeval buildings. Subsequent meetings with the building owner and scholars who might have already studied the building, could provide access to additional documentation.

2.2.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.2.3 Data acquisition

The analysis path to be followed in order to determine the characteristics of the building from a historical and architectural point of view, consists of a series of actions that involve different skills and disciplinary areas.

The first cognitive approach concerns the analysis of historical, textual, archival and image-based data in order to acquire meaningful data regarding:

- pre-existing building fabrics on the site;
- purposes, methods, phases and timing of projects and transformations;
- intended use of the building;
- any constraints and problems in the implementation of interventions or transformation phase; and also,
- to identify clients, architects, workers and the organization of the site whenever possible;
- to understand the functional, visual and conceptual relationships with the neighbourhood, the city and the territory.

The survey should also be conducted in specific archives and libraries, as well as digital databases and repositories, where it is possible to retrieve useful information about the building phases (and other changes occurred over time).

Data from the available historical sources (such as bibliographic, archival, cadastral, cartographic, images) require appropriate interpretation. Through a critical interpretative analysis of the gathered material, the building's historical transformations and stratifications will be identified. This process allows to retrace the history of the building starting from the first building nucleus, to all subsequent transformations, with particular attention to the modifications, restorations and partial destructions that might have occurred over time. The interpretation of the building's construction phases and modifications should also be achieved through the interpretation of the materials and construction techniques used, as they are often indicative of the succession of interventions that have been stratified on the building.

The information deriving from the historical-architectural analysis should then be comparatively assessed with the ones of the geometric survey (§ 2.3) in order to conclude on the morphological and geometrical aspects of the building. This integrated approach allows a) to determine the presence of one or more buildings and therefore the construction units, b) to distinguish the original structures from those added and c) to understand the construction features in order to identify the structural functions and the masonry stratigraphy. Furthermore, from the comparative analysis of the results it is possible to make an initial diagnosis of the actual state of the artefact and to direct the research towards other fields of investigation through the use of field and laboratory analyses, if needed.

2.2.4 Output

The analyses aimed at identifying the main features of the architectural complex should be organised in the form of a report describing the main characteristics of the architectural complex and the building transformations that the building has undergone over time.

The analysis on the building site must include:

- Geographical and territorial framework
- Topography and climate
- Location, (urban or rural or other context) urban transformations, access, orientation, etc.

The analysis on the regulatory framework of the building must include a list of the main urban regulations, listed building national and local regulations, heritage conservation national and local regulation and specific regulation on the building as for example any regulatory constraints on the intervention.

The historical and architectural analysis must describe main historical and architectural features of the building including:

- its historical context and local architecture background,
- the analysis and assessments of changes undergone by the building over time,
- a brief analysis of the existing geometric dimensional knowledge of the building,
- typological, architectonic and decorative characters,
- restoration or structural reinforcement interventions

For a reference template on this analysis see Annex **Error! Reference source not found.**.

2.2.5 BIM integration

The information collected and organised provides the basis for the modeling activities of the building's construction elements in both geometric and informative representation, based on the dimensional data collected in the geometric survey.

2.3 Geometric survey

The following paragraphs describe the geometric survey, as intended to support the energy audit process of a historical building, as well as the BIM modelling.

2.3.1 Purpose of the analysis

The activity regards the integration of traditional and innovative techniques (topographical, terrestrial laser scanner, photogrammetry) in the survey phase will supply an accurate representation of the building, and will provide the basis for geometric modelling of the HBIM model and hence of the energy model for energy and environmental simulation.

The following information are absolutely needed in order to develop a robust HBIM model of the building, with a detail accuracy that can be compared to a 1:20 drawing scale (as a general reference, LOD 500 of the American Institute of Architects 2013):

- a georeferenced geometric survey with topographical information of the exterior and interior of the building.

If planned accordingly, the geometric survey can also provide an invaluable source of information for the general conservation state analysis (see §2.5)

2.3.2 Pre-planning

Prior to data acquisition in the field, it is critical to conduct pre-planning meetings with the involved stakeholders (i.e. building owner representatives, building technical and management staff, occupants representatives, consultants, service providers) to discuss:

- measurement objectives: a clear and concise scope of the geometrical survey effort should be established in this stage with a detailed list of the measurements to be taken, the measurement resolution and level of detail, the required accuracy for each (which may not be the same), and the required file format for deliverables (if relevant);
- security and access constraints: ensuring unhindered access is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- mobilisation strategy.

2.3.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.3.3 Data acquisition

Regarding the geometric survey, the type of survey techniques to prefer depend on the current information already available on the building, linked to the building complexity. Therefore, this guideline foresees two different path of survey-analysis for two extreme cases that are proposed below:

- **CASE 1** if geometric information is almost complete
- **CASE 2** if no geometric information is available.

Depending on their particular case, the actors involved can develop middle ground strategy.

2.3.3.1 CASE 1

If robust information on the geometric characteristics of the building is available (e.g. digital drawings or paper-based survey documentation at scale 1:50, including plans of all floors, all elevations and at least 3-4 sections in both axes), the activities should focus on:

- a measurement verification of the existing information, and
- if needed, geometric data integration to attain the required survey accuracy,
- integration of image-based survey information (e.g. photogrammetry) on the external building elevation and the main internal elements

Recommended instruments for improving this type of geometric survey could be total station, photogrammetry with calibrated camera and/or laser scanner.

2.3.3.2 CASE 2

If there is no reliable geometric information of the building available, the activities should provide:

- a complete georeferenced geometric survey of the exterior and interior of the building using:
    - o traditional-direct survey methods and,
    - o photogrammetry or laser scanner data, with RGB information.

In both cases, georeferencing the building and the topographical network is recommended (although not strictly necessary for the building's energy modelling using BIM and BPS), as it can improve the overall documentation of the building and may also be used in subsequent activities/interventions. Ground and/or aerial scans could also be performed in order to obtain a complete representation of the building.

2.3.4 Output

2.3.4.1 CASE 1

For the verification and completion of the existing information, the activity should reproduce and integrate the existing drawings in digital vector-based files, covering (at least) the following :

- plans of all the floors;
- all elevations;
- 3-4 main sections in different axis;
- significant details.

The plans must show the main linear dimensions of each room, the thickness of internal and external walls, fenestrations, and the main dimensions of the entire building. The elevations (referring to a single dimensioned plan common to all vertical representations), the internal heights and the surfaces of the single rooms should also be indicated. The representation scale should be 1:50 or less, for the plans, sections, and elevations, and 1:20 for the details.

For the integration of the existing geometric data with photogrammetric survey on the external building facades and specific internal elements, the activity should produce at least the rectified photography of the external building elevation and the main internal elements as coordinate-controlled imagery or scaled rectified imagery or other controlled method. A resolution of 300 dpi is generally recommended as appropriate.

It is strongly suggested, when performing a photogrammetric survey, to also produce a point-cloud of the building (at least of the exterior) because it can be really useful in the modelling HBIM activities. In fact, technological developments in the involved equipment (cameras) and software are facilitating the process of extracting photogrammetry data to point cloud, which is becoming increasingly easy to develop, less time consuming and expensive.

2.3.4.2 CASE 2

The activity should produce the registered 3D point cloud of the building exterior and interior. Data exchange format and non-proprietary format should be preferred to streamline the importing process in the most widespread BIM authoring software. In addition to the laser intensity value, RGB colour information, acquired on a per point basis at each scan position, is required.

Normally point clouds that are very detailed can be very large in file size, resource demanding and difficult to manage with current IT workstations in the subsequent phases of the process. Within the current workflow, the point cloud should convey the geometric base data for BIM modelling activities; therefore, attention must be paid to the trade-off between accuracy and feasibility in the use of files.

There are many workflows to help solving this issue. For example, the raw point cloud acquired can be decimated (reduced in file size) to a given level of detail. The surveyor could also perform a differentiated survey of exterior (more detailed to capture decorations) and interior (less detailed, just to define spaces and building envelope thicknesses). Moreover, the whole point cloud file could be divided into portions of a fixed file size, corresponding to specific building sections, that can be differently integrated, in the BIM model, making all the process smoother and less demanding in terms of IT resources.

Within this guideline the suggested accuracy for the laser scanner survey is:

- The required maximum tolerance for precision of detail is: 1:20 +/- 6mm - 1:50 +/- 15mm
- The required point density/rate of capture of measured points is: 1:20 ≤2.5mm - 1:50 ≤5mm

For a reference template on this analysis see Annex **Error! Reference source not found.**.

2.3.5 BIM integration

Usually geometric survey information, either 2D vectorial data file or 3D point clouds can be imported in the most common BIM Authoring tool and used as a base to model building elements. Point clouds in particular can be used to discretise and acquire the main geometric configuration of the building and the single measures of external and internal elements.

2.4 Energy and environmental analyses

The following paragraphs describe the energy and environmental analyses as intended to support the energy audit process of a historical building.

2.4.1 Purpose of the analysis

The environmental and energy analyses described in this technical guideline document will serve, along with the other (historical, geometric, etc.) analyses, to define the thermophysical characteristics of the opaque and transparent envelope. The environmental monitoring part, if present, will help calibrating the building model used for the dynamic energy simulation and the subsequent drafting of the energy retrofit scenarios. The energy Auditor is the figure who follows the entire process from the data collection phase, to the development of the energy audit. For the aforementioned purposes, the following data need to be obtained:

- climatic data;
- building occupancy profiles;
- thermophysical characteristics of the opaque and transparent envelope;
- building systems and operation profiles;
- building energy consumption and energy bills;
- indoor environmental and comfort conditions in the spaces [not mandatory];

2.4.2 Pre-planning

Prior to data acquisition in the field, the energy Auditor should conduct pre-planning meetings with technical representatives of the building owner and interested parties (e.g. occupants representatives), to discuss the environmental and energy analyses objectives, security or access constraints, mobilisation strategy, details about the involvement of building occupants and to agree on all the operating procedures for carrying out the analyses.

During the meetings, the service provider (i.e. the energy Auditor) agrees with the organization on how to access the building, how to gather the available technical documentation, how to access its energy systems, the data to be provided at the end and the analysis execution program. The aspects covered in the meeting are:

- Purposes and measurement objectives: a clear and concise scope of the analyses effort should be established in this stage with a detailed list of the measurements to be taken, the measurement resolution and level of detail, and the required file format of the deliverables;
- Clear definition of each building structure to be surveyed with the appropriate tools;
- Verification of existing technical documentation
- Mobilisation strategy – The expertise of the service provider is essential for establishing the mobilisation strategy: how many survey points, timing of field surveys during the year or the day, delivery deadlines, etc.;
- Level of involvement of the building occupants
- Security and access constraints: Ensuring unhindered access for service providers is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- Health and safety.

All investigations and tests of any kind must be agreed in advance with the competent local Heritage Conservation Authority.

2.4.2.1 Deliverables

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.4.3 Data acquisition

The first part for the energy and environmental analysis to be conducted by the energy Auditor, is the collection of the existing technical documentation concerning the energy behaviour of the building. The second part concerns a set of environmental field analysis (i.e. mandatory environmental monitoring and optional analyses).

2.4.3.1 Technical documentation

An indicative and non-exhaustive list of the technical documentation survey part, that the energy Auditor shall collect (according to EN 16247) contains:

- Energy Management Service or/and Energy Supply contracts;
- Energy related data (mainly through the Energy Bills of the last three years, or from individual metering, if available) such as: energy and water consumption data, delivered, produced and exported energy per energy source (if available) and short-interval (e.g. hourly) energy demand (if available);
- Climatic data for energy simulation purposes (see Annex **Error! Reference source not found.**)
- Any changes that have occurred in the building in the last three years (change in the use of the spaces, in the set-points of the environmental parameters, management interventions on the systems, energy improvement interventions, etc.);
- Any previous energy analyses performed on the building, if present;

2.4.3.1.1 Deliverables

The deliverable of the technical documentation survey is a technical report containing all the documentation found on the building and an outline of the key data contained (see § **Error! Reference source not found.**).

2.4.3.2 Field analyses

Regarding the field analyses survey, a mandatory and an additional data set of measurements are described below. The mandatory analyses are necessary to provide robust information on the building use, the thermophysical properties of opaque and transparent envelope and the building's systems. Additional field analyses are strongly recommended as they allow stakeholders to attain a better and more accurate analysis of the building performance, and define the interventions strategies and the related Return of Investments in a more efficient way. The type of survey techniques to be performed depends on three key factors:

- the tool/approach selected to perform energy simulations, that also depends on the country regulation;
- the current information already available on the building, and the building's complexity;

- the available budget and timeframe of the retrofit process.

2.4.3.2.1 *A. Mandatory analysis (data verification through visual and heat flux meter analysis)*

Integrating the data collected so far by the actors involved (following the required verification), the energy Auditor shall provide the following information through site visits and heat flux meter analysis:

- Existing technical documentation on building geometry and confirmation of the provided data deriving from the geometric survey (floor area and building volume as-built); record of any external factor that may influence the energy performance of the building (e.g. shading by adjacent trees or buildings);
- Building occupancy patterns (intended use of spaces and occupancy schedules):
  - Occupancy schedule;
  - Window opening patterns (time schedule for each window operation time schedule and percentage of opening), (*These data are gathered through frequent visual inspection or occupant survey);*
- Building systems information, including:
  - Heating system and cooling system (overall typology, generation characteristics, terminals position and characteristics, etc.);
  - Domestic Hot Water system;
  - Forced ventilation system (typology, Air Handling unit, terminals);
  - Lighting systems (lighting position and characteristics);
  - Other equipment (other specific systems, building automation systems…);
  - Control diagrams and settings (e.g. heating and cooling setpoint and setback temperatures);
  - Air changes per hour of every space *(if the building has no forced ventilation, the value can be estimated or it can be detected in detail with an indoor environmental monitoring – see additional analysis B3*);
  - Heating and cooling operation schedules;
  - Hourly internal gains due to people, appliances, equipment, and all the heat sources in the area;
  - Hourly indoor water vapour production;
  - Minimum and maximum relative humidity set point (if a humidity control system is present);

- Opaque envelope information (referring to any thermal frontier with the outside environment or with unheated rooms, e.g. perimeter walls characterized by different stratigraphy, roofing, floors, slab on ground, etc.):
  - Thermal conduction resistance [m^2K/W];
  - Heat capacity [J/m^2K];
  - Hypothesis on the detailed stratigraphy of the structure with thickness, conductivity and thermal capacity of each layer (including internal

partitions, box awnings (if present) and portion of opaque wall under the window);
   - Presence of condensation and surface or interstitial humidity;
   - Increase in the thickness of the masonry (if any);
   - Degradation, swelling, detachment or cracking of the plaster and surface finishes;
   - Bacteriological germination, surface efflorescence, mould and fungi;

- Transparent envelope information, including:
  - Geometry;
  - Frame materials;
  - Glass type and materials;
  - Thermal transmittance [W/m^2K];
  - Usage profile and shading devices (if present);
  - General conservation state of the windows (crack analyses, air tightness, water sealing).

2.4.3.2.2 Deliverables

The deliverable on the mandatory field analysis is a technical report on the analyses performed that contains the aforementioned data regarding the opaque and transparent structures. The deliverable also consists of technical floor plans and technical data sheets showing in detail the data collected on the building systems (see § **Error! Reference source not found.**).

2.4.3.2.3 B. Additional field analyses

When information on the thermophysical properties of opaque and transparent envelope is incomplete or there is a need to collect more information on their properties in order to formulate a solid hypothesis on the stratigraphy, additional field analyses are recommended. The analyses are also relevant to provide further data to help defining input data of dynamic energy simulation to be performed at later stages and calibrating it. Such additional analyses are the following:

- IR thermographies (B1);
- Simplified indoor environmental monitoring (B2);
- Air flow rate measurements and complete environmental monitoring (B3);
- Occupant thermal comfort assessment (B4)

2.4.3.2.4 B1. IR Thermographies

IR thermographies analyses shall be performed according to local technical regulation or following international guidelines. If carried out, they should precede the heat flux meter analyses in order to help defining the measuring spots of the heat flux measurements.

Additional data to be reported are:

- Thermal bridges;

- Air cracks;
- Materials emissivity;
- Capillary rise of water (estimated);
- Irregularities in the installation of the materials, any infrared visible degradation in the internal layers.

2.4.3.2.5 Deliverables (B1):

The additional deliverable on the thermophysical characteristics of the opaque and transparent envelope is a technical report on the analyses performed that contains thermograms and photographs shoots taken during the analyses pointing out the temperature levels and the building parts where defects or irregularities were found.

2.4.3.2.6 B2. Simplified indoor environmental monitoring

A short monitoring campaign of the indoor environmental indicators of air temperature and relative humidity shall be conducted for selected, characteristic thermal zones of the building. The suggested monitoring period is 2 - 3 weeks (20 days) during winter, summer and mid-season (if possible). Access to the exterior weather data during the monitoring period is strongly recommended (through a credible local meteorological station or in-situ monitoring through the installation of a portable weather station in the vicinity). These data shall be used for the calibration of the digital model and the dynamic energy performance simulation. Additional data to be reported are:

- Time series of indoor Dry Bulb Temperature (°C) in each selected zone
- Time series of indoor Relative Humidity (%) in each selected zone
- Time series of exterior Dry Bulb Temperature (°C) (strongly recommended)
- Time series of exterior Relative Humidity (%) (strongly recommended)

2.4.3.2.7 Deliverables (B2):

The additional deliverable of the indoor environmental monitoring is a technical report that presents the location of the data logger, the selection of the characteristic thermal zones to be monitored, the timeseries of the results for each zone and each monitoring period.

2.4.3.2.8 B3. Air flow rate measurements and complete environmental monitoring

The estimation of the air flow rate and air tightness of the building envelope shall be performed according to local technical regulation or following international guidelines. For the determination of air permeability of the building, the fan pressurization method (blower door) (ISO 9972:2015) or the tracer gas dilution method (e.g. monitoring the concentration of carbon dioxide CO2) (ISO 12569_2017) may be used. Additional data to be reported is:

- Air permeability (ach)

Additional data to be monitored, if possible, are:

- Air velocity (m/s)
- Illuminance (lx)

- Surface temperatures (°C)
- Concentration of polluting agents in the air (e.g. CO2)

2.4.3.2.9 Deliverables (B3):

The additional deliverable of the air flow measurement is a technical report that describes the method that was followed and the results obtained.

2.4.3.2.10B4. Occupant thermal comfort assessment

A questionnaire survey shall be conducted in order to highlight potential issues in terms of usage profile of the building and occupants' comfort. The questionnaire shall contain a simple checklist to collect information on the occupants (and the space in which they work) concerning:

- Thermal comfort assessment and thermal preference (too cold, too hot, etc.) during: a) winter and b) summer;
- Overall thermal comfort (general acceptance, complaints);
- Visual comfort assessment (for the visual task or for glare)

The sampling rate of the occupants' responses should be defined by the researchers, depending on the level of in-depth analysis required, the availability of the monitoring equipment and the occupants' commitment (e.g. seasonal distribution of the questionnaire with simultaneous monitoring of the indoor thermal environment is an option for insightful thermal comfort assessment, yet it requires more resources).

2.4.3.2.11Deliverables (B4):

The additional deliverable of the thermal comfort assessment is a technical report that describes the method that was followed, presents the questionnaires and the results obtained.

2.4.4 Output

All the deliverables produced within these analyses should be organised in a specific report that takes into account also the EE-HBIM Model approach (see §2.4.5).

For a reference template on this analysis see Annex **Error! Reference source not found.**.

2.4.5 BIM integration

The data from Energy and Environmental analyses should be funnelled into the HBIM model. The organization of collected data can support both a check of the completeness of the data collected for the energy analysis, and a library of the functional data for insertion in the simulation software.

To allow this transfer from field analysis to model, data should be consistent with the BIM Model Element Table (see § **Error! Reference source not found.**) if any or BIM model parameters. Any definition of property set (Pset) for .file format export should take the issue into account.

To be identified inside the model, all objects must be referenced with a unique alphanumeric identification code, that must be consistent with the BIM model identification system.

As stated throughout the report template (see § **Error! Reference source not found.**), all these data should be integrated in the HBIM model: depending on the case study specifics, software used for BIM modelling and simulation and data integration process, it is paramount to define a coherent data input strategy.

2.5 General conservation state

The following paragraphs describe the general conservation state analyses as intended to support the energy audit process.

2.5.1 Purpose of the analysis

The general conservation state analysis is considered as a preliminary visual analysis useful for the building knowledge and, mainly, to support energy analysis and the selection of energy improvement technologies capable also of reducing possible decay causes while being compatible with international restoration charts. A preliminary detection and mapping of the various alteration and decay patterns found on the exposed surfaces and macroscopic elements of criticality affecting the structures, should be developed with a particular consideration for factors (for example, a very significant humidity problem in the basement, or the exceptional lack of air tightness of a window, etc.) that can strongly affect energy efficiency. Of course, if the buildings presents particular criticality that cannot be enough understood with preliminary analyses and can affect the intervention strategies, further diagnostics analyses should be planned and executed.

The minimum information needed is the visual detection and mapping of the materials and the various alteration and decay patterns found on the exposed surfaces (external and internal), with elaboration of technical sheets.

2.5.2 Pre-planning

Prior to data acquisition in the field, it is critical to conduct pre-planning meetings with the involved stakeholders (i.e. building owner representatives, building technical and management staff, occupants representatives, consultants, service providers) to discuss:

- analysis objectives: a clear and concise scope of the general conservation state analysis should be established with the required deliverables (see §**Error! Reference source not found.**);
- security and access constraints: ensuring unhindered access is essential to avoid additional costs incurred due to delays in mobilisation or access to target areas;
- mobilisation strategy

Any supplementary in-depth investigations that could involve destructive analyses of any kind must be agreed in advance with the competent local Heritage Conservation Authority.

2.5.2.1 *Deliverables*

The deliverables of the pre-planning phase are:

- minute of the meetings;
- activity and mobilisation plan specification;
- updated time schedule of activities.

2.5.3 <u>Data Acquisition</u>

The following visual analysis and investigations relating to the general conservation state should be performed:

- material analysis: survey and mapping of structural and finishing materials and thematic mapping of existing finishes (including windows and external doors, surfaces, stone or wooden artefacts);
- decay and deterioration pattern and crack pattern analysis;
- identification and graphic representation of the building elements construction phases.

The analysis shall follow the local national and international regulation requirements on General conservation state analysis (see § **Error! Reference source not found.**).

2.5.4 <u>Output</u>

The analysis must include:

- technical report on the analysis findings;
- technical data sheets consisting of descriptive, graphic (thematic maps) and photographic sections, on the architectural surface analysis, material analysis, decay and deterioration pattern and crack pattern analysis, following the local national and international regulation requirements;
- if relevant, description and explanation of the annexes schemes, legends, etc.

The documents described above can be produced in pdf format for the descriptive and photographic section and .dxf format scale 1:50-1:20 for the thematic maps, if not differently specified by the local regulation.

If there are no local regulation available, the following international regulations are suggested:

- ICOMOS. Principle for the Analysis, Conservation and Structural Restoration of Architectural Heritage; International Council on Monuments and Sites: Paris, France, 2003.
- ICOMOS. Illustrated Glossary on Stone Deterioration Patterns; International Council on Monuments and Sites: Paris, France, 2008

- EN 16096:2012. Conservation of Cultural Property—Condition Survey and Report of Built Cultural Heritage; European Committee for Standardization, 2012.

For a reference template on this analysis see Annex **Error! Reference source not found.**.

2.5.5 BIM integration

The general conservation state analysis does not have to go directly in the BIM model: to the best of our knowledge, up to know, there is no defined way to represent decay in a BIM model as a property of the element it belongs to (for example, a moist area as belonging to the wall it is on), primarily for limitations of BIM software; there are several workarounds, but, for us, none is, up to know, a real improvement in the building information process from the traditional thematic maps referred to the building elevations.

Therefore the general idea is to integrate the General conservation state report as an external link to the model. For specific issues it would be possible to link more detailed analysis, if performed, or to add specific information to given building elements, but this is not a primary goal of the process.

3. ENERGY EFFICIENCY HERITAGE BUILDING INFORMATION MODEL (EE-HBIM)

The following paragraphs describe the Energy Efficient Heritage Building Information Modelling activities as intended to support the energy audit process.

3.1 Purpose of the EE-HBIM modelling

The purpose if the EE-HBIM model is to act as a centralized repository to optimize the management of the large amount of information (geometrical, alphanumerical and documents) deriving from the analysis and simulation process for the energy amelioration of built heritage. The advantages of the model will be the simplification and effectiveness in ensuring the permanence, consultation and implementation of data, accessible and understandable by different stakeholders.

The model should be developed in two different stages. Within Stage 1, corresponding to the ex-ante building state, the EE-HBIM model will integrate the previously collected information deriving from the performed analysis (geometric, diagnostic, energy and environmental data, see § 2.2, 2.3, 2.4, 2.5) to create a comprehensive documentation of the building's current state.

The EE-HBIM model of Stage 1 will be used as a basis to inform a subsequent energy-environmental improvement concept, through energy renovation scenarios that are both compatible with the identified historic buildings and capable of enhancing their energy and environmental performance. Scenarios' energy performance will be evaluated with specific dynamic energy simulation software (to be described in the next release of this guideline – Output 4.5).

In Stage 2 (to be described in the next release of this guideline – Output 4.5), the technical characteristics of each scenarios and its energy performance will be integrated within the EE-HBIM model (4D - 5D – 6D – 7D), in order to facilitate a ROI analysis and the drafting of the Energy Performance Contracting.

3.2 Pre-Planning

3.2.1 BIM Execution Plan (BEP)

Before starting the modelling process, it is critical to develop a BIM Execution Plan (BEP). In line with the definition of ISO 19650, the BEP defines the methodologies, requirements and timeframe on which the information modelling will be carried out. A BEP should detail not only how information is created and delivered, but also the 'why' (defining the BIM use), and the 'who' (assigning responsibility for it). It specifies the management, technical, commercial and project information and deliverables required for the project in a way that is specific, measurable, achievable and realistic. All stakeholders involved must adhere to and follow the BEP.

There are numerous templates for BEP following ISO 19650 requirements; based on those documents, the actors should adapt BEP to buildings' peculiarity, model uses, data available and stakeholders' skills and tools.

The BEP describes models federation, model uses, naming convention, LOD and modelling strategy, providing a flexible overall methodology for EE-HBIM. The main topics of a BEP are provided below.

3.2.1.1 Roles and responsibilities

The BEP shall indicate the Project Team Members carrying the following roles, indicating their capability and experience to fulfil the requirements of the roles: BIM Manager, whose function is to manage the whole information process; CDE manager, whose function is to manage the Common Data Environment; BIM Coordinator, whose function is to manage each discipline model; BIM Specialist (generally more than one), whose function is to model the model containers. The same person can fulfil different roles.

3.2.1.2 Model uses

Model uses must be defined as they direct the main modelling approaches. Within Stage 1 and Stage 2 of the modelling process, the main objectives and their corresponding model uses are:

Phase	**Objectives**	**Uses**
Stage 1	Constructive HBIM model definition	Integration and representation of building geometrical and technical information according to the documentation provided by the Employer (geometric survey, drawings, etc.) Definition of building elements Space, areas and volumes analysis
	Management of the knowledge	Integration of historical

	documentation on the historical building	documentation provided by the Employer (information sheets, links, etc.) Integration of diagnostic information provided by the Employer (materials and structure survey, etc.)
	Management of the environmental-energy analysis	Integration of energy and environmental analyses developed by the Employer.
Stage 2	Support of three energy intervention scenarios and of choice of adapted renovation strategies and technologies	Integration of three energy improvement intervention scenarios (short/medium/long term) provided by the design activity of the Employer with data concerning Time, Costs and management (4D, 5D, 6D, 7D)
	Assessment of ROI of the environmental-energy intervention scenarios	Integration of Return of Investment evaluation method based on the intervention costs and energy saves of the interventions

3.2.1.3 Level of Information Need

When modelling geometrically complex objects, typical of historical buildings, it is paramount a clear specification of the Level of Information Need (ISO 19650-1 2018; UNI EN 17412 2020), that expresses the level of maturity required for a particular information deliverable at a particular plan of work stage. It is important to avoid the delivery of too little information, which increases risk, and the delivery of too much information, which is wasteful.

Depending on the model uses, the necessary information should therefore be balanced between geometrical correspondence and alphanumeric data. The perceived benefits (in terms of information quality and completeness, visualisation requirements, etc.) should be carefully weighed against model functionality, file restrictions and time–effort. In order to be cost-effective, the minimum level of graphical detail sufficient for the purpose of the model should be specified.

The development of an EE-HBIM model requires to articulate in a shared definition the content and detail of model objects: for instance, the clear description of which building elements to model, their standard classification, the Level of Information Need for each modelled element, including both their geometrical information and alphanumerical information provided through model parameters.

An effective way to organize this information is using the Model Element Table (BIMForum 2019), that is a table in which a building is decomposed into modelling elements (walls, floors, etc.) according to a breakdown structure, following Omniclass classification (Construction Specifications Institute 2019). Each modelling element is associated to a Relevant Attribute Table, that are tabs containing attribute information for the associated model objects to be inserted in the BIM model using specific parameters. Relevant Attribute Tables, therefore, condensed the required alphanumeric information for any given model object. An example of Model Element Table and a more detailed explanation on how to use it is provided in Annex **Error! Reference source not found.**.

The main issues in the use of the Model Element Table, and therefore the OmniClass classification for historical building arise from the fact that all building classifications based on ISO 12006 have been developed for the contemporary industrial process of the construction sector and the most widespread construction systems and technologies; so they may not be appropriate to include the complex, not standard elements and technologies of built heritage. For example, the definition of structural element reflect the separation between structural frame and enclosures that is normally not applicable to historical buildings. Top levels may still work well, as they indicate in broad terms the object type, while detail that is introduced in lower levels can be misleading. A lite classification (top of pyramid) with additional commentary is the likely way (Brookes 2017).

3.2.1.4 Model federation and data segregation

The BEP shall indicate a federated model strategy, depending on the historic building dimension and on the energy simulation process. It is recommended to separate at least the architectural model and the MEP model, including terminals and heating and cooling production system– useful for the energy analysis. A separated structural model is more useful with a frame concrete or wood structure.

3.2.1.5 Data sharing and collaboration

A Common Data Environment (CDE) complying with ISO 19650 and ISO 27001, must be used for the management or sharing of data, in order to facilitate collaboration and information sharing between members of the project team. It is essential that common BIM standards are established and agreed in advance.

3.2.1.5.1 Naming convention

It is paramount to define naming specification to be used for all document types uploaded to a CDE, in line with IEC 82045-1 and BS 1192:2007(A2) 2016. For the object naming convention, an existing standard can be applied; when using the Model Element Table, that is based on Omniclass classification, Omniclass standard could be applied, keeping in mind its limits when describing historic buildings (see § 3.2.1.3)

3.2.1.5.2 Modelling strategy

A description of the modelling strategy, data exchange formats, common coordinate system should be provided.

For an example of the BEP for energy and environmental improvement of historical buildings, please refer to Annex **Error! Reference source not found.**.

3.2.2 <u>Outsourcing of the EE-HBIM model - tender process</u>

If the BIM modelling activity is outsourced, the actors involved in the tender process shall follow the bidding procedure defined by ISO 19650. The Employer shall define an Exchange Information Requirements (EIR), that is a tender document setting out the information to be delivered, and the standards and processes to be adopted by the Consultant as part of the project delivery process, outlining the Employer strategic approach and specifying the management, technical, commercial and project information and deliverables required for the project.

The Consultant shall deliver a Pre-contract BIM Execution Plan (BEP) for the project as a direct response to the EIR. If selected, The Consultant shall deliver a Post-contract BEP and review their BEP regularly and additionally when there is any change to their contract.

3.3 Output: EE-HBIM Modelling

The modelling process should be based on the geometric and technical information (geometric survey, drawings, etc.) collected during the analysis phase (see § 2). Based on the collected information, the model will represent the constructive system and technological characteristics of the building (vertical and horizontal structural system, materials, etc.) as accurately as possible within the Level of Information Need. The walls, roofs and floors will be modelled with their stratigraphy (know or assumed). Decorative elements can have a simplified representation, as long as their constructive system is detailed.

The HBIM model development will take advantage of the parametric tools of native software (e. g. system families) as much as possible, avoiding non-parametric tools such as mass modelling. The correct representation of the building technical, constructive and environmental features is paramount, even when leading to simplification of uneven features, typical of historical buildings (e.g. assuming planarity of walls), if needed.

Historical and diagnostic information (materials and structure survey, energy analyses, etc.) collected during historical and architectural analysis (see § 2.2) and general conservation state analysis (see § 2.5) should be incorporated in the model. If the information cannot be directly integrated in the elements, it can be linked using reports, sheets, drawings, etc.

In order to support environmental-energy intervention scenarios, the energy information collected in energy and environmental analyses (e.g. transmittance values for walls and windows, occupancy data, etc., see §2.4) should be integrated in the model. Occupancy and uses profiles for each room and/or thermal zones, if not included in the model, should be linked as external files (reports, sheets, etc.).

Regarding MEP system, HVAC systems terminals and plants should be represented. If no specific MEP system is modelled, room/areas information could include data on plants and terminals.

Regarding object insertion and constraints, all objects (walls, roofs, ceilings, floors, HVAC systems, structures, windows, etc.) must be constrained to the corresponding lower and upper level.

If a federated model strategy is developed, all models should be geo-referenced according to the same absolute origin established in the union file. The reference grids of the federated files may refer to a relative origin, suitably identified due to the geometric and disciplinary complexity of the work, but these grids must conform to the georeferencing of the absolute origin.

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4.1.2 Selection of the Main Restoration Charters

The Athens Charter for the Restoration of Historic Monuments – 1931

https://www.icomos.org/en/167-the-athens-charter-for-the-restoration-of-historic-monuments

International charter for the conservation and restoration of monuments and sites (the Venice charter 1964)

https://www.icomos.org/charters/venice_e.pdf

The Declaration of Amsterdam - 1975

https://www.icomos.org/en/and/169-the-declaration-of-amsterdam

European Charter of the Architectural Heritage - 1975

https://www.icomos.org/en/charters-and-texts/179-articles-en-francais/ressources/charters-and-standards/170-european-charter-of-the-architectural-heritage

Charter for the conservation of historic towns and urban areas (Washington charter 1987)

https://www.icomos.org/charters/towns_e.pdf

The Nara Document on Authenticity (1994)

https://www.icomos.org/charters/nara-e.pdf

The Aalborg Charter (1994)

http://www.sustainablecities.eu/fileadmin/repository/Aalborg_Charter/Aalborg_Charter_English.pdf

4.2 Energy and Environmental Analyses regulation

EN 15758:2010 Conservation of Cultural Property -Procedures and instruments for measuring temperatures of the air and the surfaces of objects

EN 15759_2018_Conservation of cultural heritage - Indoor climate - Part 2 Ventilation management for the protection of cultural heritage buildings and collections

CYS EN 16515:2015 Conservation of Cultural Heritage - Guidelines to characterize natural stone used in cultural heritage

EN 12569_2017_Thermal performance of buildings and materials - Determination of specific airflow rate in buildings - Tracer gas dilution method

EN 16798_Energy performance of buildings - Ventilation for buildings - Part 7 Calculation methods for the determination of air flow rates in buildings including infiltration

EN 12569_2017_Thermal performance of buildings and materials - Determination of specific airflow rate in buildings - Tracer gas dilution method